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NATO

NAVAL ARMAMENT GROUP
SPECIAL WORKING GROUP 6
(SWG/6)

ON

ADVANCED NAVAL VEHICLES

ASSESSMENT OF POINT DESIGNS

VOLUME II

DETAILED ASSESSMENT

NOVEMBER 1987

CHAIRMAN, SWG/6 (OPNAV 321C)
ASSESSMENT TEAM

EXECUTIVE SUMMARY AND RECOMMENDATIONS

VOLUME I SYNOPSIS

VOLUME II DETAILED ASSESSMENT

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FOREWORD

This report was prepared by Special Working Group 6 (SWG/6) of the NATO Naval Armaments Group (NNAG). The purpose of the report is to assess the effectiveness, feasibility and cost of the Advanced Naval Vehicles (ANVs), which were designed, at the pre-feasibility level of detail, by member nations of Special Working Group 6.

The assessment is documented in three separately bound volumes. Volume I - Synopsis, Volume II - Detailed Assessment (as presented herein) and Volume III - Supporting Documents. A short Executive Summary, with recommendations to the NNAG, was also issued under separate cover.

An Assessment Team, reporting to the SWG/6 chairman, conducted the assessment using inputs from all SWG/6 nations and iterating draft reports through a sequence of reviews by all SWG/6 nations.

ACKNOWLEDGMENT

SWG/6 acknowledges the contributions made to this program of work by Information Exchange Group 6 (IEG/6), by SACLANT and CINCHAN representatives and by other national government agencies and private companies who provided expertise without which this study could not have been performed.

ABSTRACT

The eight nations of NNAG Special Working Group 6 (SWG/6), consisting of **Canada, France, Germany, Italy, Norway, Spain, United Kingdom** and **United States**, have concluded their program of work to provide recommendations by which nations can decide upon their future involvement in NATO applications of Advanced Naval Vehicle (ANV) technology. The results of this work are presented herein.

SWG/6 work on this particular project was initiated in 1984 with the development of Outline Nato Staff Targets (ONSTs) for Hydrofoils, Surface Effect Ships (SES) and Small-Waterplane-Area Twin-Hull (SWATH) ships. Each ONST called for a multi-mission capability with emphasis on the Anti-Submarine Warfare (ASW) role. The objective was to assess the feasibility of increasing the operational capabilities of NATO Naval Forces by augmenting existing and planned forces with new platforms capable of operating at high speed and/or maintaining high mission capability through improved seakeeping under all sea conditions.

Seven designs were developed by SWG/6 at the pre-feasibility level of detail and were assessed as to their military value, affordability and technical feasibility. The development needs for each were identified and most of these are currently being pursued by one, or more, member nations. It is concluded that the program has the potential of significantly increasing the combat cost effectiveness of NATO forces entering service after the year 2000.

This effort by SWG/6 has also provided a carefully focused cooperative exchange of experiences and technology. The product of this effort, the group believes, is a sound basis of data and analysis from which to proceed into the feasibility phase for NATO ANV Corvettes when a convergence of national interests so indicates. In addition, this intense collaboration, sustained over a period of four years, is, in itself, an achievement which has benefited and will continue to benefit national ANV programs, bringing the convergence of interest close to reality. As a related matter, this cooperative effort has deepened and broadened the collective experience of SWG/6 and has enhanced the group's ability to employ an effective systems approach to the NNAG's needs in its area of expertise.

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1.0 BACKGROUND AND OBJECTIVES

During its more than 10 years of existence, the NATO Special Working Group 6 (SWG/6) on Advanced Naval Vehicles (ANVs) has pursued a program of work intended to provide a sound basis upon which nations can make decisions with regard to their future involvement in the application of Advanced-Naval Vehicles to the NATO Anti-Submarine Warfare (ASW) mission. Having concluded that NATO nations need improved speed and sea-state capabilities for naval vehicles, the group embarked on the development of three Outline NATO Staff Targets (ONSTs) for **SWATH, SES** and **Hydrofoil ASW Escort ships.** These ONSTs addressed a common NATO threat, a similar mission and comparable environmental conditions. Each ONST was tailored; however, to exploit each platforms unique characteristics. The draft ONSTs were developed by three nations: Canada (SWATH), France (SES) and USA (Hydrofoil). These ONSTs were subsequently reviewed by all SWG/6 nations and issued as NATO documents, Reference 1. A common **Study Guidance Document,** Reference 2, was also issued to ensure a commonality of design criteria and of information that would be provided by each design study. During 1985, five point designs, or pre-feasibility, studies were initiated:

SES - UK
SES - France
SES - USA with input from the Federal Republic of Germany
SWATH - Canada with input from the USA
Hydrofoil - USA

With the exception of the Canadian SWATH design, (which was completed and presented in November 1986), all of these designs were presented at the May, 1986, SWG/6 meeting. At this same meeting, a draft **Methodology for Assessing the Designs** was also presented and subsequently approved for issue as Reference 3.

Starting in May 1986, an assessment effort was initiated by the nations of SWG/6 following the common methodology. In this assessment, detailed herein, the effectiveness, life-cycle costs, development needs, and feasibility of the five point designs were addressed. The assessment was subsequently expanded to include, where possible, a *Spanish SES* design presented in September 1986 *(SP SES)* and a *Canadian Hydrofoil* option presented in 1985 *(CA Hydrofoil).* Conventional monohull frigates and destroyers were included throughout the assessment as comparative baselines. They included the U.S. *FFG 7,* the U.S. *DD 963,* the *NFR 90,* the Italian *Lupo* class, the Spanish *Descubierta* class, the Canadian *Tribal* class, and representative *French* and *UK* monohulls.

Unlike the MO2005 study, the SWG/6 program of work concentrated on the determination of technical feasibility rather than mission feasibility. Although the value to specific ASW tasks of high-speed and high-sea-state capability was assessed by SWG/6, the overall mission effectiveness of each design was not considered. However, SWG/6 liaison with the developing MO2005 study was maintained and the SWG/6 designs may be correlated with the MO2005 matrix of projected ship types. Conclusions regarding capabilities may differ, however, as the SWG/6 studies were focused in the ASW area and the development of actual Point Designs permitted the determination of the technical feasibility, performance and cost of each concept to a level of confidence not available from the broad mission-related MO2005 study.

The ONSTs for each platform type were, however, significantly different from each other, so that the designs of the different types of ANVs could not be directly compared. For example, the Hydrofoil ONST was met by a 773-ton Hydrofoil with no helo and the SWATH ONST resulted in a 9500-ton SWATH with four helos. Also, since the ONSTs were fairly specific, the designs could not necessarily be considered as being typical of a particular class of ANV. Assessments were, therefore, conducted separately for each type of ANV and comparisons were made between each platform and current ASW ships.

In the case of "competing" candidates within a platform type, such as the four SES designs, the approach was not to determine a "winner" but to determine what is achievable fro the experience of the several designs.

In reviewing the results of this assessment, SWG/6 joined with Information Exchange Group 6 (IEG/6). This has encouraged a carefully focused exchange of experience and technology between the nations so that the designs of the resulting advanced ships could take full advantage of the combined capabilities of all participating nations.

The methodology used by SWG/6 (Reference 3) established three broad objectives for the assessment of the pre-feasibility designs:

1. Assess the military value of ANV Point Designs that offer high speed and/or high sea state capability with emphasis on NATO applications to ASW missions.

2. Assess the development, acquisition, operating and support cost of each ANV Point Design for comparison with the equivalent costs of conventional modern ASW monohulls.

3. Assess the technical feasibility of and development needs for ANVs that are designed to meet the requirement of the ONSTs and that are intended to enter NATO ASW service after the year 2000.

The approach used to achieve these objectives is summarized in the following section.

2.0 INTRODUCTION

The approach to the assessment is illustrated graphically in Figure 2-1. To support this activity, information was requested from the participating nations. This information is illustrated at the bottom of the figure. The information provided included:

- The reports of the 7 point designs prepared by Special Working Group 6,
- A questionnaire completed for each design to help in the estimation of cost, and
- A series of technology-related questionnaires completed by both SWG/6 and IEG/6 participants to:

  (a) help in the estimation of RDT&E risks and required development effort and

  (b) to help assess national needs and the perceived value and shortfalls of advanced naval vehicles.

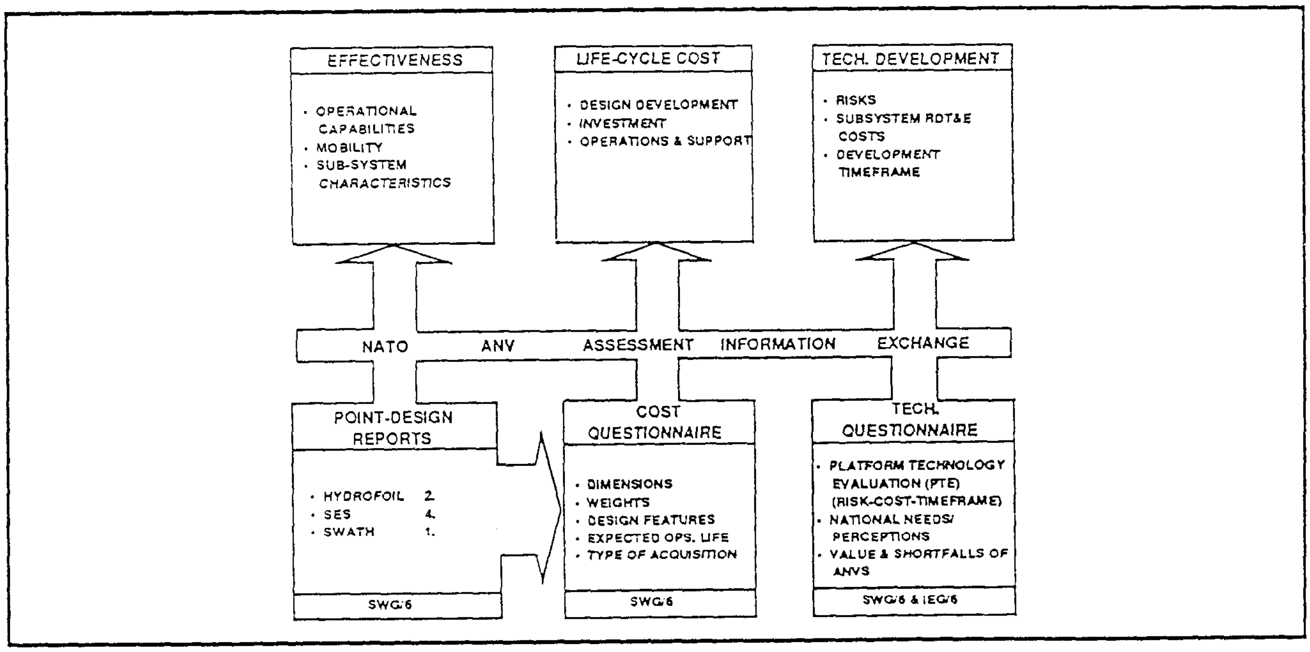

Figure 2-1. Approach to Point-Design Assessment.

Effectiveness was investigated to assess platform Operational Capabilities, Mobility and Ship-System Characteristics as illustrated in Figure 2-1.

The assessment of platform operational capability addressed the warfare areas which are applicable to each point design. This assessment, although generally of a qualitative nature, has drawn heavily upon the conclusions derived from the more quantitative assessment of mobility in terms of speed, seakeeping, etc. and subsystem-related characteristics such as hull form, general arrangement, habitability, ship interfaces, etc.

The assessment of mobility focused principally upon identifying the advantages and disadvantages in speed, ship motions, range and maneuvering capability relative to modern monohull designs. The assessment of subsystem-related characteristics (Figure 2-1) was aimed at validating the reported design characteristics utilizing trend data to establish comparisons with prior ships and ship-design studies. The primary purpose of this assessment was to identify and characterize the technologies found in the ANVs developed under this program to assist in the performance assessment of Section 3.2 and to serve as input to the identification of R&D needs in the Platform Technology Evaluation (PTE) process contained in Section 4.0. Although point designs, particularly at such an early stage in the design process, do not necessarily represent an optimum ship-design solution, it was assumed that the technologies and approaches used in these cases would be representative of those that could be considered appropriate for ANVs such as those proposed.

In performing the subsystem assessments, the emphasis was on providing a general comparison with established conventional monohull and ANV practice as opposed to providing a detailed component by component analysis. This was considered to be more appropriate to the state of development of the designs, the level of detail presented in the design reports, and the overall goals of the program.

The FFG 7-Class of ASW frigate (in particular FFG 36, USS UNDERWOOD) was used as the principal point of reference for SESs and Hydrofoils with respect to design practice for modern "conventional" ships. Comparisons with other "conventional" ships such as the NFR 90 and DD 963, etc. were included for comparison with the larger SWATH design, as appropriate. Data on other conventional monohull frigates and destroyers were also used throughout the assessment as comparative baselines. These ships were not used to imply the "correct" approach since mission differences and the unique design drivers associated with ANVs make such a direct comparison inappropriate.

Some of the subsystem assessments make use of various parametric plots. These are used to highlight any gross deviations from "current" ANV or monohull practice which may indicate the use of unique technologies or design approaches. As with comparisons with the FFG 7, these plots are not used to imply correctness, or lack thereof, in the point designs; instead, they are used as an aid in characterizing the point design and ANV technologies.

The Acquisition Cost and Life-Cycle Cost (LCC) was examined for each point design to determine the cost to design, procure, and operate the ship and its support facilities over a specified lifetime period. For each of the cost elements, emphasis was placed on achieving consistency in the cost estimates across all the designs being considered. To achieve this consistency the same basic Life-Cycle Cost (LCC) structure and cost-estimating relationships (CERs) were used to ensure that cost differences between designs were due solely to differences in the platforms' characteristics. The estimated costs have been computed from CERs which have been derived from historical data and modified where necessary to reflect technological differences.

It has been recognized, however, that the absolute value of life-cycle cost will vary from nation to nation due to differences in such items as:

(a) Government procurement processes
(b) Manning, watch systems and deployment and logistic support policies.
(c) Use of Military Specifications (MIL SPECS)
(d) Habitability standards
(e) Design, construction and service-life margins
(f) Design criteria imposing varying levels of risk
(g) National preferences in the choice of particular platform and weapon subsystems.

All of these differences have not been accounted for, since for consistency the cost estimates have assumed US design and construction practices and cost. For the purpose of comparison, however, an independent assessment of the cost of the SES point designs was requested of each nation.

For the determination of Research and Development (R&D) needs, a previously developed procedure was used to evaluate the development status of those technologies and subsystems which were to be incorporated in each design and which were not currently state-of-the-art or otherwise approved for full production. This methodology, designated the "Platform Technology Evaluation" (PTE) procedure, provided the means to evaluate specific proposed subsystems on the basis of need (relative to the mission and candidate design), current state-of-development, RDT&E status, and development timeframe (relative to proposed funding). Assessments of cost and development timeframe for individual technologies, and for the total platform, were developed using the PTE procedure as described in Reference 3. The assessment of overall risk for individual subsystems and technologies, and for the total platform, is the principal output of the PTE procedure. The methodology involves the completion of an evaluation matrix entitled the "Platform Technology Evaluation (PTE) Summary Sheet".

It was proposed in Reference 3 that each national design team complete the PTE Summary Sheet for their own point design, and provide the detailed support and rationale for their assessments. It was also proposed that each design team, and other nations within IEG/6, complete PTE Summary Sheets for the other candidate point designs in the areas of need, current state-of-development, and RDT&E status. This was to be provided to facilitate an exchange of information as a first step towards a consensus evaluation of the developmental risk of each design. The results of this survey are summarized in Section 4.

A complete assessment of both the point designs and of ANVs in general also requires the identification and consolidation of information pertaining to current and projected future ANV technology developments, design capabilities, manufacturing capabilities, operational experiences and national needs and perceptions among the NATO nations. The NATO Hydrofoil, SWATH and SES point designs are intended to serve as a focus for the exchange of this information. Additionally, it was recognized that relevant technology, design and operational experience, which was not specifically applied to the point designs, exists among the SWG/6 and IEG/6 members.

Specific information which was requested to be provided by the SWG/6 point-design teams in Reference 3, included:

(a) Data requested for each point design in the Study Guidance Document (Reference 2).
(b) Costing data for each point design
(c) Technology development status data.

The procedure and format for providing this information was also contained in Reference (3).

Additional information which was requested from all SWG/6 and IEG/6 nations for the purpose of influencing and assisting in the point-design evaluations and NNAG recommendations, included:

(I) ANV Technology-status evaluations in addition to those provided by the SWG/6 point-design teams (item (c) above)

(II) Assessments of National and NATO needs for ANVs (the value of ANV attributes)

(III) Assessment of the Potential Shortfalls of ANVs

(IV) Assessment of ANV Design/Performance Prediction Capabilities

(V) Assessment of ANV Cost Predictions and Acquisition Policy

(VI) Assessment of National Perceptions of ANVs.

The results obtained from this survey are summarized in Section 6. This has provided a means for exchanging and consolidating information relating to advanced naval vehicles and has assisted in providing a sound basis for making recommendations to the NNAG regarding the various advanced ship types.

2.1 POINT DESIGN SUMMARIES

The following is a summary of the principal features of each ANV Point Design and the monohull baselines against which they have been compared.

It is important to note that it has been recognized from the assessment that, in general, each ANV has been designed, or at least has been presented, to a different level of detail. The UK SES and FR SES designs, for example, appear to have gone beyond the minimum level of detail required of a pre-feasibility level design and their designs appear to have resulted from more indepth trade-off studies of hullform and subsystems than has the US/G SES and US Hydrofoil. The SP SES has been developed using primarily theoretical methods rather than from extensive empirical data. The low-cost hydrofoil option from Canada is defined in relatively little detail, while the SWATH design appears to have been developed at a level of detail approaching that of the UK and FR SES designs. Thus, although all of the point designs have been assessed as being feasible, they have been assessed as possessing different degrees of risk.

2.1.1 UK SES Point Design

The primary role of the UK SES will be full ASW in the open ocean, against the major threat defined as high-speed, extensively noise-reduced SSNs. The vessel will have the secondary role of anti-surface vessel warfare (SUW) and will have an anti-air capability for self defense.

To satisfy the primary role, a considerable underwater detection capability is required. To meet this, the UK SES has been designed to carry a twin, passive, towed-array sonar system, and an active, hull-flank sonar array. It is also designed to support and operate a medium ASW helicopter, the EH101, with dunking sonar. For prosecution, lightweight torpedoes can be dropped by the EH101 or fired from the ship. Although not presently included, the ship could also carry Missile Carried Torpedoes (MCTs).

The ship carries a suite of surface-to-surface missiles for surface warfare and a double-headed point-defense missile system, small caliber guns and chaff decoys for self defense. The ship has a mission duration of 30 days and carries a crew of 113.

To support these systems and to meet the requirements in the Outline NATO Staff Target (ONST), an SES having a structure of fiber-composite construction, with a full-load displacement of 1600 tons, and an overall length of 93 m, has been designed. Principal characteristics are given in Figure 2.1-1. The hull form has been based on the Vosper Hovermarine Deep-Cushion-Craft concept which is designed to offer good speed and motion performance in high sea states. This concept has been thoroughly investigated in model form over the past few years.

For mobility, the UK SES has twin-shaft CODOG* propulsion consisting of two Rolls Royce Spey Gas Turbines and two MTU Diesels. The diesels are used to power the lift fans when operating on-cushion and to provide propulsion power when hull-borne. Together, these engines provide a total maximum installed power of 46,800 KW. Twin waterjet propulsors have been specified and these provide for both high-speed cushionborne operation, and long-range cruising in the displacement mode.

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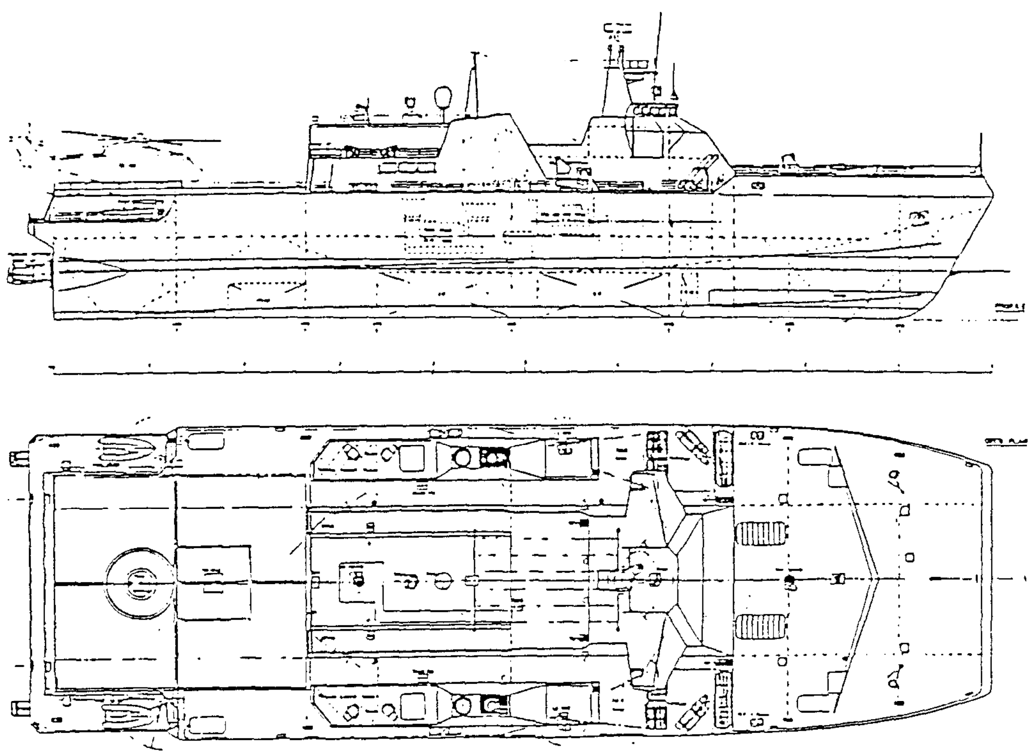
*Combined diesel or gas turbine; diesel for lift-air supply and gas turbines for high-speed propulsion; the diesels are also used for low-speed propulsion.



U.K. SES POINT DESIGN

LENGTH OVERALL	92.9	m
BEAM OVERALL	29	m
KEEL TO WETDECK CLEARANCE	7.5	m
DRAFT ON-CUSHION (AFT)	1.5	m
DRAFT OFF-CUSHION (MEAN)	4.6	m
FULL-LOAD DISPLACEMENT	1601	MT
LIGHT-SHIP DISPLACEMENT	1041	MT
PRINCIPAL STRUCTURAL MATERIAL	GRP	
PROPULSION POWER - 2 RR SPEYS (SM 1C)	(MCP) 36,000	KW
LIFT POWER - 2 MTU 20 V 1163 TB83	(MCP) 10,800	KW
PROPULSORS - 2 WATERJETS		
TOTAL COMPLEMENT	113	#
MAXIMUM CONTINUOUS SPEED AT FULL LOAD IN SS0/SS6	50/30	KNOTS
RANGE AT MAXIMUM CONTINUOUS SPEED IN SS0	1800	NM
MAXIMUM RANGE AT 10 KNOTS IN SS0/SS6	7500/2640	NM
MAXIMUM RANGE AT 20 KNOTS IN SS0/SS3	3200/2900	NM

SS: SEA STATE

Figure 2.1-1. Principal Characteristics of UK SES

In addition to high-speed performance capabilities, the UK SES design offers the following significant advantages in comparison with current conventional warships:

- The catamaran hull form is inherently very stable and together with the large deck area, will therefore be suitable, despite the small ship size, for helicopter operations in rough seas (up to sea-state 6)

- The wide beam also permits broad separation of the twin towed-array sonar system enabling more accurate target resolution; these lightweight arrays can be recovered quickly or, if necessary, towed at speeds of up to 40 knots.

- With most of the craft supported on an air cushion, lower acoustic and pressure signatures are anticipated, together with a reduced susceptibility to shock damage from underwater explosions.

- The waterjets are expected to provide a quiet form of propulsion suitable for ASW operations; low-speed maneuverability is predicted to be excellent due to the widely-separated, steerable propulsors.

- The use of a composite (i.e., fiber reinforced resin) structure is predicted to result in reduced hull maintenance and a low magnetic signature, the layout permits a novel form of zoning to be adopted, that together with the hull sub-division is expected to improve survivability in a damaged condition.

2.1.2 FR SES POINT DESIGN

The FR SES (EOLES) is designed, like the other two SES, with the principal emphasis on ASW. A good self-defense capability is also provided for anti-surface and anti-air warfare.

The principal means of ASW detection is a 300 m long towed linear-array passive sonar (ETBF) (listen Very Low Frequency 100-200 Hz). It is deployed from the center section of the ship and can be towed on a 2000 m cable at speeds up to about 18 knots. Its depth is controlled by a depressor. For the detection of quieter targets, a 1000 Hz emitter is located in the depressor, to provide an active array. The ship is also equipped with an active dipping sonar, derived from the DIODON. This sonar operates in the 10 to 15 kHz range. It can be used on, or off, cushion at zero forward speed. The localization from the ETBF passive towed-sonar array is normally accomplished by embarked helicopters which have their own means of detection (sonar, HS12, bouys, MAD).

The ship is equipped with two ASW helicopters of the medium/heavy type which are used as the main method of attack. The helicopters are armed with four light torpedoes MURENE (NTL 90). The aviation weapons magazine holds 16 NTL 90 torpedoes. The ship is also equipped with four missile-launched torpedoes.

When operating hullborne, the ship uses a standard electro-acoustic decoy device of the NIXIE type. An adaptation of the anti-torpedo defense system (SLAT), planned for the French nuclear aircraft carrier (PAN), is also planned for the FR SES. This system is composed of a passive linear array (for the detection of torpedoes) and an acoustic-decoy launcher belonging to the SAGAIE system.

Long range detection for Air-Surface Warfare is accomplished by: a V15 search radar, a radar detector (type ARBR 17 or DR 4000), a VHF/UHF interceptor (type TELEGAN VI) and the embarked helicopters (radar and/or optical sensors belonging to the helo.)

The close-in detection designed into the anti-air and anti-missile self-defense systems is accomplished by the radars of the SAAM and SDARAL systems (RODEO radar).

Four MM40 missiles are used for anti-surface warfare. Anti-air and anti-missile self defense is accomplished by SAAM (2x8 missiles) and SATCAP SADRAL (2x6 missiles). The ship also has two SAGAIE decoy launchers and two ARBB 33 jammers.

The principal characteristics of the FR SES are shown in Figure 2.1-2. The hullform has a length-to-beam ratio midway between that of the UK SES and US/G SES. The hull is of aluminum alloy although studies are continuing to define a hull of composite construction which France believes would be preferred. The seal system is based on the system used effectively on the MOLENES 5.5 ton manned test craft. The bow seal is a new innovation designed to more readily track the surface of waves than other designs. This offers a means of passive ride control as a less expensive substitute for active control of cushion air. The FR SES uses a combined gasturbine-diesel (CODOG) power plant. Two LM 2500 gas turbines provide propulsion power in the on-cushion mode of operation and two 4400 KW diesels (such as the SACM 195 V20 H) provide power for the lift fans when on-cushion and for propulsion when hull-borne. In both modes of operation, two KaMeWa waterjets are used to provide both propulsion and steering.

2.1.3 US/G SES POINT DESIGN

The US/G SES Corvette, Figure 2.1-3, is a surface escort vessel dedicated to a single-role ASW mission, namely the anti-submarine defense of surface groups composed of Naval and Merchant shipping. The IOC is 2000 AD.

The ship's AAW and SUW capabilities are expanded somewhat by the inclusion of a LINK-11 data link which allows this ship to send target information to the rest of the battle group, or to act as a weapon platform with target data received from the battle group.

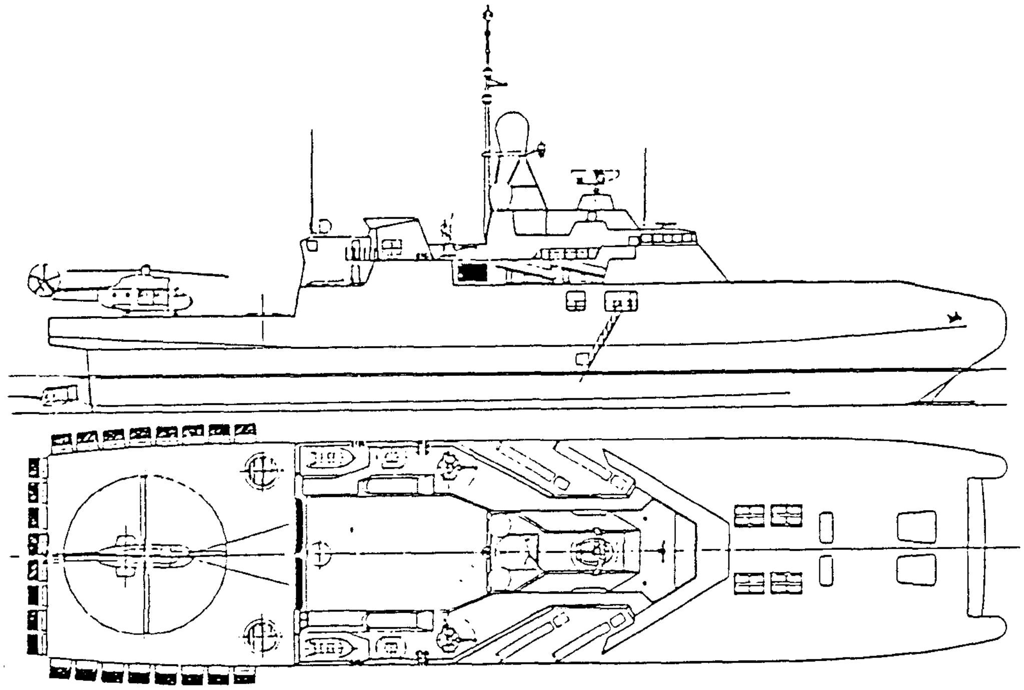
The ship is equipped with two LAMPS III helicopters and with a notional Underwater-Surveillance System comprised of three major components; a LAMPS Processor (SQQ-28), a notional Variable Depth Sonar (VDS) and a notional towed array. This system is projected to satisfy the tactical need to be able to be retrieved rapidly, or to be towed at 40-50 knots.

Both air and subsurface countermeasures are proposed. The electronic warfare system chosen is the SLQ-32. A MK-36 system common for larger surface units was modified for this ship by reducing the number of launcher sites from six to four. A Surface Ship Torpedo Decoy (SSTD) is included in the countermeasure suite due to the need for extensive hullborne operation. The SSTD is under development and is an automatic system that senses a torpedo and fires a decoy. Armaments include a 30 mm gun with fire control (Goalkeeper) and two Javelin tripod launchers attached, two eight-cell Vertical Launcher Systems (VLS) and two MD-32 triple torpedo tubes. The gun is for close in surface and air targets. The Javelins are for short range air defense. The two VLS can be loaded out to match the mission. The normal load is six ASW Standoff Missiles, six SUW Missiles, and four Medium Range Standard Missiles.

The Swedish Sea Giraffe Naval Search Radar is the primary air and surface search sensor. This radar is a multi-purpose type installed on many small warships and patrol boats. The radar provides all-weather, anti-ship missile detection as well as long range aircraft detection in an ECM environment. It has surface search capability out to the horizon. This system is able to provide data to a fire control system allowing easy integration with other combat system components. To assist in identifying the enemy a MK XV IFF and a Kollmorgen MK 35 electro-optical sensor are included in this system.

The structure is of High Strength-Low Alloy (HSLA) steel. Although this choice of material results in a performance penalty due to the increase in structure weight, as compared to the more conventional choice of aluminum alloy for an SES, it represents a concerted effort to seek a less expensive and more robust material more suited to conventional large ship-building practice.

The design also includes a Combined Diesel and Gas Turbine propulsion (CODOG) plant with diesels, producing a total of 6714 kW, serving (as on the other two SES) the double function of lift-fan prime movers and low-speed propulsion. Although combined plants are not uncommon in foreign navies, they have not yet been widely applied in the U.S. Navy. The design incorporates two LM 2500 gas turbine engines rated at 27000 shp each. This rating is not

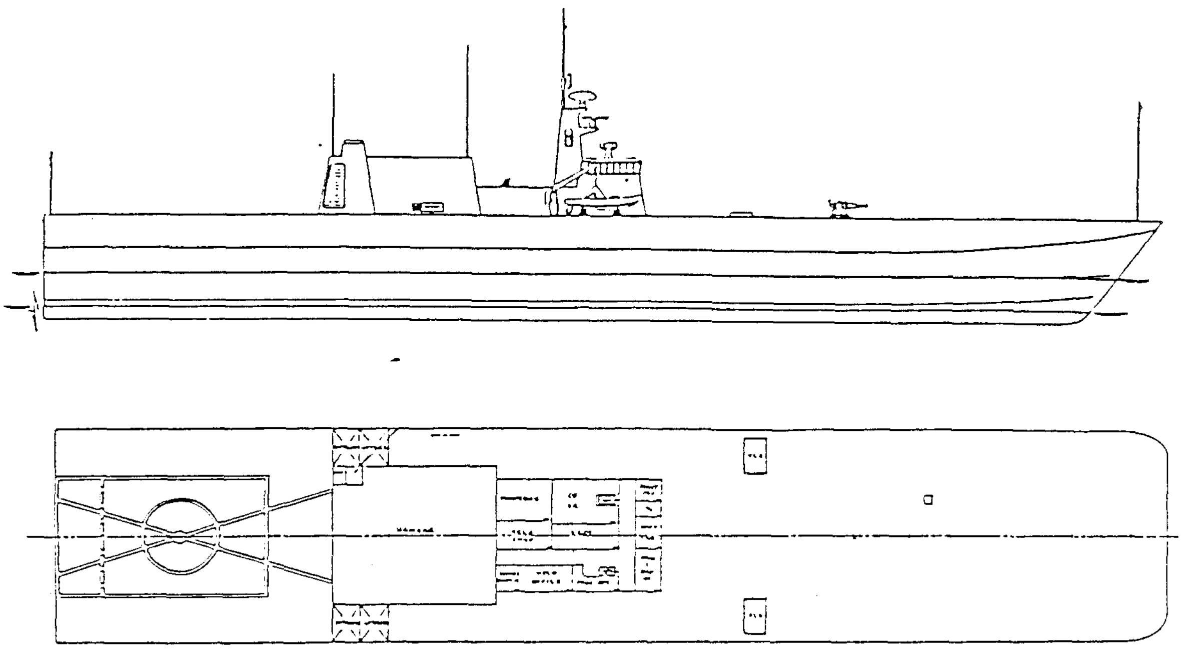


FR SES POINT DESIGN

LENGTH OVERALL	89	m
BEAM OVERALL	21.1	m
KEEL TO WETDECK CLEARANCE	5.4	m
DRAFT ON-CUSHION (AFT)	1.58	m
DRAFT OFF-CUSHION (MEAN)	4.00	m
FULL-LOAD DISPLACEMENT	1400	MT
LIGHT-SHIP DISPLACEMENT	910.8	MT
PRINCIPAL STRUCTURAL MATERIAL	AL. ALLOY	
PROPULSION POWER - 2 GE LM 2500	(MCP) 44,200	KW
LIFT POWER - 2 UD33 V20 M9 12 20	(MCP) 8,800	KW
PROPULSORS - 2 WATERJETS		
TOTAL COMPLEMENT	94	#
MAXIMUM CONTINUOUS SPEED AT FULL LOAD IN SS0/SS6	57/37	KNOTS
RANGE AT MAXIMUM CONTINUOUS SPEED IN SS0	1900	NM
MAXIMUM RANGE AT 12 KNOTS IN SS0/SS6	7150/2850	NM
MAXIMUM RANGE AT 20 KNOTS IN SS0/SS3	3400/3250	NM

SS: SEA STATE

Figure 2.1-2. Principal Characteristics of FR SES



US/G SES POINT DESIGN

LENGTH OVERALL	104	m
BEAM OVERALL	19.5	m
KEEL TO WETDECK CLEARANCE	6.7	m
DRAFT ON-CUSHION (AFT)	1.2	m
DRAFT OFF-CUSHION (MEAN)	4.3	m
FULL-LOAD DISPLACEMENT	1936.5	MT
LIGHT-SHIP DISPLACEMENT	1513.5	MT
PRINCIPAL STRUCTURAL MATERIAL	HSLA STEEL	
PROPULSION POWER	(MCP) 40,284	KW
LIFT POWER	(MCP) 6,714	KW
PROPULSORS - 2 CRP MARINE SCREWS		
TOTAL COMPLEMENT	99	#
MAXIMUM CONTINUOUS SPEED AT FULL LOAD IN SS0/SS6	55/33	KNOTS
RANGE AT MAXIMUM CONTINUOUS SPEED IN SS0	1320	NM
MAXIMUM RANGE AT 12 KNOTS IN SS0/SS6	9900/5150	NM
MAXIMUM RANGE AT 20 KNOTS IN SS0/SS3	4900/-	NM

SS: SEA STATE

Figure 2.1-3. Principal Characteristics of the US/G SES currently approved for the U.S. Navy. The design also features twin semi-submerged, super-cavitating controllable-reversible pitch propellers.

Much of the internal partitioning uses very-light-weight unpainted Nomex honeycomb composite structures. This type of structure has been used successfully in merchant ships but is not normal in U.S. Navy practice.

The principal characteristics of the US/G SES are shown in Figure 2.1-3. The outstanding features of the US/G SES are its high length-to-beam ratio the transversely stiffened membrane (TSM) bow seals and the semi-submerged, supercavitating propellers.

2.1.4 SP SES Point Design

The SP SES was designed for ASW protection of surface groups, submarine hunting and effective self-defense against air and surface threats. Its air and surface warfare capabilities include a LING II (or similar) data system and a MEROKA close-in weapon (CIW) self-defense gun. The ship's combat suite also comprises one Oto Melara (76/62) gun, three Javelin tripod launchers, and an eight-cell vertical-launch system for six ASW, four SM-2 and six SUW (harpoon-type) missiles. Two triple torpedo tubes for 18 Mk-50 torpedoes are also provided along with two decoy launchers, and two air-surface fire-control radars.

The ship is equipped to handle one LAMPS MK-III helicopter, one towed sonar array and one Variable Depth Sonar (VDS) located under the helicopter flight deck. ESM and ECCM systems are installed in the main mast and upper parts of the superstructure. The principal characteristics of the ship are summarized in Figure 2.1-4. The hullform has a length-to-beam ratio greater than that of the FR SES but less than that of the US/G SES. The hull of the ship, like the US/G SES, is constructed of steel and the bow and stern seals are relatively conventional bag-finger and multi-lobed designs, respectively. On-cushion propulsion power is provided to twin KAMEWA waterjets by two LM-2500 gas turbines while MTU diesels are used to power either the lift-air supply system, or the waterjets in the off-cushion condition in a CODOG arrangement.

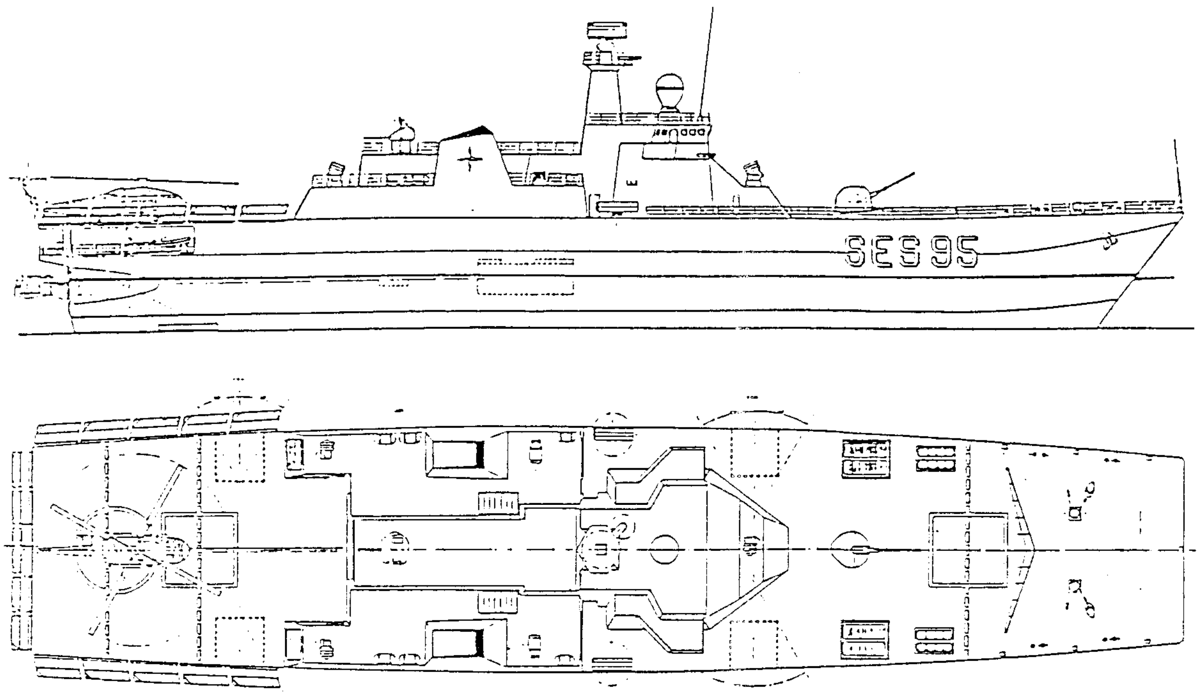
2.1.5 US Hydrofoil Point Design

The broad tasks, for circa 2000 operations of the Hydrofoil Point Design, Figure 2.1-5, are escort operations, open-ocean sea-control operations, surveillance and reconnaissance, barrier or containment operations, mine warfare (optional), and other less demanding tasks such as, protection of maritime resources, and search and rescue. As required by the ONST, the principal emphasis is on Anti-submarine Warfare (ASW) and Surface Warfare (SUW) with anti-air warfare (AAW) limited to a self-defense capability only. This ship is not required to, and is therefore, not designed to carry a helicopter. Consequently, emphasis is placed on the control and use of off-ship assets, such as aircraft, for initial detection of hostile targets. This ship can deploy a high-speed towed array (HITAS) or a high-speed variable depth sonar (HYTOW).

A notional combat system is proposed which includes a 30 mm close-in-weapon system. For this the GE/Signal GOALKEEPER, is chosen for AAW and ASMD self-defense because it is a stand alone, automatic weapon system. The operation of this system is completely automatic from target detection to target destruction. Additional AAW and ASMD defense if provided by the 21 cell Rolling Airframe Missile (RAM) launcher and two, three cell JAVELIN launchers. The JAVELIN launchers are mounted directly to the side of the 30 mm gun while the RAM launcher is a self-contained unit located on the aft end of the deckhouse. These three systems provide an overlapping defense shield against aircraft and missile targets.

The primary offensive weapon capability is a lightweight, 8 cell Vertical Launcher System (VLS). The VLS allows a flexibility in weapon loadout, depending on the mission profile, between ASW weapons (ASROC) or SUW weapons (Harpoon). The VLS gives the hydrofoil a stand-off ASW capability as well as the necessary SUW offensive weapon.

Two, triple torpedo tube launchers are located on the forecastle. These provide a close-in ASW offensive capability. These launchers can handle either the older MK 46 torpedoes or the newer MK 50 torpedoes.

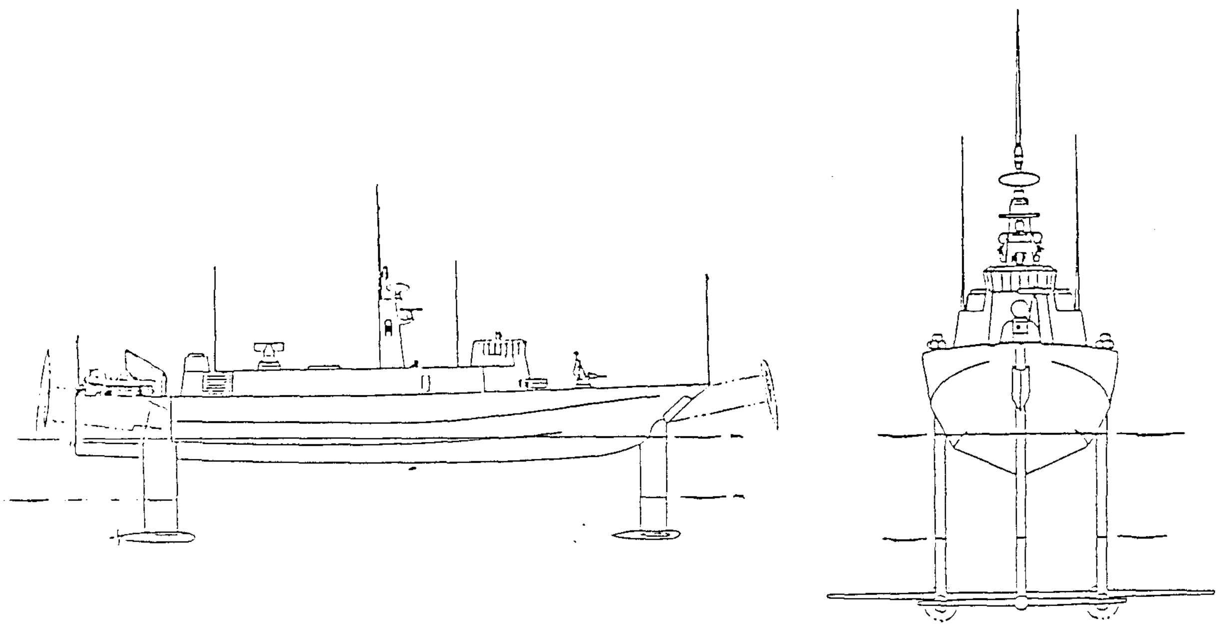


SP SES POINT DESIGN

LENGTH OVERALL		95	m
BEAM OVERALL		20.4	m
KEEL TO WETDECK CLEARANCE		6.1	m
DRAFT ON-CUSHION (AFT)		1.25	m
DRAFT OFF-CUSHION (MEAN)		4.38	m
FULL-LOAD DISPLACEMENT		1741.9	MT
LIGHT-SHIP DISPLACEMENT		1327.6	MT
PRINCIPAL STRUCTURAL MATERIAL		STEEL	
PROPULSION POWER	- 2 (LM-2500-30)	42,000	KW
LIFT POWER	- 2 MTU 16 V & 20 V-538-TB93)	12,410	KW
PROPULSORS	- 2 WATERJETS	-	
TOTAL COMPLEMENT		95	#
MAXIMUM CONTINUOUS SPEED AT FULL LOAD IN SS0/SS6		52	KNOTS
RANGE AT MAXIMUM CONTINUOUS SPEED IN SS0		2500	NM
MAXIMUM RANGE AT 12 KNOTS IN SS0/SS6		6500/-	NM
MAXIMUM RANGE AT 18 KNOTS IN SS0/SS3		3800/-	NM

SS: SEA STATE

Figure 2.1-4. Principal Characteristics of SP SES



US HYDROFOIL POINT DESIGN

LENGTH OVERALL	66	m
BEAM OVERALL	23.3	m
KEEL CLEARANCE	3.66	m
DRAFT FOILBORNE	3.60	m
DRAFT HULLBORNE (FLUID DOWN)	8.63	m
DRAFT HULLBORNE (FOILS RETRACTED)	2.62	m
FULL-LOAD DISPLACEMENT	773.3	MT
LIGHT-SHIP DISPLACEMENT	577.2	MT
PRINCIPAL STRUCTURAL MATERIAL	AL. ALLOY	
PROPULSION POWER - 2 RR SPEYS (SM 3A)	(MCP) 22,380	KW
- 2 MTU	(MCP) 3,133	KW
PROPULSORS - 2 CRP MARINE SCREWS		
TOTAL COMPLEMENT	54	#
MAXIMUM CONTINUOUS SPEED AT FULL LOAD IN SS0/SS6	50/48	KNOTS
RANGE AT MAXIMUM CONTINUOUS SPEED IN SS0	1400	NM
MAXIMUM RANGE AT 6 KNOTS IN SS0/SS6	8300/-	NM
MAXIMUM RANGE AT 15 KNOTS IN SS0/SS3	3150/-	NM

SS: SEA STATE

Figure 2.1-5. Principal Characteristics of the U.S. Hydrofoil Point Design

Space and weight allowances have been made to include Remotely Piloted Vehicles (RPVs) as a sensor. However, no attempt has been made to choose an existing system.

The principal characteristics for the NATO Open-Ocean Hydrofoil, are shown in Figure 2.1-5. The majority of the machinery is located in the watertight compartments aft of the Vertical launch System.

Foilborne and hullborne propulsion are provided by a CODOG arrangement of two separate sets of engines driving through a common, mechanical transmission. These engines, both gas turbine and diesel, drive two controllable and reversible pitch transcavitating propellers mounted at the aft end of two nacelles located at the main (aft) foil/strut intersection. Power is transmitted to these propellers by a mechanical "Z" drive transmission that is housed inside the aft struts. The ship is also equipped with auxiliary, hydraulic motors for emergency and shallow-water propulsion. Foilborne steering is accomplished by the forward strut. Hullborne steering is accomplished by the forward strut and by differential thrust of the two propellers. Basic power to the electrical system is supplied by three, diesel-driven generators. The generators are sized so that any two can handle the ship's predicted battle condition loads.

The ship's Automatic Control System (ACS) provides continuous dynamic control of the ship during takeoff, landing, and all foilborne operations. In addition to providing ship roll stability, the ACS controls the height of the hull above the water surface, initiates and holds coordinated turns, and attenuates ship motions caused by wave action. The combination of the ACS and fully-submerged foils permits the ship to operate in seas up through Sea State 6. This system is similar to the ACS presently in use on the PHM. The addition of a forward-looking radar will provide smoother ride conditions than achieved by previous hydrofoils.

2.1.6 CA Hydrofoil Point Design

For a point design, Figure 2.1-6, Canada offered a previously developed design which, although it did not satisfy the complete SWG/6 ONST, it represented a favorable compromise between performance and cost. Rough-water speed, for example, was limited to 38 knots, as opposed to the 41 knots of the US/G hydrofoil. Endurance and range capability was held acceptable by the weight saved in using a fixed-foil system as opposed to a retractable system as used on the US/G Hydrofoil Point Design. At a full-load displacement of 458 MT it is 59% of the full-load displacement of the US Hydrofoil.

The objective of the Canadians was to offer an ocean-going hydrofoil which was smaller, more austere and which would cost less than one third of the cost of a "Standard Frigate". By selecting a fixed, but fully-submerged, design an extreme canard-foil configuration was selected, which in addition to saving weight, produced both a seakeeping advantage and a lower stress for the steerable bow foil which is normally a serious problem for large hydrofoils equipped with retractable foils.

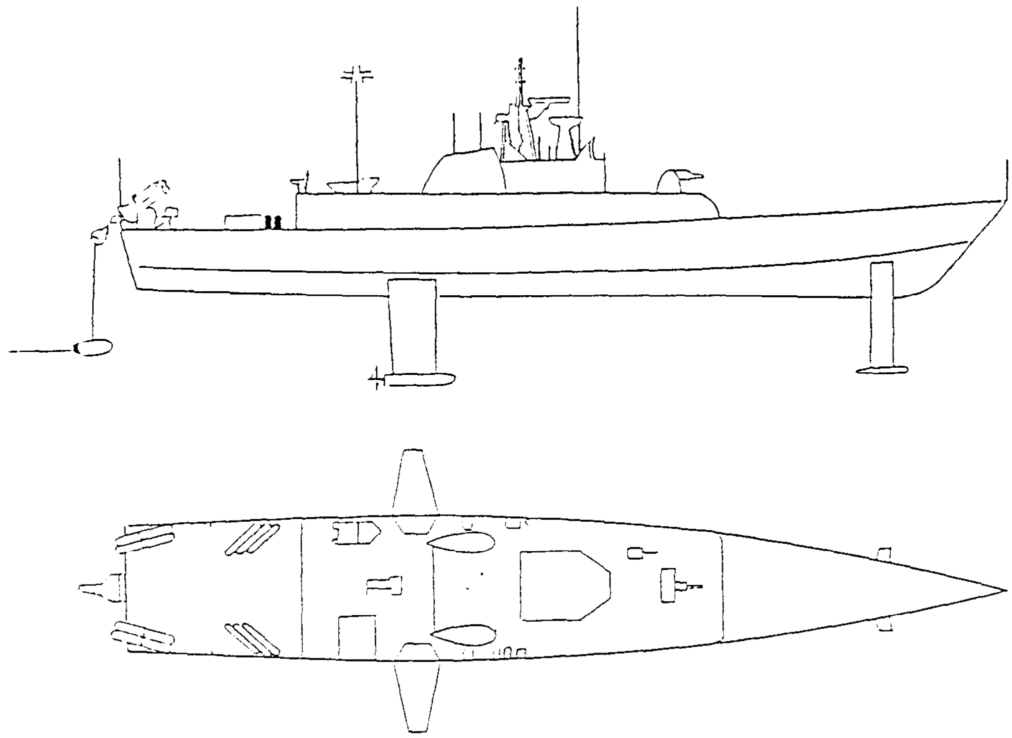
Although the mission-related payload of the low-cost option is 87% of the payload of the US Hydrofoil it is equipped with a similar combat capability.

Major weapons include: one Goalkeeper SGE-30 CIWS, eight Harpoon anti-ship missiles and six MK-32 Mod-9 torpedo tubes. Major sensors include: one AN/SPS-58 air-search radar, one RCA R-76 tracking radar, one AN/SPS-67 surface radar, a HITAS towed-array sonar and a HYTOW variable-depth sonar (VDS). Although the ship does not carry a helicopter it is provided with three remotely piloted vehicles (RPVs).

2.1.7 SWATH Point Design

The ONST for the SWATH described two ships, one an outer screen ASW ship equipped with passive sensors and point air defense and the other an inner screen general purpose combatant providing supportive air defense, active sensors and air resources for the prosecution of contacts made by other ships. To fully exploit the advantages of the SWATH over a monohull, the former concept of operations was selected to be the subject of the SWATH study.

To meet this objective the ship carries and provides Level-2 support for four large ASW helicopters and ten RPVs. The ASW suite includes TAS, VDS, conformal HMS and a mix of torpedoes and vertically launched ASROC.



CA HYDROFOIL POINT DESIGN

LENGTH OVERALL	64	m
BEAM OVERALL	19.84	m
KEEL CLEARANCE	2.6	m
DRAFT HULLBORNE	8.14	m
DRAFT FOILBORNE	3.60	m
FULL-LOAD DISPLACEMENT	457.7	MT
LIGHT-SHIP DISPLACEMENT	286.1	MT
PRINCIPAL STRUCTURAL MATERIAL	AL. ALLOY	
PROPULSION POWER - 2 DDA-570KB	(MCP) 14,000	KW
- 2 MTU-12V493	(MCP) 2,000	KW
PROPULSORS - 2 CRP MARINE SCREWS		
TOTAL COMPLEMENT	40	#
MAXIMUM CONTINUOUS SPEED AT FULL LOAD IN SS0/SS6	45/-	KNOTS
RANGE AT MAXIMUM CONTINUOUS SPEED IN SS0	1635	NM
MAXIMUM RANGE AT 6 KNOTS IN SS0/SS6	6500+/-	NM
MAXIMUM RANGE AT 15 KNOTS IN SS0/SS3	3925/-	NM

SS: SEA STATE

Figure 2.1-6. Principal Characteristics of the CA Hydrofoil Point Design

The AAW suite selected is primarily for self defense, however, a measure of local-area air defense is achieved by the use of 56 MK41 vertically-launched AMRAAM missiles. The GE FAST3-D air-defense radar, an AN/SPS-49 surveillance radar and a passive AN/SAR-8 are the primary AAW sensors. Medium-range self defense is provided by a Bofors 57 mm gun and close-in defense by two Phalanx CIWS.

HARPOON anti-ship missiles are the main SUW weapon; a total of eight are box-mounted port and starboard at midships. The Bofors 57 mm gun provides a measure of SUW in a policing role.

The propulsion and electrical systems are integrated electric; the motive power produced by two 20-MW Rolls Royce Spey gas turbines (intercooled, regenerated) and three 3.2-MW Pielstick diesels each driving liquid-cooled stator synchronous generators. Two cross-connected propulsion switchboards supply power to the two 22-MW liquid-cooled induction motors which directly drive the slow turning (120 rpm max) seven-bladed propellers. Ship-service electrical power is derived from the propulsion switchboards (6300 volts) and converted to 440 volts by solid-state power converters.

The ship is divided into four damage-control zones; each zone being self-supporting in terms of its vital services such as HVAC, electrical power, water and firefighting. Vital compartments are located inboard of less critical compartments, thereby achieving added protection against a cheap kill.

The principal characteristics and an outboard profile of the SWG/6 SWATH are presented in Figure 2.1-7.

The lower hulls are contoured and are oblong in cross-section. The contours were developed from the U.S. Navy's FFX design but were modified to trade-off some cruise speed efficiency for extra speed at maximum power. The eccentricity of the hulls in cross-section contributes to a smaller draft than circular hulls would provide and has the added advantage of increasing heave, pitch and roll damping. The lower hull centerlines are inset approximately 1.4 m from the strut centerlines in order to reduce the overall beam without affecting the transverse stability, (GM_T).

The design features short, single struts and a combined stabilizer/rudder ("stabiludder") concept.

A two deck (plus inner bottom) box was selected. The box does not extend the full length of the ship for two reasons; as an effort to reduce excess internal arrangeable volume and to reduce the frequency and severity of box slamming. The wet deck is tapered upward at the bow and stern to further reduce slamming. The box clearance at midship is 4.5 m and at its fore and aft extremities is 6.5 m.

The superstructure comprises two deckhouses. An attempt has been made to reduce radar cross-section (RCS) by eliminating the 90 degree re-entrant angles between the faces of the deckhouse with itself and with the main deck.

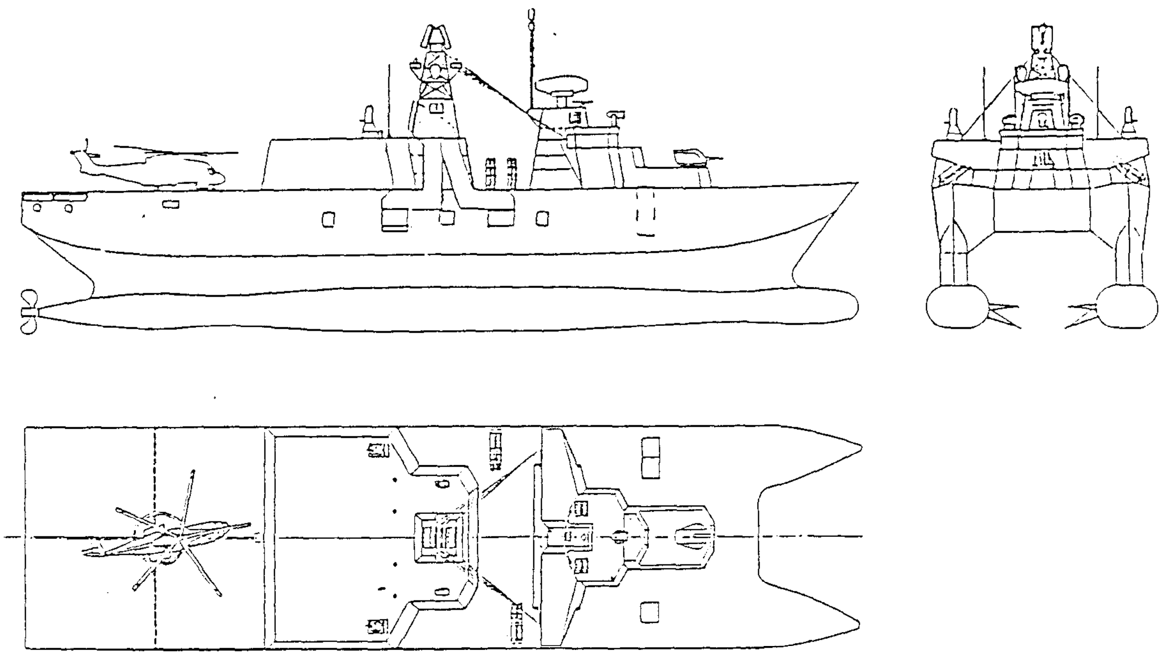
2.2 Baseline Monohulls

2.2.1 FFG 7

The Oliver Hazard Perry FFG 7-Class frigate, FFG 36 (the USS UNDERWOOD), has been chosen as representative of the FFG 7 class since its full-service weight margin has been utilized. This ship, commissioned in January 1983, is intended primarily for ASW with additional provision for limited AAW defense to amphibious groups, military convoys and replenishment groups. The principal characteristics of the ship are summarized in Figure 2.2-1.

Its EW capabilities are enhanced by an SLQ-32(V)2 sonar, SLQ-25 Nixie torpedo countermeasures, and a keel mounted SQS-56 sonar.

For its ASW mission, the FFG 36 relies primarily upon its two SH-60B Seahawk helicopters and, to a lesser extent, on the ship-mounted MK 32 torpedo tubes. Additional armaments include one 76 mm AA MK 75 cannon; one MK 13 Mod 4 missile launcher, and a 20 mm Phalanx CIWS M16.

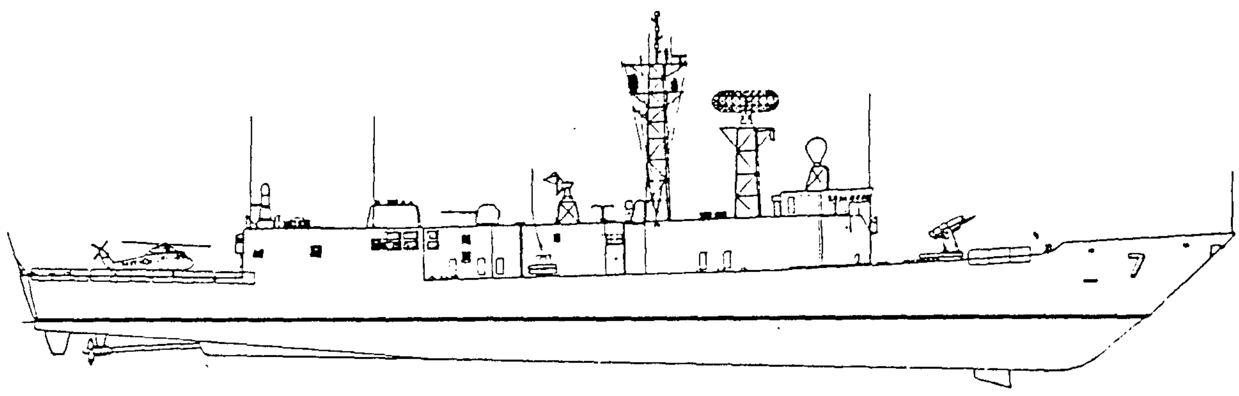


SWATH POINT DESIGN

LENGTH OVERALL	115.8	m
BEAM OVERALL	30.5	m
KEEL TO WETDECK CLEARANCE	4.5	m
DRAFT	9.2	m
FULL-LOAD DISPLACEMENT	9548	MT
LIGHT-SHIP DISPLACEMENT	7391	MT
PRINCIPAL STRUCTURAL MATERIAL	STEEL	
PROPULSION POWER - 2 RR SPEYS (ICR)	(MCP) 20,000	KW
AUXILIARY POWER - 3 PIELSTICK	(MCP) 9,600	KW
PROPULSORS - 2 FP MARINE SCREWS		
TOTAL COMPLEMENT (TWO HELICOPTER VARIANT)	279	#
MAXIMUM CONTINUOUS SPEED AT FULL LOAD IN SS0/SS6	25.8/-	KNOTS
RANGE AT MAXIMUM CONTINUOUS SPEED IN SS0	3400 (INITIAL); 2200 (ENDLIFE)	NM
MAXIMUM RANGE AT 10 KNOTS IN SS0	10,200 (INITIAL); 6850 (ENDLIFE)	NM

SS: SEA STATE

Figure 2.1-7. Principal Characteristics of SWATH Point Design



FFG 7 DESIGN

LENGTH OVERALL	135.6	m
BEAM OVERALL	13.7	m
DRAFT	7.5	m
FULL-LOAD DISPLACEMENT	3731	MT
LIGHT-SHIP DISPLACEMENT	2800	MT
PRINCIPAL STRUCTURAL MATERIAL	STEEL	
PROPULSION POWER	30,575	KW
PROPULSORS	1 CRP MARINE SCREW	
TOTAL COMPLEMENT	193	#
MAXIMUM CONTINUOUS SPEED AT FULL LOAD IN SS0/SS6	28+	KNOTS
RANGE AT MAXIMUM CONTINUOUS SPEED IN SS0		
MAXIMUM RANGE AT 12 KNOTS IN SS0/SS6		
MAXIMUM RANGE AT 20 KNOTS IN SS0/SS3	4500/-	NM

SS: SEA STATE

Figure 2.2-1. Principal Characteristics of FFG 7 Design

Powered by two GE LM2500 gas turbines driving a single shaft, the UNDERWOOD can sustain a calm-water speed of 28 knots using a single (5 m, 16.5 ft) CRP propeller. In the event of main propulsion failure, a 6 knot "come home" capability is provided by two 325 hp engines power-retractable propeller pods located aft of the sonar dome. The ship is equipped with four 1000 kW diesel ships-service generators.

2.2.2 LUPO-Class Frigate

The Italian LUPO class frigate, (F64), Figure 2.2-2, was commissioned in September 1977 and was designed primarily for convoy-escort work with a surface warfare capability. Surface weapons include one 5-inch, 54 caliber gun, four 40 mm/70 (twin Breda) guns and a NATO Sea Sparrow missile launcher. Six (2 triple) MK 32 torpedo tubes and helicopter launched torpedoes comprise the ASW weaponry. Air/surface missiles can also be carried by the single Agusta-Bell 212 ASW helicopter. Electronic warfare capability is provided by RAN 105 Air-Search and SPQ2-F Surface-Search Radar with Orion 10X and Orion 20X Fire-Control systems. The sonar suite consists of a DE 1160B (Raytheon) hull-mounted array.

The LUPO is a multi-purpose ship intended to patrol, control, and protect traffic lanes with the capability for offensive and defensive actions. Displacing only 2462 tons and fitted with two LM 2500 gas turbines, the LUPO is capable of calm-water speeds in excess of 35 knots. The principal characteristics of the LUPO are shown in Figure 2.2-2.

2.2.3 Descubierta-Class Corvette

The Spanish Descubierta-Class Corvette, Figure 2.2-3, was commissioned in November 1978. One 76 mm Oto Melara cannon, two 40 mm/70 (single Breda) guns, and one Sea Sparrow (or Albatros) missile launcher are fitted. ASW weapons include six (2 triple) MK 32 torpedo launchers and a Bofors 375 mm A/S rocket twin launcher. Weight and electrical power margins have been provided for the installation of S/S missiles and two 4-cell Harpoon launchers are being considered. The 1520 ton ship does not embark any helicopters, but has the capability to control helicopters during ASW operations.

The Descubierta's electronic warfare suite includes an air/surface search radar, two optical detectors, and a fire-control system. The sonar system consists of a hull-mounted Raytheon 1160B scanning and attack sonar. A variable-depth sonar can also be installed.

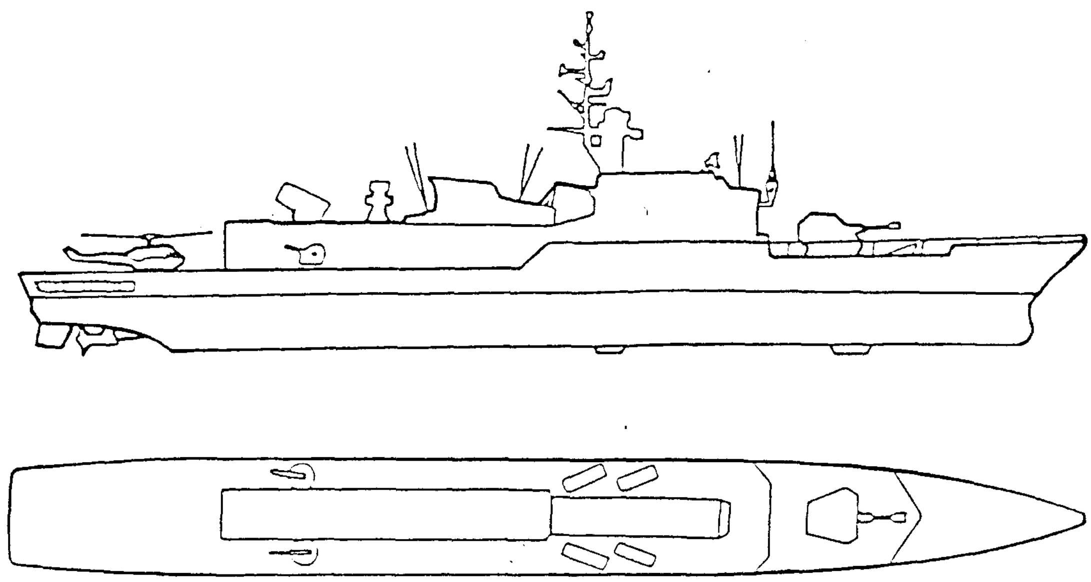
Four MTU diesel engines provide an installed MCP of 21,476 kW giving the ship a 25 knot speed capability, and fin stabilizers are fitted. The principal characteristics of the Descubierta are shown in Figure 2.2-3.

2.2.4 Tribal Class Destroyer

The Canadian Tribal-Class Destroyer, (DD 280), Figure 2.2-4, was commissioned in July 1972. Designed as anti-submarine ships, they are deck equipped with double hauldown and beartraps for their two Sea King CHSS-2 A/S helicopters. One 5-inch 54 caliber gun and two Sea Sparrow quad-launchers comprise the surface weapon suite. Ship-fitted ASW weaponry consists of six (2 triple) MK 32 torpedo launchers.

The electronic warfare capability is provided by a surface warning and navigation radar and a fire-control system. The sonar suite consists of an SQS 505, hull-mounted in a 14 ft dome, and an SQS 505 VDS with an 18-foot towed body. The ship is equipped with a CBR washdown system and enclosed citadel.

An installed horsepower of 44,104 kW is provided by two main gas-turbine engines and two other gas turbines provide cruise power. Maximum speed is in excess of 28 knots and the ship is installed with flume-type anti-rolling tanks for stabilization. The principal characteristics of the Tribal-class destroyer are shown in Figure 2.2-4.

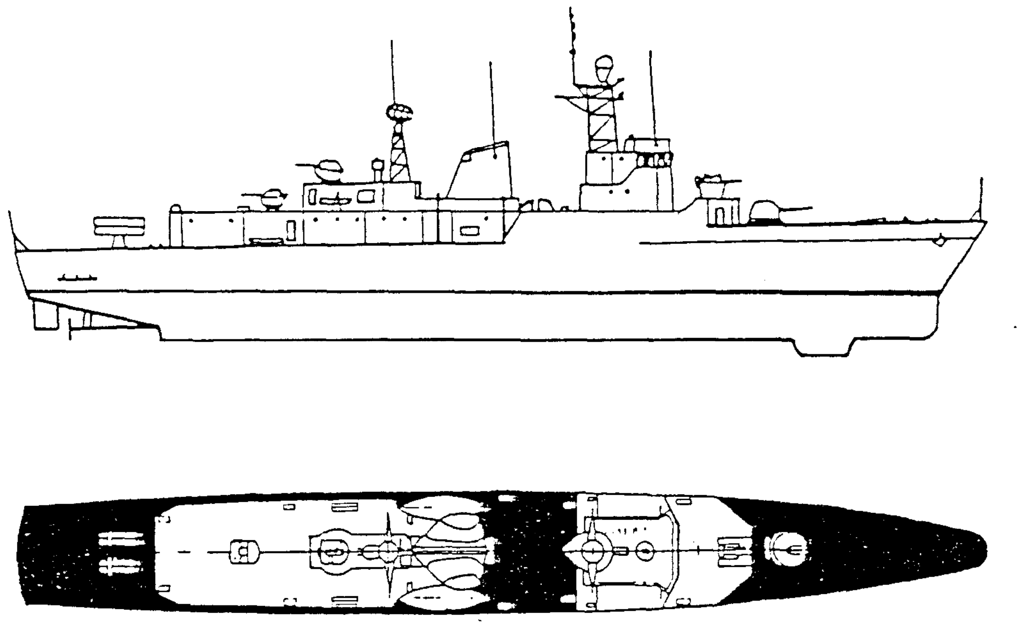


LUPO CLASS FRIGATE DESIGN

LENGTH OVERALL	113.2	m
BEAM OVERALL	11.3	m
DRAFT	3.7	m
FULL-LOAD DISPLACEMENT	2462	MT
LIGHT-SHIP DISPLACEMENT	2000	MT
PRINCIPAL STRUCTURAL MATERIAL	STEEL	
PROPULSION POWER - 2 GM LM 2500's	(MCP) 40,000	KW
PROPULSORS	2 CRP MARINE SCREWS	
TOTAL COMPLEMENT	205	#
MAXIMUM CONTINUOUS SPEED AT FULL LOAD IN SS0	>35	KNOTS
RANGE AT MAXIMUM CONTINUOUS SPEED IN SS0	1200	NM
MAXIMUM RANGE AT 10 KNOTS IN SS0	7700	NM
MAXIMUM RANGE AT 20 KNOTS IN SS0	4800	NM

SS: SEA STATE

Figure 2.2-2. Principal Characteristics of LUPO Class Frigate

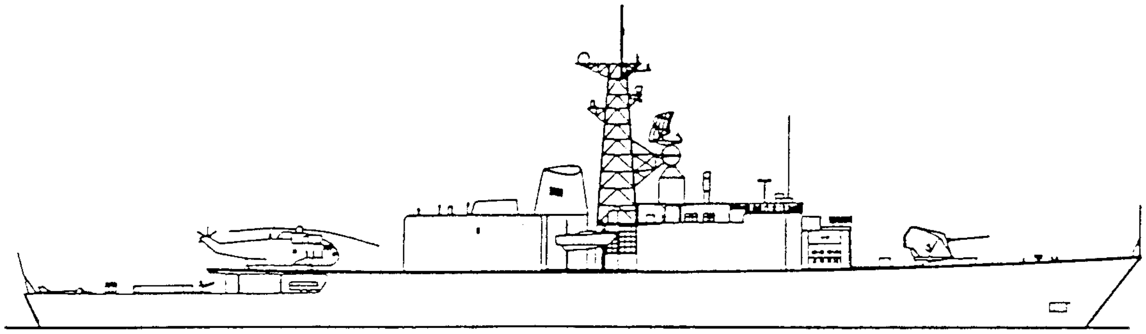


DESCUBIERTA CLASS CORVETTE

LENGTH OVERALL	88.9	m
BEAM OVERALL	10.4	m
DRAFT	6.2	m
FULL-LOAD DISPLACEMENT	1520	MT
LIGHT-SHIP DISPLACEMENT	-----	MT
PRINCIPAL STRUCTURAL MATERIAL	STEEL	
PROPULSION POWER - 4 MTU Diesels	(MCP) 21,476	KW
PROPULSORS	2 CRP MARINE SCREWS	
TOTAL COMPLEMENT	-----	#
MAXIMUM CONTINUOUS SPEED AT FULL LOAD IN SS0	25.5	KNOTS
RANGE AT MAXIMUM CONTINUOUS SPEED IN SS0	-----	
MAXIMUM RANGE AT 18 KNOTS IN SS0	4000	NM

SS: SEA STATE

Figure 2.2-3. Principal Characteristics of Descubierta Class Corvette



TRIBAL CLASS DESTROYER

LENGTH OVERALL	129.8	m
BEAM OVERALL	15.2	m
DRAFT	4.7	m
FULL-LOAD DISPLACEMENT	4690	MT
LIGHT-SHIP DISPLACEMENT	3695	MT
PRINCIPAL STRUCTURAL MATERIAL	STEEL	
PROPULSION POWER	44,104	KW
PROPULSORS	2 CRP MARINE SCREWS	
TOTAL COMPLEMENT	274	
MAXIMUM CONTINUOUS SPEED AT FULL LOAD IN SS0/SS6	28.8	
RANGE AT MAXIMUM AND ENDURANCE SPEEDS	--	

SS: SEA STATE

Figure 2.2-4. Principal Characteristics of Tribal Class Destroyer

2.2.5 Additional Baseline Monohulls

The United Kingdom has provided characteristics, seakeeping and maneuvering data, and a major system weight breakdown for a 4362 ton frigate which they have designated the "UK System NOM 4000T frigate". France has provided ship motion program predictions and towing tank seakeeping data for three ships which they have designated CASM 70 (6000T), FL 25 (3000T), and F67 (5000T).

2.2.6 DD 963

The Spruance class destroyer, DD 963, was commissioned in September 1975. Its primary mission is anti-submarine warfare including operations as an integral part of attack carrier task forces.

Electronic warfare capability is provided by SQR-19 TACTAS, and a bow mounted SQS-53 sonar as well as both SPS 40 and SPS 55 search, and SPG 60 and SPQ 9A fire-control radars.

The DD 963 is equipped with two 5-inch, 54 caliber, DP MK 45 cannons as gunnery. One 8-tube, MK 16 twin cell ASROC missile launcher, two MK 32 triple torpedo tubes and one SH-3 Sea King helicopter comprise the anti-submarine weaponry.

The Spruance were the first large US warships to employ gas turbine propulsion. Each ship has four GE LM2500 engines powering two CP propellers; each engine is fitted with self-noise reduction features. Three gas turbine generators of 2000 kW each are provided.

One engine can propel the ship at 18 knots, two at 27 knots and four at calm-water speeds in excess of 30 knots.

The principal characteristics of the DD 963 are shown in Figure 2.2-5. Extensive use of the modular concept is used to facilitate initial construction and block modernization. The ship is highly automated resulting in a 20% reduction in personnel over a similar ship with conventional systems.

2.2.7 Baseline NFR 90

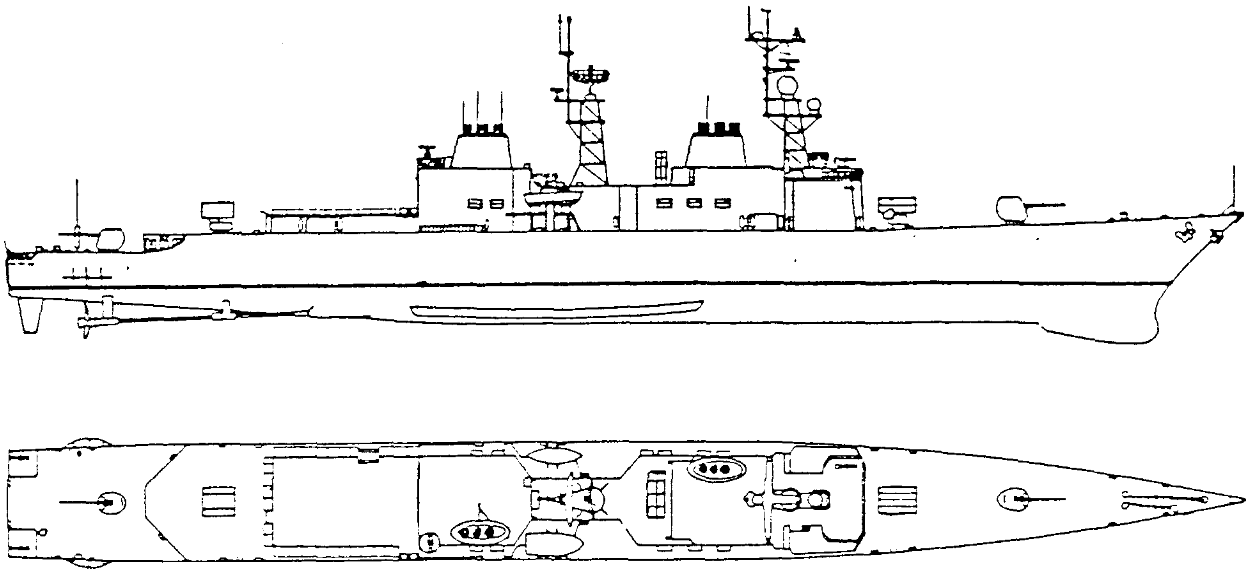
The NFR 90 (NATO frigate replacement for the 1990s) is potentially the largest cooperative program in the history of NATO, variously estimated at $15-20 billion. It was conceived as a result of the observation that many of the NATO nations were going to require replacements for their frigates in the mid-1990s.

The program is following the NATO PAPS (phased armaments programming system) process with each phase of PAPS including an industrial effort followed by a Government decision period.

The prefeasibility study concluded that it was technically and economically feasible to proceed, and in April 1984 eight nations (i.e., Canada, France, Germany, Italy, the Netherlands, Spain, the United Kingdom, and the United States) signed a memorandum of understanding (MOU) to conduct a feasibility study. This has now been completed and the nations are currently in Government decision period 1.

The general layout and leading particulars of the baseline NFR 90 are shown in Figure 2.2-6.

The ship has an integrated suite of weapons and sensors for anti-submarine warfare, anti-air warfare and surface warfare. For ASW the ship has bow mounted, variable depth and towed array sonars; side launched and missile carried torpedoes; and two helicopters. In AAW she has local area, multiple engagement capability by means of a multi-function radar (MFR) and local area missile system (LAMS), as well as two CIWS. She has cannister launched surface-to-surface missiles and a 127 mm gun for SUW. The combat system architecture is fully integrated by means of a data bus using a distributed/federated philosophy. It is flexible and reconfigurable. Special attention was paid to reducing ship signatures.

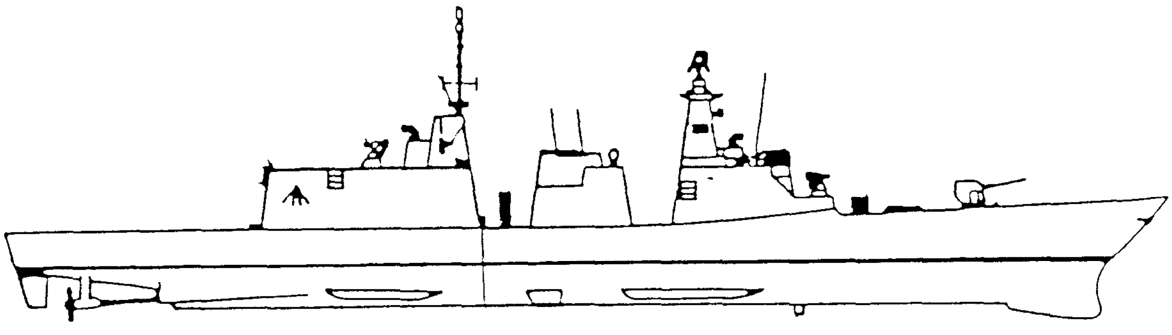


DD 963 DESIGN

LENGTH OVERALL	171.8	m
BEAM OVERALL	16.8	m
DRAFT	8.8	m
FULL-LOAD DISPLACEMENT	7925	MT
LIGHT-SHIP DISPLACEMENT	5781	MT
PRINCIPAL STRUCTURAL MATERIAL	STEEL	
PROPULSION POWER	59,656	KW
PROPULSORS	2 CRP MARINE SCREWS	
TOTAL COMPLEMENT	324	#
MAXIMUM CONTINUOUS SPEED AT FULL LOAD IN SS0/SS6	33	KNOTS
RANGE AT MAXIMUM CONTINUOUS SPEED IN SS0		
MAXIMUM RANGE AT 12 KNOTS IN SS0/SS6		
MAXIMUM RANGE AT 20 KNOTS IN SS0/SS3	6000/-	NM

SS: SEA STATE

Figure 2.2-5. Principal Characteristics of DD 963



NFR-90 DESIGN

LENGTH OVERALL	140.5	m
BEAM OVERALL	15.8	m
DRAFT	5.0	m
FULL-LOAD DISPLACEMENT	5059	MT
PRINCIPAL STRUCTURAL MATERIAL	STEEL	
PROPULSION POWER (CODOG)	POWER NOT AVAILABLE	
PROPULSORS	2 CRP MARINE SCREWS	
TOTAL COMPLEMENT	201	#
MAXIMUM CONTINUOUS SPEED AT FULL LOAD IN SS0/SS6	30/24	KNOTS
MAXIMUM RANGE AT 19 KNOTS IN SS0	5000	NM
MAXIMUM RANGE AT 28 KNOTS IN SS0	2000	NM

SS: SEA STATE

Figure 2.2-6. Principal Characteristics of NFR-90 Design

For propulsion, a CODOG system has been selected using gas turbines for high-speed operation or diesels for lower speed cruise and transit. The two propellers have controllable and reversible-pitch.

A summary of the leading particulars of each ANV and monohull design is given in Tables 2.2-1 and 2.2-2.

Table 2.2-1. Summary of SWG/6 Designs

	UK SES	FR SES	US/G SES	SP SES	US HYDRO	CA HYDRO	CA SWATH	US FFG 7	US DD 963
OVERALL LENGTH, m	92.9	89	104	95	66	64	115.8	135.6	171.8
OVERALL BEAM, m	29	21.1	19.5	20.4	23.3	19.8	30.5	13.7	16.8
F-L DISPLACEMENT, tons[6]	1601	1400	1937	1742	773	458	9548	3731	7925
HULL MATERIAL	GRP	AL. ALLOY	STEEL	STEEL	AL. ALLOY	AL. ALLOY	STEEL	STEEL	STEEL
PROPULSION POWER, kw	36000	44200	40284	42000	22000	16000	44000	30575	59656
LIFT POWER, kw	10800	8800	6714	12410	—	—	—	—	—
PROPULSORS	2 WATER-JETS	2 WATER JETS	2 CRP[7] MARINE SCREWS	2 WATER-JETS	2 CRP[7] MARINE SCREWS	2 CRP[7] MARINE SCREWS	2 FP[8] MARINE SCREWS	1 CRP MARINE SCREWS	2 CRP MARINE SCREWS
MAX. CONT. SPEED IN CALM WATER, knots	50	57	55	52	52	45	25.8	28+	33
ANNUAL AVERAGE MAX. SUSTAINED SPEED IN NORTHERN NORTH ATLANTIC, knots	34.7	38.6	38.2	38.7	40.6	38.1	22.1	22.5	25.1
MISSION PAYLOAD, tons[6]	150.5	138.4	193.6	147.1	64.1	55.8	532	382	770
NUMBER OF EMBARKED HELICOPTERS	1	2	2	1	RPV[9]	RPV[9]	4	2	2
INVESTMENT COST PER SHIP[1]									
WITHOUT PAYLOAD, $	107M	100M	127M	107M[4]	135M	85M	326M	162M	370M
WITH PAYLOAD, $	157M[4]	150M[4]	189M	157M[4]	192M	125M	476M[5]	255M	440M
LIFE CYCLE COST PER SHIP[2], $	408M[4]	359M[4]	388M[4]	373M[4]	344M[4]	246M[4]	1198M[4,3]	599M[3]	1160M[3]

COST FOOTNOTES: All Costs in 1986 U.S. Dollars
All Costs U.S. Navy Estimates Except as Noted

1 Average Cost for a Twelve Ship Buy (Development Costs Not Included)
2 Average Development, Investment, and Operating & Support Cost per Ship Over Total Service Life (20 Years Except 30 Years for SWATH). Includes Payload Acquisition Costs But Not Payload Development.
3 30 Year Service Life
4 Cost is Assessment Team Estimate
5 Payload Cost is Canadian Estimate
6 All Weights are in Metric Tons
7 CRP - Controllable & Reversible Pitch
8 FP - Fixed Pitch
9 RPV - Remotely Piloted Vehicle

Table 2.2-2. Summary of Baseline Monohulls

	U.S. FFG-7	U.S. DD963	NATO NFR 90	ITALY LUPO	SPAIN DESCUBIERTA	CANADA TRIBAL
OVERALL LENGTH, m	135.6	171.8	140.5	113.2	88.9	129.8
OVERALL BEAM, m	13.7	16.8	15.8	11.3	10.4	15.2
F-L DISPLACEMENT, tons	3731	7925	5059	2462	1520	4690
PROPULSION POWER, kw	30575	59656	N/A	40000	21476	44104
PROPULSORS	1 CRP MARINE SCREWS	2 CRP MARINE SCREWS	2 CRP MARINE SCREWS	2 CRP MARINE SCREWS	2 CRP MARINE SCREWS	2 CRP MARINE SCREWS
MAX. CONT. SPEED IN CALM WATER, knots	28+	33	30	35+	26	29
ANNUAL AVERAGE MAX. SUSTAINED SPEED IN NORTHERN NORTH ATLANTIC, knots	22.5	25.1	23.6	N/A	N/A	N/A
MISSION PAYLOAD, tons	382	770	488	200 (est)	N/A	422 (est)
NUMBER OF EMBARKED HELICOPTERS	2	2	2	1	0	2
INVESTMENT COST PER SHIP[1]						
WITHOUT PAYLOAD, $	162M	370M	205M[4]	N/A	N/A	N/A
WITH PAYLOAD, $	255M	440M	350M[4]	N/A	N/A	N/A
LIFE CYCLE COST[2], $ PER SHIP	599M[3]	1160M[3]	775M[4, 3]	N/A	N/A	N/A

COST FOOTNOTES: All Costs in Constant 1986 U.S. Dollars
ALL Costs U.S. Navy Estimates Except as Noted

1 Average Cost for a Twelve Ship Buy (Development Costs Not Included)

2 Average Development, Investment, and Operating & Support Cost per Ship Over Total Service Life (30 Years). Does Not Include Payload Development Costs.

3 30 Year Service Life

4 Cost Is Assessment Team Estimate

N/A: Not Available

2.3 Comparison of Point Designs

2.3.1 SESs

The main differences between the SES designs include:

- The wide range of full-load displacements.

  - UK - 1601 MT
  - FR - 1400 MT
  - US/G - 1936.5 MT
  - SP - 1742 MT

- The extreme spread of selected length to beam ratios ranging from 3.2 for the UK ship to 5.3 for the US/G ship.

- The spread of wet-deck heights ranging from 7.5 m for the UK ship to 5.4 m for the French ship.

- The choice of material for hull construction:

  - UK-GRP
  - France - Aluminum Alloy
  - US/G and Spain - High-Strength Steel

- The choice of propulsors:

  - UK, France, and Spain - Waterjets
  - US/G - Surface Piercing Marine Screws

- The number and type of lift fans, the air distribution systems, the design of end seals and the methods used for ride control.

All are powered by gas turbines to meet calm-water speeds of at least 50 knots and sea-state 6 speeds of at least 30 knots.

The assessment has shown that the high length/beam ratio of the US/G design offers advantages as far as forward speed in calmwater is concerned. The greatest stability, however, is offered by the UK short L/B design. The US/G SES and FR SES designs have less margin against capsize in synchronous beam seas and when turning at high speed. The assessment of structural materials highlights the weight penalty for using steel and the fire and fatigue hazard with aluminum alloys. Composites emerge as a possible optimum structural material, although manufacturing techniques for this size of structure need to be developed. The different seals offer merits in different areas, although the UK and French bow seals and French aft seals appear most promising. Discussion of the lift systems raises queries concerning the low values used by the US/G SES for lift-air flow and installed lift power, and also concerning the location of the French air supply to the cushion. These become more important as higher sea states are reached.

All the SES designs include similar equipment fits for the ASW role, although there are differences in the anticipated performance. The proposals for other warfare areas, however, differ considerably in the proposed systems fit. This is probably due to different national perceptions of the air and surface threats, and of the operational roles of the SES.

2.3.2 Hydrofoils

The main differences between the hydrofoil designs include:

- Foil Configuration:
  - US - Retractable (Canard)
  - CA - Non-Retractable (Extreme Canard)
- Displacement
  - US - 773.3 MT
  - CA - 458 MT

Lack of available resources prevented Canada from developing a point design for a hydrofoil ship to the SWG/6 standards. Nevertheless, the Canadian "intermediate" hydrofoil concept may be considered to address the ONST since it incorporates ideas to reduce the risk and cost of hydrofoil ships, and has some features that may be of interest to the smaller NATO nations. It is viewed, not as proposing a competing design, but as introducing some topics worth investigating in further development of any multi-national hydrofoil program.

The concept originated from lessons learned the hard way with HMCS BRAS D'OR. These led the Canadians to conduct parametric studies of a 400 tonne design known as FH-6, addressing a 1975 Statement of Requirements for an ASW hydrofoil having less design margins than those required of the SWG/6 designs. By encompassing a wide range of both surface-piercing and fully-submerged foil configurations and different power-plant and propulsion concepts, these studies provided a basis for assessing the performance merits and cost (or risk) penalties of major design features.

For Canadian requirements, the compromise between performance and costs led to an "intermediate" hydrofoil - intermediate in the sense that the concept lies between aeronautically-based USN designs, such as the PHM, and the simpler commercial European designs, such as RHS-160. A 460 tonne ship known as E5 is the latest of several such designs, and one that addresses the ONST prepared by SWG/6, in principle if not precisely.

Fundamental to the low-cost, low-risk concept is:

a. Reduced power per ton, with foilborne speeds of 40 knots,
b. A non-retracting, flap-controlled, fully-submerged foil system,
c. An extreme canard configuration, with only 10 to 15% of the weight on the bow foil,
d. Conventional propellers, and no separate hullborne propulsion system,
e. An emphasis on long range and good seakeeping qualities hullborne at 15 knots, necessary for the multi-purpose operational concept envisaged for this ship.

2.3.3 SWATH

The SWATH was established to be technically feasible and could satisfy most of the operational requirements set out in the ONST. The notable exception was in the failure to achieve the required maximum speed of 30 knots. It is a fact of life that even large SWATH ships require an exorbitant amount of power to achieve speeds approaching 30 knots. The design philosophy for this ship permitted trading-off 30 knots in favor of improving other performance characteristics and reducing cost.

The SWATH Point Design is larger than had been expected by some members of SWG/6. Factors contributing to its large size are:

a. SWATHs are structurally inefficient; hence large structural weight fractions;

b. SWATHs are sensitive to weight changes; hence must carry future growth margin from commissioning to restrict draft changes; and

c. As weight critical ships, SWATHs generally have excess volume requiring more structure.

A significantly smaller, less expensive, variant is achievable only at the expense of reduced payload, performance or margins or by increased risk in terms of using newer technology.

The ship is well-suited to its primary ASW role. As a very stable platform with a large deck, it can support and deploy at least four modern ASW helicopters. It has been designed for low self-noise so that its own sonars will be effective and it will be difficult to detect.

Arrangement flexibility has contributed to this ship's relatively good protection against fragment and blast effects. Damage below the waterline, however, will cause pronounced trim and heel, severely affecting the ship's ability to continue fighting until counterflooded.

It is concluded that this SWATH offers unique operational attributes suited to the ASW mission but it also presents special concerns and a cost comparable to a DD 963.

3.0 ASSESSMENT OF PLATFORM EFFECTIVENESS

Platform effectiveness was investigated under the following major topics:

- Assessment of Operational Capabilities
- Assessment of Mobility
- Assessment of System Characteristics

The assessment of platform operational capability addressed the warfare areas which are applicable to each point design. This assessment drew heavily upon the conclusions derived from the subsequent quantitative assessment of mobility in terms of speed, seakeeping, etc. and the assessment of subsystem-related characteristics such as hull form, general arrangement, habitability, ship interfaces, etc.

The assessment of mobility focused principally upon identifying the advantages and disadvantages in speed, range, ship motions and maneuvering capability relative to the design of modern monohulls, such as the FFG 7.

The assessment of subsystem-related characteristics was aimed at validating the reported design characteristics utilizing trend data to establish comparisons with prior ships and ship-design studies.

The approach examined effectiveness from the bottom up starting at the subsystem level as illustrated in the bottom half of Figure 3-1. The results, however, are reported in the reverse to the order shown starting with assessment of ship mission effectiveness in terms of overall operational capability.

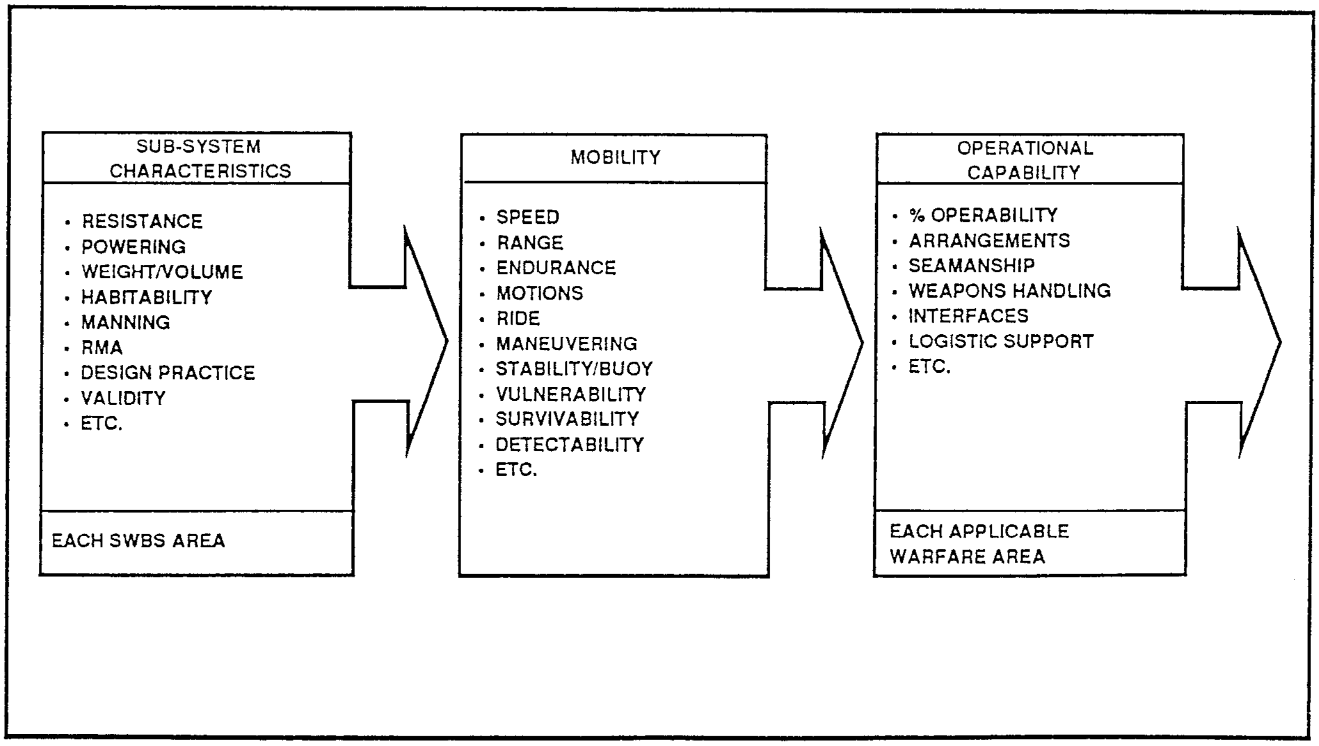


Figure 3-1. Approach to Assessment of Effectiveness.

3.1 ASSESSMENT OF OPERATIONAL CAPABILITY

3.1.1 Mission Requirements

3.1.1.1 General Concept of Operations

The mission requirements to which each point-design has been developed are stated in the respective Outline NATO Staff Targets (ONSTs) of Reference 1. The purpose of each ONST is to amplify the broadly defined mission parameters and functional capabilities required and to translate this information into overall system requirements, interface requirements and operational capabilities. In addition, the ONSTs have formalized the military operational need and have set forth the design goals and thresholds for each ship.

The required operational capabilities for each design have been categorized in the ONSTs by maritime mission areas. These maritime mission areas have been defined so as to parallel traditional naval warfare and support areas.

The ONSTs also contain a general summary of the Warsaw Pact's maritime capabilities postulated through the 1990's and into the twenty first century. Since the Warsaw Pact is capable of initiating and conducting a wide range of actions affecting any portion of the NATO maritime area, it has not been practical to define explicitly the missions, tasks and roles for NATO maritime forces. This is because the diversity of tasks or types of response to Warsaw Pact actions will vary from area to area depending on the type of action, area of operation and circumstances prevailing at the time. Therefore, planning by the Major NATO Commanders (MNCs) is oriented toward flexibility in response to aggression with provision for a variety of response options depending upon the size and scope of the aggression. Such a maritime flexibility depends on maximum mobility, the capacity for quick reaction, rapid response, sound reinforcement and logistics support.

In peacetime, the primary role of NATO's maritime forces is deterrence. Such deterrence is demonstrated by an ability to respond effectively to Warsaw Pact initiatives over a wide range of options without escalation. In times of tension, the dispatch of immediate reaction forces and the rapid reinforcement of local forces may prevent a local situation of tension from developing into aggression. In war, the maritime forces must be capable of engaging the aggressing forces throughout the whole of the NATO area while responding to aggression at any level.

In the early days of hostilities, it is anticipated that merchant shipping and maritime forces at sea, or in the process of deploying, will be elements of the Atlantic and Mediterranean Striking Fleets; advance elements of the Amphibious Task Force; Underway Replenishment Groups; advance elements of SACEUR's Strategic Reserve embarked in Special Military Convoys; a limited number of merchant convoys; fast independents carrying vital cargoes transiting under positive control; and, various Allied ships not yet under naval control enroute to safe ports.

All of the above-mentioned NATO maritime forces, including Allied merchant shipping, require adequate defense against the prevailing air, sub-surface and surface threat. Although some of these forces may have the capability of facing the threat, to a certain extent they will be unable to cope with the entire spectrum of the threat without reaching saturation in any one area. Therefore it is considered that NATO maritime weapons platforms for the 1990's and into the twenty-first century will be required to play a primary role in the defense of the maritime forces and Allied shipping against the air sub-surface and surface threats.

The mission of NATO maritime forces is to contribute to the deterrence of all forms of aggression and to establish and maintain control of the vital sea areas in order to ensure the free use of the sea for all seaborne traffic of the Alliance in times of war, crises and peace. In war, the NATO maritime forces would provide the capability to conduct:

(a) Combined or independent operations intended as offensive measures against submarines and surface ships

(b) The protection of task groups, underway replenishment groups, military and mercantile convoys, single ships of high value, and other Allied shipping from attack by aircraft, submarines and surface ships.

The achievement of the foregoing requires a substantial increase in the operational availability and numbers of NATO ships. It has been perceived that ANVs with their high speed, good endurance, good seakeeping, large aircraft-compatible deck areas, and relative invulnerability to torpedo and mine attack, potentially offer a smaller air-compatible ship that is an economic and effective force multiplier to augment existing and currently planned NATO forces.

3.1.1.2 Operational Requirements

The principal threat is represented by silent, nuclear-powered submarines capable of high speed (45 knots), operating at great depths (1000 meters) and able to deliver surface-launched missiles of medium range (approximately 50 nm). Diesel-electric, torpedo-carrying submarines must also be considered.

The mission is "to operate offensively, in the presence of Warsaw Pact air, surface or sub-surface threats, independently or withstrike, anti-submarine or amphibious forces, underway replenishment groups and military or merchantile convoys against surface or sub-surface threats; and to provide effective self-defense".

The broad tasks, for circa 2000 operations, are escort operations, ocean-area sea-control operations, surveillance and reconnaissance, barrier or containment operations, mine warfare (optional) and other less demanding tasks such as protection of marine resources and search and rescue.

Principal emphasis is on Anti-Submarine Warfare (ASW) and Surface Warfare (SVW). Specific requirements are listed in Table 3.1.1.2-1 below for the SES, Hydrofoil, and SWATH point designs.

Table 3.1.1.2-1. Operational Requirements

(a) Operational Capabilities	
Anti-Air Warfare (AAW)	
SES:	• Self defense against missiles and aircraft
HYDROFOIL:	• Provide early warning of transiting aircraft
SWATH:	• Protect ships using supportive surface-to-air missiles • Capability to direct combat aircraft • Long-range air surveillance • Passive measurement of bearing and elevation • Effective point defence system • Automatic close-in weapons system
Anti-Submarine Warfare (ASW)	
ALL DESIGNS:	• Detect, classify, localize and track submarine targets • Employ torpedo warning and countermeasures
SES:	• General - utilize unique potential of SES - "Sprint & Search", for example • Destroy submarine targets • Conduct airborne ASW operations • Conduct ASW operations in cooperation with other forces
HYDROFOIL:	• Detect, localize and destroy enemy submarine forces, both deep and shallow • Adequate communication for the control of ASW aircraft assets
SWATH:	• Localize and destroy enemy sub-surface forces • Attack using embarked aircraft and over-the-side weapons • All-weather stand-off ASW weapon desirable • Conduct airborne ASW options
Surface Warfare (SVW)	
SES:	• General - "good anti-ship capability" is desirable • Over-the-Horizon via embarked helo • Over-the-Horizon anti-surface ship missiles
HYDROFOIL:	• Utilize surface-to-surface missiles with Over-the-Horizon targeting from third party sources
SWATH:	• Over-the-Horizon targeting provided by embarked helos, RPVs, and third parties • Over-the-Horizon anti-surface ship missiles
Command, Control and Communication (CCC)	
ALL DESIGNS:	• Secure communications with other NATO units (MC195 refers) • Appropriate NATO data link systems • Act as commander Task Group • Inter-operable equipment • Emphasis on secure voice communications

Table 3.1.1.2-1. Operational Requirements (Continued)

Electronic Warfare (EW)

ALL DESIGNS:
- ESM equipment for threat frequency bands (including IR and Laser)
- On and off-board ECM and IRCM capability against threat missiles
- Automated and integrated ESM and ECM equipment in the combat system

HYDROFOIL:
- Employ Electronic Counter-countermeasures (ECCM) for most shipboard RF emitters
- Short reaction time chaff and IR self-defense system

Intelligence (INT)

ALL DESIGNS:
- Collect and disseminate threat information

Logistics (LOG)

ALL DESIGNS:
- Standard NATO UNREP capability (ATP-16A and STANAGS apply)

(b) **Mobility Capabilities**

Hull

ALL DESIGNS:
- Transit Panama Canal

SES:
- Fit NATO nation dry docks
- Assess beaching capability

HYDROFOIL:
- Maximum draft not specified. Therefore, foil system must be able to be either fixed or retractable

SWATH:
- Draft shall be such that special facilities will not be required in any envisaged ports.

Propulsion

ALL DESIGNS:
- Must be capable of quiet running speed

SES:
- Must operate with equal facility on, off and with partial cushion

Performance Characteristics

SES:
- An effective partial-cushion cruise speed on the order of 20 knots is desired
- Fuel reserves must provide an endurance of 24 hours at maximum cushionborne speed and at least 7 days at cruising speeds of about 18 knots in Sea State 3
- Maximum continuous speeds and ranges in accordance with the following are required.

Condition	Seastate No. (Significant Wave Height)	Speed (Knots) Goal	Speed (Knots) Minimum Required	Range (N. Miles) Goal	Range (N. Miles) Minimum Required
Cushionborne	0	50	40	2500	1500
Cushionborne	6 (5.0m)	40	30		
Cruise	0	20	16	5000	3700
Transit	0	12	10		5000
Survival	6	3	0		

HYDROFOIL:
- Maximum continuous speeds and ranges in accordance with the following are required.

Condition	Seastate No. (Significant Wave Height)	Speed (Knots) Goal	Speed (Knots) Minimum Required	Range (N. Miles) Goal	Range (N. Miles) Minimum Required
Foilborne	0	50	40	2000	1500
Foilborne	6 (5.0m)	45	30		
Hullborne (foils down)	0	18	16		3700
Transit (foils down)	0	10			5000
Survival	6	3	0		

Table 3.1.1.2-1. Operational Requirements (Continued)

SWATH: • Maximum continuous speeds and ranges in accordance with the following are required.

Condition	Seastate No. (Significant Wave Height)	Speed (Knots)		Range (N. Miles)	
		Goal	Minimum Required	Goal	Minimum Required
Rough Water	5 (3.0m)	32	30		
Rough Water	6 (5.0m)	30	28		
Cruise	0		25	3700	2500
Transit	0		20	6000	5000
Survival	6	3	0		

<u>Ship Motions</u>

SES:
- Attain transit to fully operational cushion-borne speed at full load displacement at all headings in Sea State 6
- Hullborne motion must also be acceptable

HYDROFOIL:
- Attain transit to fully operational foil-borne speed at full load displacement at all headings in Sea State 6
- Hullborne motions must also be acceptable

SWATH:
- Attain transit to fully operational speed at full load displacement at all headings in Sea State 6

<u>Maneuverability</u>

SES:
- Must be at least comparable to a "traditional ship" including ASW towing

HYDROFOIL:
- Tactical diameter less than 500 meters in calm water when foilborne.
- Advance and transfer less than 500 meters in calm water when foilborne.
- Average turn rate at least 6 degrees per second
- Rough water (4.6m significant wave height and 26 knot wind velocity) average turn rate shall exceed 4 degrees per second

SWATH:
- Tactical diameter of 800 meters and an advance of 800 meters at all speeds in seas up to 3.0 meter significant wave height.
- Maintain any average heading at all speeds in seas of 5.0 meter significant wave height.

<u>Rates of Operation</u>

SES:
- Hullborne at ASW speed 60%
- Cruise speed 10%
- High-speed cushion-borne 30%

HYDROFOIL:
- At monitoring speed 60%
- At cruise speed 10%
- Foilborne at high speed 30%

SWATH:
- None stated

<u>Mooring and Anchoring</u>

ALL DESIGNS:
- Anchoring to 80 meters depth

(c) <u>Survivability and Vulnerability</u>

<u>Signature Characteristics</u>

ALL DESIGNS:
- Exploit existing and emerging technology

<u>Shock Hardness</u>

ALL DESIGNS:
- 0.3 vertical shock factor at the keel

<u>Ballistic Protection</u>

ALL DESIGNS:
- Provide for magazines, vital propulsion and fuel systems, vital combat systems equipment, Combat Information Center (CIC).
- SES and hydrofoil provide protection for the Automatic Control System (ACS)

Table 3.1.1.2-1. Operational Requirements (Continued)

Air Blast	
ALL DESIGNS:	• Over-pressure equal to 3 psi for 5.5 seconds • Dynamic pressure of 0.2 psi for 5.5 seconds
NBC Protection	
SES and HYDROFOIL:	• Provide a "pressurized citadel", protective personal gear, a water washdown system and a personal decontamination station
SWATH:	• Provide nuclear fallout protection, protective personal gear, a water washdown system and a personnel decontamination station.
Fire Protection	
SES and HYDROFOIL:	• Prevent bulkhead or deck collapse for a period of at least 30 minutes when subjected to an oil fire
SWATH:	• Prevent bulkhead and deck collapse in areas subject to oil fires. • Where passive fire protect is installed, prevent bulkhead or deck collapse for at least one hour when subjected to an oil fire.
EMP and TREE	
ALL DESIGNS:	• Fighting capablities to survive "nuclear incident"
Manning	
ALL DESIGNS:	• Adequate to meet the operational and maintenance requirements • Reduce the crew by providing automated systems • 10% accommodation growth margin • Centralize workshop and administrative facilities
SES and HYDROFOIL:	• Reduce crew with a repair-by-replace policy
(d) **Personnel Performance**	
Overall Ride Quality Criteria	
ALL DESIGNS:	• Use International Standards Organization (ISO) two-hour criteria and O'Hanlon crew performance degradation criteria • Pay particular attention to hullborne motions
Readiness and Availability	
SES:	• Availability, quayside readiness and alert stages must be the same as those applicable to other ships of the fleet • 30-days mission duration must be considered -- irrespective of fuel capacity
HYDROFOIL:	• Minimum availability of 0.75 percent • 20 year service life • Mission duration goal 21 days
SWATH:	• Total ship system availability of 0.75 percent • Capable of sustained operations for at least 30 days without external support other than fuel and ammunition.

3.1.2 Platform Effectiveness Summary

The objective of this section is to summarize, on the basis of the evidence presented by the various point-design teams, the overall effectiveness of the point designs in providing platforms which can be used to carry out the NATO missions and operational requirements described in Section 3.1.1. The scope of the assessment is limited to the capability of the point designs as platforms able to operate in a manner which contributes to mission goals within various general warfare areas. Specific mission scenarios and the effectiveness of the weapons systems and sensors are not addressed. Ideally the mission performance of the various concepts should be assessed by a model which integrates the component performance of the combat system and the platform performance, so as to assess the mission effectiveness of the total system. Lack of definition of performance parameters of the respective combat systems has led to the decision to restrict this assessment to consideration of ship platform effectiveness.

Figures 3.1.2-1 through 3.1.2-3 show a summary of the overall assessment of the SES, Hydrofoil, and SWATH Point Designs. The figures compare platform effectiveness, platform cost, and platform R&D needs relative to a baseline represented by a conventional monohull. (R&D needs and platform costs are discussed in Sections 4.2 and 5.0, respectively.) Bars above the monohull baseline indicate attributes which contribute to a favorable assessment of the Point Design as an ASW ship, relative to a monohull. Bars below the monohull baseline indicate attributes which contribute to an adverse assessment of the Point Design as an ASW ship, relative to a monohull. The monohull "baselines" for each point design are considered, in general, to be the following U.S. Navy ships:

SES Point Designs:	FFG 7
Hydrofoil Point Designs:	FFG 7
SWATH Point Design:	DD963

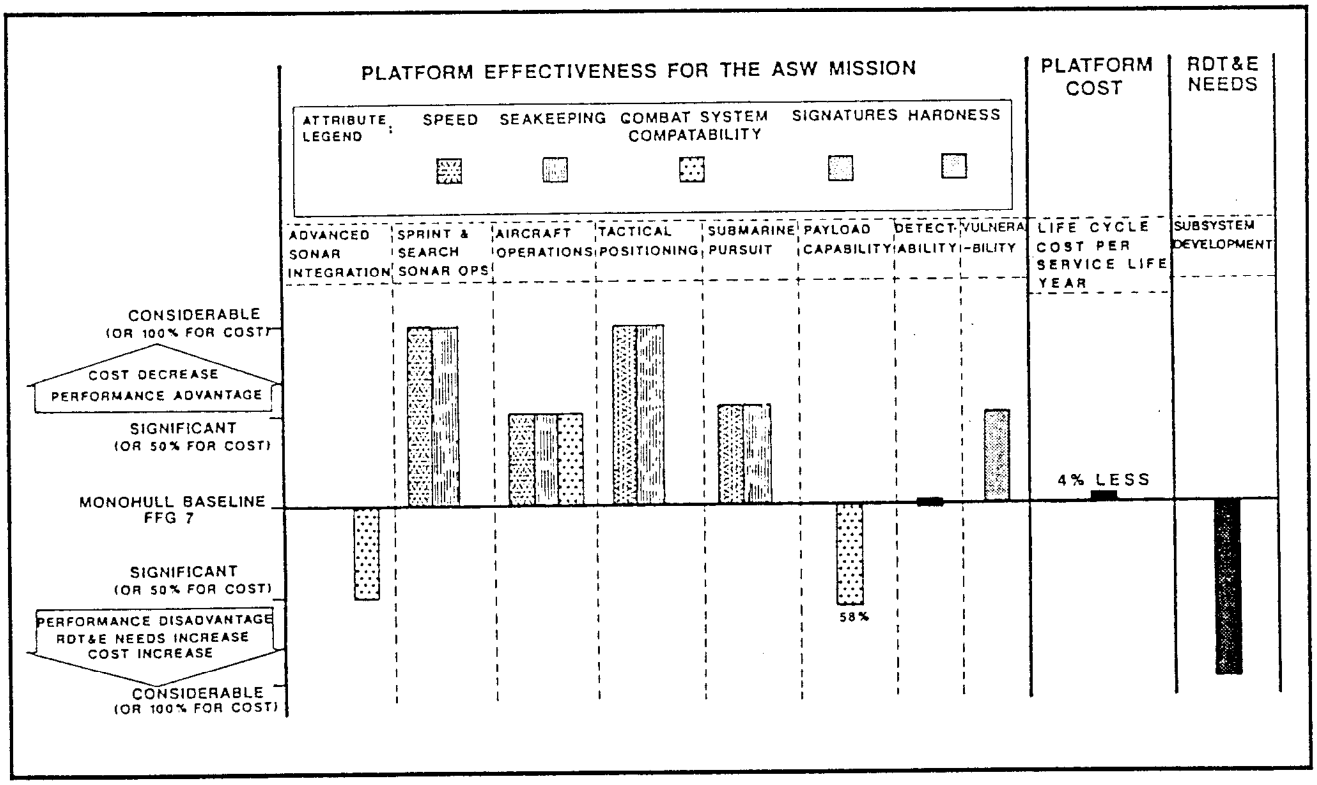


Figure 3.1.2-1. Summary of SES Assessment

Figures 3.1.2-1 through 3.1.2-3 summarize the assessment of the capabilities of the Point Designs to perform the various tasks required for the ASW mission. The ASW mission subtasks are listed across the top of the left-handed portion of each figure. The important platform attributes which have been assessed as providing superior, or inferior, operational capabilities relative to a monohull, are keyed at the top of the figure. The attributes of speed, seakeeping, combat-system compatibility, signatures, and hardness have been assessed as providing significant or considerable performance advantage or disadvantage in the ASW mission relative to the baseline conventional ship.

Note that important differences exist between the ASW mission subtasks listed on Figure 3.1.2-3 for the SWATH and those on Figure 3.1.2-1 and 3.1.2-2 for the SES and Hydrofoil. This is because the SWATH speed attribute is considered to be its ability to maintain design speed in high sea states, rather than a high-sprint-speed capability of the SES and Hydrofoil in the ASW role.

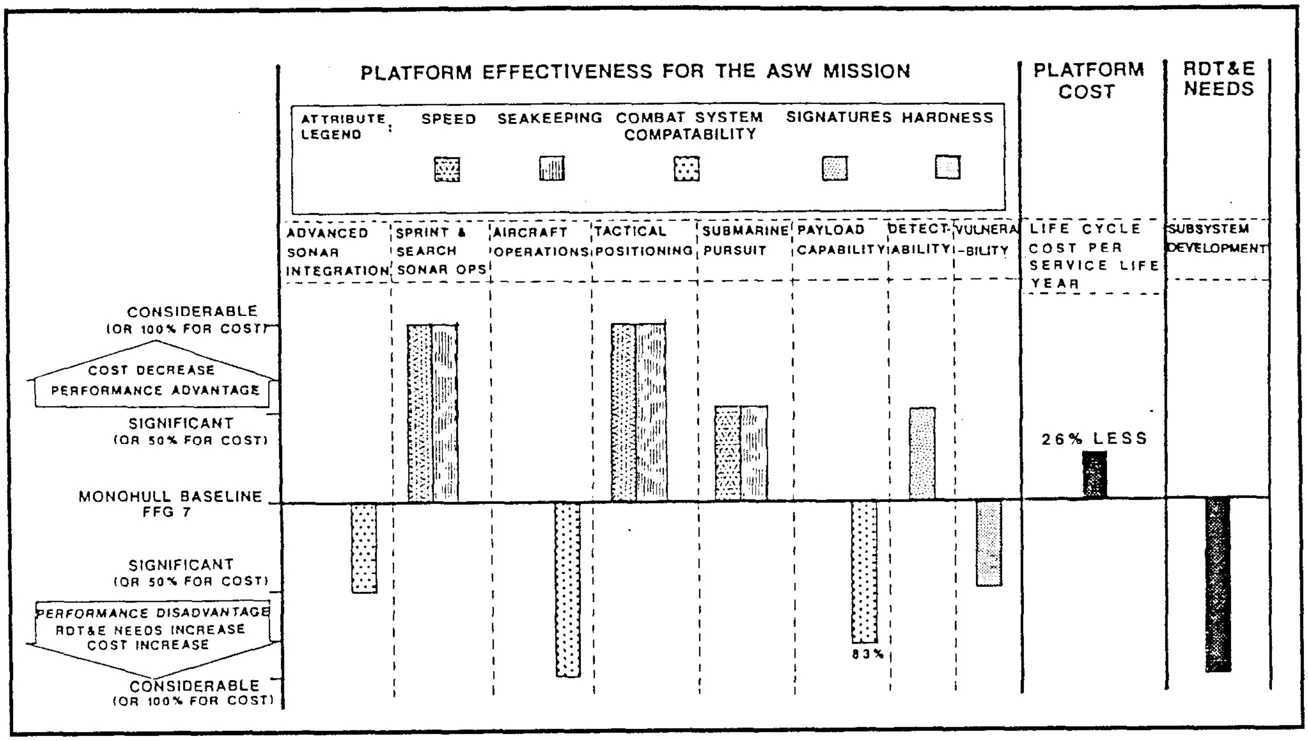


Figure 3.1.2-2. Summary of U.S. Hydrofoil Assessment

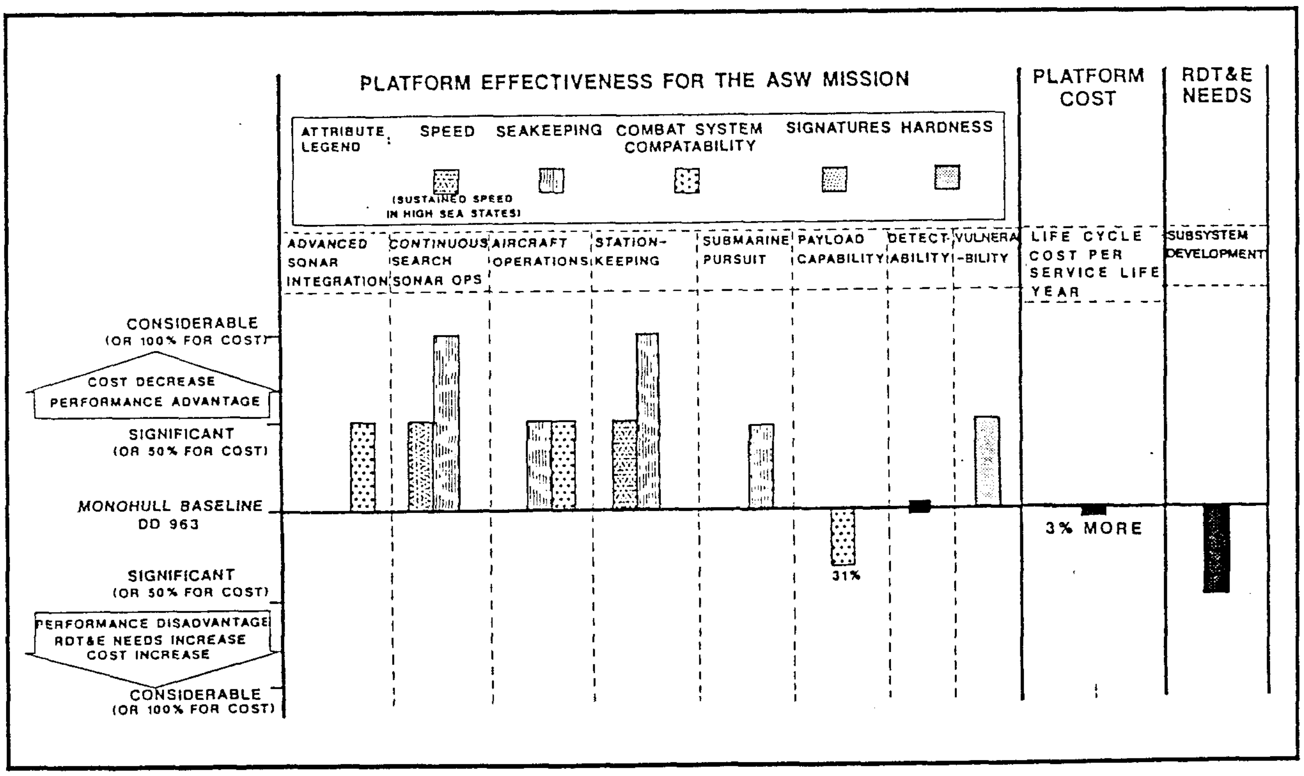


Figure 3.1.2-3. Summary of SWATH Assessment

3.1.2.1 Speed

The higher sustained-speed capabilities of the SES and Hydrofoil have been shown to have a very considerable advantage in sprint-and-search sonar operations. It allows sprint-and-search operations even with 30-knot convoy SOAs. The ability to search at low speeds increases the accuracy and range of sensors. This same high-speed sprint capability is a considerable advantage in tactical positioning and screen station keeping. As the tactical distance between the convoy and its escorts increase, as may result from increased range of future submarine or surface-launched weapons, the ability to regain proper station after a convoy course change, a submarine prosecution, or a resupply or refueling operation, is highly dependent on maximum-speed capability. The study has shown that the reduced off-station time and increased low-speed sweep time will allow the number of SES or Hydrofoil escorts to be reduced relative to the required number of baseline monohulls. The high-speed capabilities of the SES and Hydrofoil will in many instances enable the ship to outrun and prosecute high-speed submarines.

The higher speed of the SES also provides a considerable tactical flexibility in the deployment of sonobuoy screens. The lack of an embarked helicopter may reduce the Hydrofoil's capability to deploy and monitor a sonobuoy screen but alternate tactics may be developed, which could rely on helicopters deployed from another ship. At sprint speeds, the SES and Hydrofoil will be a more difficult target for torpedoes, mines, and missiles.

The SWATH could not perform sprint-and-drift sonar operations except with low-speed convoys. However, its ability to maintain speed in high sea states will allow for continuous sonar search operations and will enable the SWATH to maintain screen station keeping even when escorting much larger ships which are capable of achieving 20-25 knots SOAs in high sea states. The maximum calm-water speed and the annual average maximum sustained speed capabilities in the North Atlantic for the Point Designs and baseline monohulls are shown in Table 2.1.6-3.

In Figure 3.1.2-4 the predicted performance of a number of other U.S. Navy ships are presented from data obtained from a survey of operators which is reported in Reference 4. In practice, ship operators report that they automatically reduce speed if their ship slams or experiences water over the deck two or three times in quick succession. The corresponding speed capabilities of the SES, Hydrofoil, and SWATH Point Designs are shown in Figures 3.1.2-5 through 3.1.2-7.

The "value of speed" to the ASW mission is discussed in Section 3.2.1 and in more detail in Appendix A. In some ways high speed interferes with the operation of some of the weapons and sensor systems, but in many ways it is advantageous. Sonar systems become increasingly ineffective at high speeds. This implies that the high-speed capability can best be used in a "sprint-and-drift" or "sprint-and-search" mode of operation. The ship operates at the optimum speed for its sonar search, for example, for as long as necessary, then sprints to the next location, where it slows down to repeat the search, and so on.

When used with proper planning, this mode of operation can be shown to be more effective than operation with an escort that travels at the convoy's speed of advance as the speed of advance may be well above the optimum search speed.

Helicopters cannot normally be launched, retrieved, and handled on the deck if the wind over the deck is much higher than 45 knots. The SES can, however, slow down or change heading to permit such operations. (This is discussed further in paragraph 3.2.3.3.) On the other hand, the ability to create high wind-over-the-deck speeds can enhance the operation of VSTOL aircraft and remotely piloted vehicles, provided that turbulence over the flight deck can be reduced to an acceptable level.

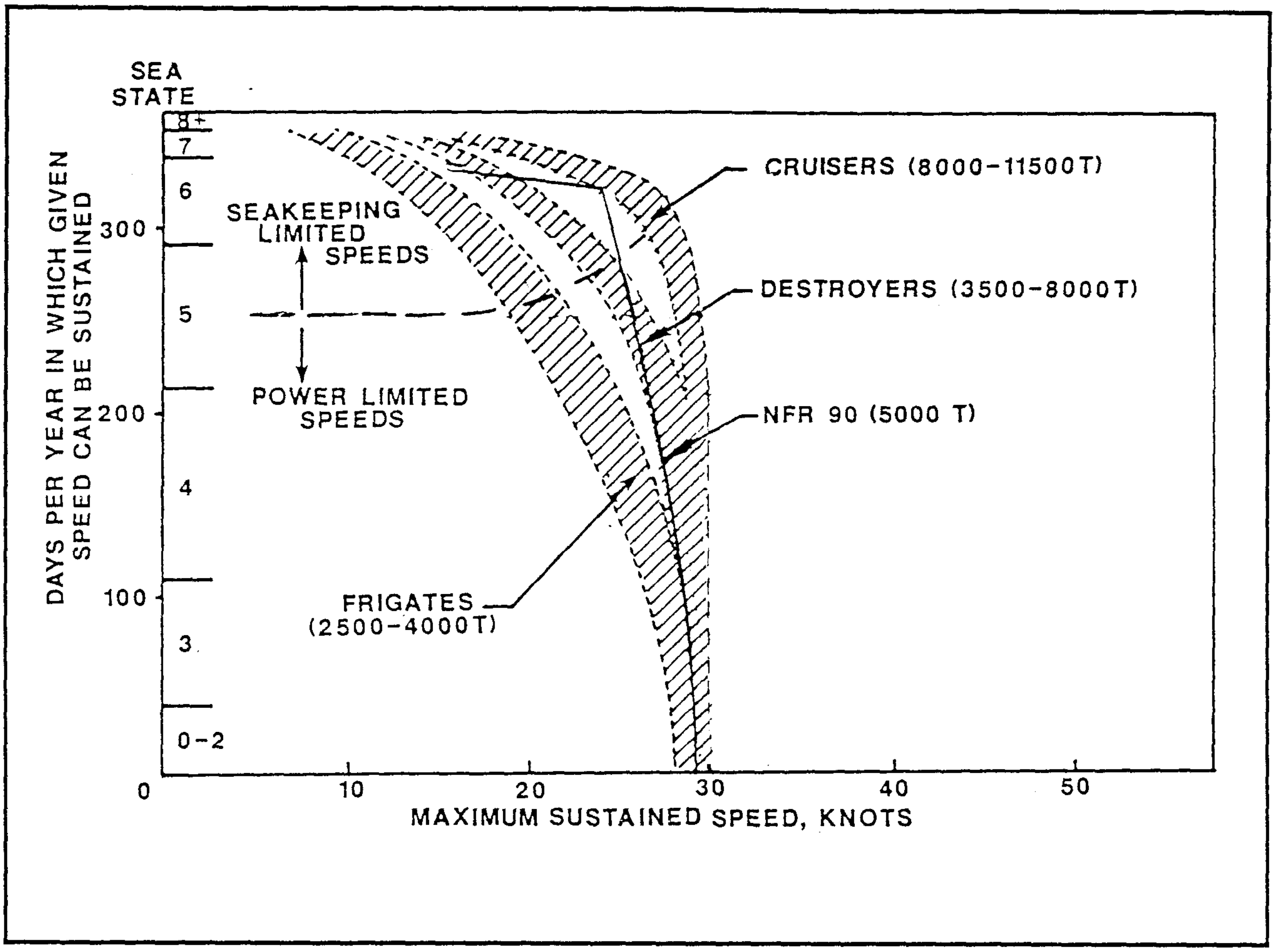


Figure 3.1.2-4. Sustained Speed Capability of Naval Ships (Reference 4)

The ability to regain its proper station at sprint speed is always advantageous to an escort vessel which may leave its station to prosecute an ASW search, to refuel or resupply from a supply ship or may be required to reposition itself after a change in direction of the convoy. This ability becomes more important as the distance between the convoy and the escort increases as may result from an increase in the range of future submarine-launched weapons. Escort sprint capability may also allow the number of escort vessels to be reduced.

The "sprint-and-drift" mode of operation may prove to be a very effective way of life for the high-speed ship. The fact that it can sprint to regain its proper position in a short period of time, means that it has the flexibility to be able to slow down and/or change heading to whatever is desirable for particular operations such as sonobuoy deployment, RPV operations and submarine pursuit, localization and prosecution.

In the NATO ASW Point Design secondary mission areas, speed can provide an advantage in surface target pursuit/prosecution, reconnaissance, patrol and surveillance operations, transport operations and search-and-rescue missions.

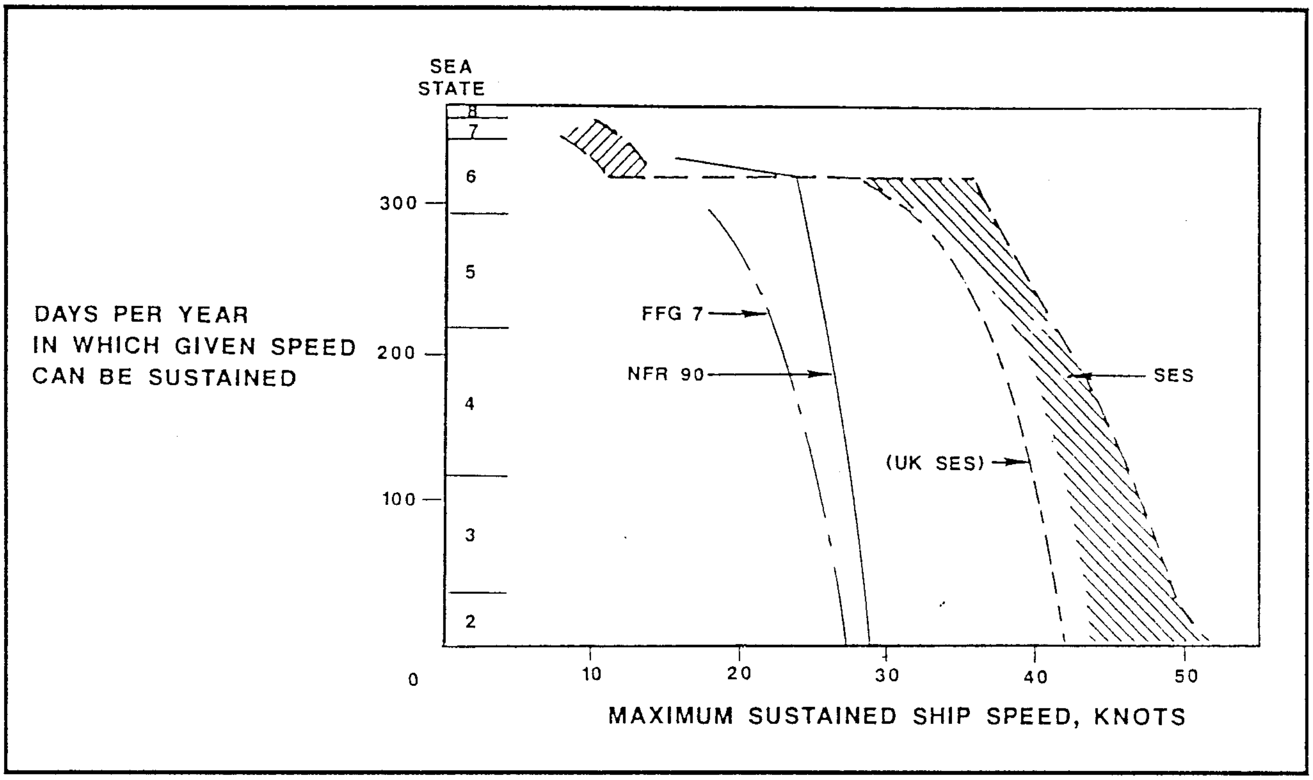


Figure 3.1.2-5. Maximum Sustained Speed for SES in North Atlantic

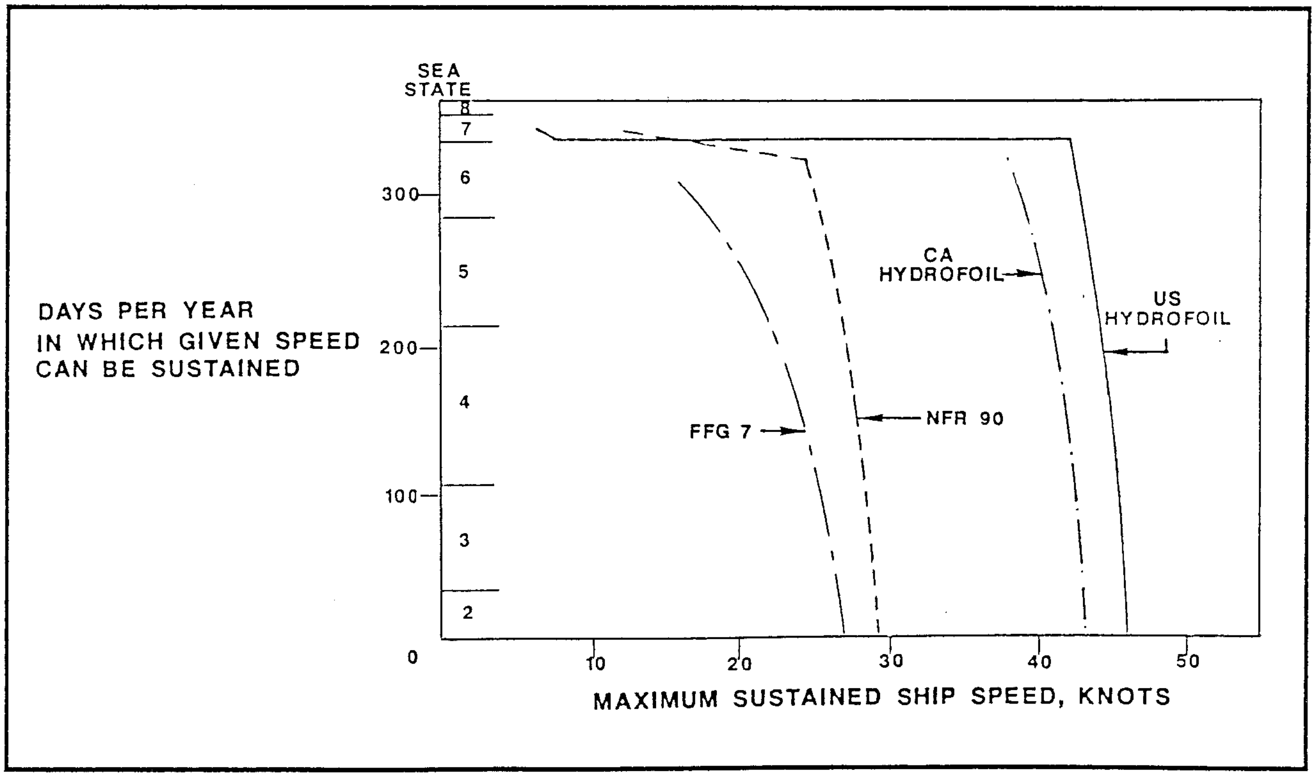


Figure 3.1.2-6. Maximum Sustained Speed Versus Sea State - Hydrofoil in North Atlantic

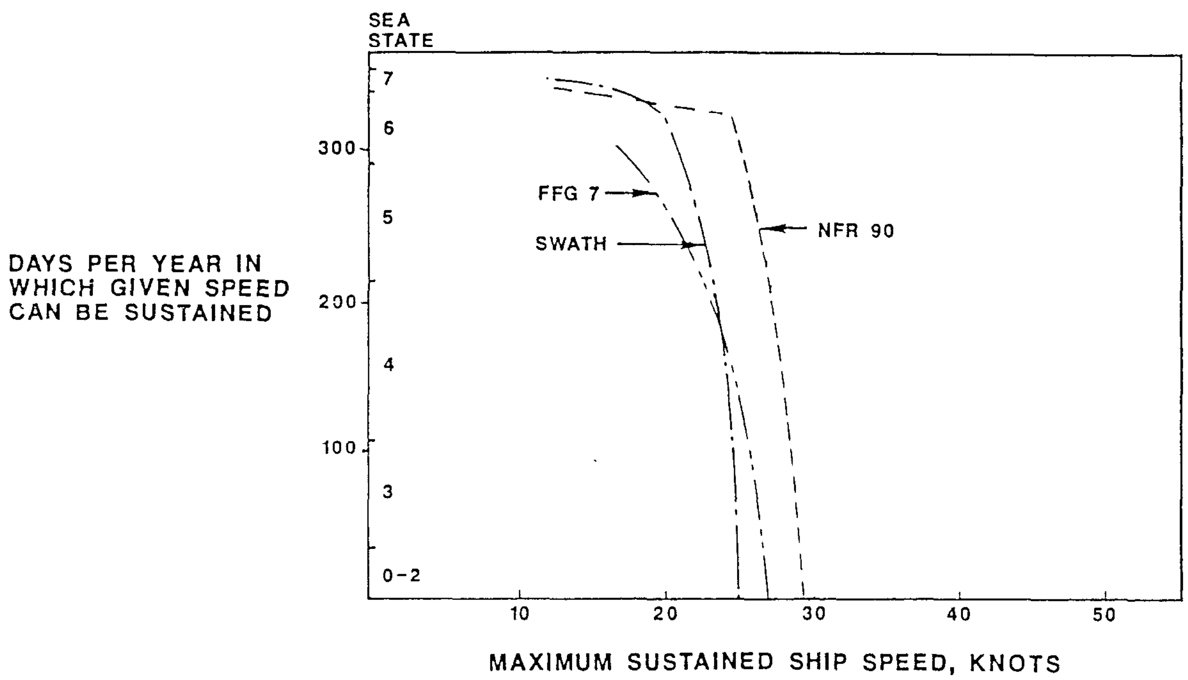


Figure 3.1.2-7. Maximum Sustained Speed Versus Sea State - SWATH in North Atlantic

3.1.2.2 Seakeeping

The SWATH, Hydrofoil, and SES are all assessed as having improved seakeeping relative to the baseline monohulls as shown on Figures 3.2.1-1 through 3.1.2-3.

Decreased ship motions are enhancing to any mission particularly when habitability and equipment handling is important. In this regard, the superior seakeeping of the SWATH and SES platforms has been shown to offer a significant advantage in the ASW mission primarily for the operation of embarked air assets. The increased capability relative to launch, recovery and in-flight refueling operations of helicopters and VSTOL aircraft, represent improved mission operability in high sea states. Improved seakeeping has several other advantages for all of the Point Designs:

- Maintains crew efficiency for longer periods
- Facilitates deployment and retrieval of towed arrays
- Improves weapons-firing capability and accuracy
- Facilitates refueling and unrep operations
- Reduces requirements for mechanical, or electronic, stabilization of hull mounted sensors and weapons.

The Seakeeping predictions for the point designs were prepared from model-test results, from frequency-domain analyses and from full-scale trials of similar ships. To establish a simple basis of comparison the ships were assumed to be capable of carrying out all of their military functions if they could operate without exceeding the following single-amplitude significant values:

- Roll 8°
- Pitch 3°
- Vertical Acceleration at the Bridge 0.40 g (=0.2g rms).

For helicopters it was also assumed that they could not operate when the wind speed exceeds 45 knots. A relative wind speed of 45 knots is the normal operating limit for helicopter operations in head winds on frigates and destroyers. For simplicity, it was further assumed that average wind speeds would exceed 45 knots when wave heights exceeded 6 meters.

It is realized that different navies have different standards for helicopter operating limits on small naval ships. Some of these are listed in Table 3.1.2-1. The Royal Navy's Lynx helicopter is limited to operations with the wind forward of the ship's beam; the design requirements for the EH 101, however, allow for operations in a 50-knot head wind or a 20-knot tail wind. The U.S. Navy tailors its limitations to each combination of helicopter type and class of ship; with the RAST automated haul down system much larger angular motions are allowed. The French Navy has generally more restrictive limits.

While these differences are noted it was considered that a single set of limitations should be used for this assessment study for the sake of uniformity and fairness.

The operational capability of each ship was evaluated for a wide range of conditions. These conditions included:

- Helicopter operations and other operations as defined above
- High-speed mode (cushion-borne, foilborne, etc.) and low-speed mode (hullborne, cushionborne)
- Operation at all headings to the sea (all headings were assumed to be equally probable)
- A wide range of sea areas (eight areas in the North Atlantic (as sketched in Figure 3.1.2-8), one in the North Sea, three in the Mediterranean, four in the Baltic) as sketched in Figure 3.1.2-8.
- Seasonal Variations: Spring, Summer, Fall, Winter and annual average conditions for each ocean area.

The results of some of these calculations are tabulated in Table 3.1.2-2. Two sea areas were selected: Area 1 is the worst area of the North Atlantic just south of Greenland; Area 4 is the North Sea.

These results for operation at high speeds and low speeds are plotted in bar graph form in Figures 3.1.2-9 and 3.1.2-10, respectively.

On an annual basis all of the ships, except the FFG 7, can expect to operate helicopters for more than 75% of the year in the North Atlantic or more than 90% of the time in the North Sea. In winter these figures drop to 50% and 83% respectively.

The seakeeping data available for each of the ships is very variable in quality and quantity. Data for the US/G SES for example was provided for two cushion-borne speeds, 20 and 30 knots. For the two other SES, data was provided for maximum sustained speed (which varies with sea state) in both the cushion-borne and hull-borne modes. This difference may account for some of the disparity between the three SES, although it must also be realized that the three are very different from each other. Both the US/G SES and the UK SES employ active ride-control systems. The UK SES claims much larger improvements in motions (due to the use of its novel ride-control system) than is anticipated for the US/G SES. The FR SES design does not include an active ride-control system. The NFR 90 seakeeping data is derived from frequency-domain analyses and it may not be entirely fair to compare it on this basis with the FFG 7 the data for which was derived from full-scale trials in relatively modest sea states.

Table 3.1.2-1. Helicopter Take-Off and Landing Limits

		Single Amplitude Angles		Sig Acc		
	Rel. Wind	Roll (°)	Pitch (°)	Vert (g)	Lat (g)	Reference
Royal Navy (UK)						
Lynx	"Fwd of Beam"					(1)
EH101 (Design Requirements)	50 (R45T O/G 45)	8	2.5	0.41	0.31	
	35 Abeam	6	3.0	0.51	0.2	(1)
	20 Astern	6	3.0	0.51	0.2	
U.S. Navy						
SH60B + FFG-7 (Day)	40 ($\pm 30^{\circ}$)	8	3	-	-	(2)
No Rast	20 Abeam	8	3	-	-	
	5 Astern	8	3	-		
Rast	45 ($\pm 20^{\circ}$)	8	3	-	-	(2)
	25 (Abeam)	8	3	-	-	
	5 Astern	8	3	-	-	
No Rast (With RSD)	30 ($\pm 30^{\circ}$)	9-15	4-6	-	-	(2)
Rast (With RSD)	35 ($\pm 35^{\circ}$)	9-15	4-6	-	-	(2)
	25 ($\pm 60^{\circ}$)	9-15	4-6	-	-	
French Navy						
Limit for "Military Functions"		5°	3°	0.2	-	-

Reference: (1) UK Message P0914112, July 1987.
(2) Helicopter Operability Motion Limits for SWG/6 Advanced Naval Vehicles, SEA 50151, 26 June 1987.

Within these limitations, however, the operational percentages are probably reasonably accurate. The SWATH is almost certainly the best platform from the point of view of seakeeping, but it scores about the same as the SES with regard to its use as a helicopter base due to the relative wind limitation. The SWATH also has a much lower maximum speed. The two Hydrofoils provide high speeds and a seakeeping capability at least as good as the larger SES, but their designs do not include helicopters. *All of the ANVs offer a very considerable improvement in* operability (and, in most cases, speed) compared with the FFG 7.

Table 3.1.2-2 Percent Operability

Ship	UK SES		FR SES		US/G SES		US HF	
Mode Speed	CB/RC 27-40.5 kt	HB 11-17 kt	CB 35-52 kt	HB 12-18 kt	CB/RC 30 kt	HB 20 kt	FB/RC 44-46 kt	HB 8-16 kt
Average Annual Ship Operability								
• Area 1	92.7	92.3	95.6	78.4	76.5	77.7	91.4	89.8
• Area 4	98.4	98.1	99.2	90.6	92.6	92.2	98.3	97.9
Average Annual Helicopter Operability								
• Area 1	85.6	65.8	86.8	72.9	74.2	73.9	-	-
• Area 4	96.9	96.5	97.3	89.4	92.1	91.4	-	-
Winter Ship Operability								
• Area 1	83.3	83.1	88.6	65.3	56.3	60.6	78.7	75.9
• Area 4	97.1	96.6	98.4	85.9	87.0	86.8	96.9	96.0
Winter Helicopter Operability								
• Area 1	67.2	65.8	69.1	53.3	51.3	52.0	-	-
• Area 4	94.3	93.6	95.0	83.7	86.1	85.3	-	-
Ship	**CA HF**		**CA SWATH**		**FFG 7**		**NFR 90**	
Mode Speed	FB/RC 45 kt	HB 15 kt	HB 25 kt	HB 10 kt	HB/FS 25 kt	HB 10 kt	HB/FS 24-30 kt	HB 12 kt
Average Annual Ship Operability								
• Area 1	86.8	87.2	100	100	65.4	55.2	76.1	90.3
• Area 4	97.3	97.0	100	100	85.7	81.0	92.5	98.1
Average Annual Helicopter Operability								
• Area 1	-	-	86.8	86.8	63.0	55.2	75.0	86.5
• Area 4	-	-	97.3	97.3	85.2	81.0	92.3	97.2
Winter Ship Operability								
• Area 1	69.1	71.8	100	100	45.0	30.3	55.0	76.6
• Area 4	95.0	94.6	100	100	77.3	70.2	87.0	96.4
Winter Helicopter Operability								
• Area 1	-	-	69.1	69.1	39.7	30.3	52.8	68.6
• Area 4	-	-	95.0	95.0	76.4	70.2	86.6	94.8

CB = Cushionborne   FS = Active Fin Stabilizers   RC = Ride Control
FB = Foilborne   HB = Hullborne

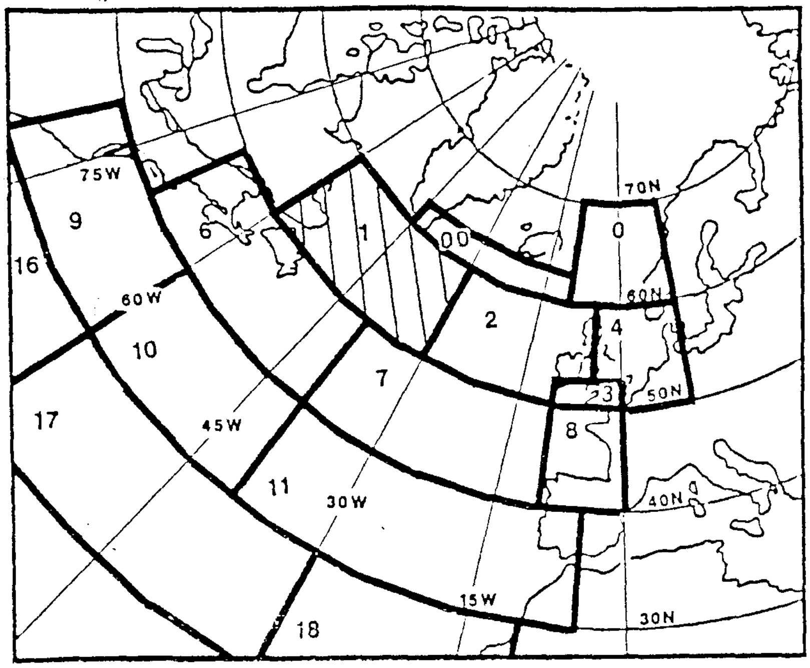


Figure 3.1.2-8. Operating Areas of the North Atlantic

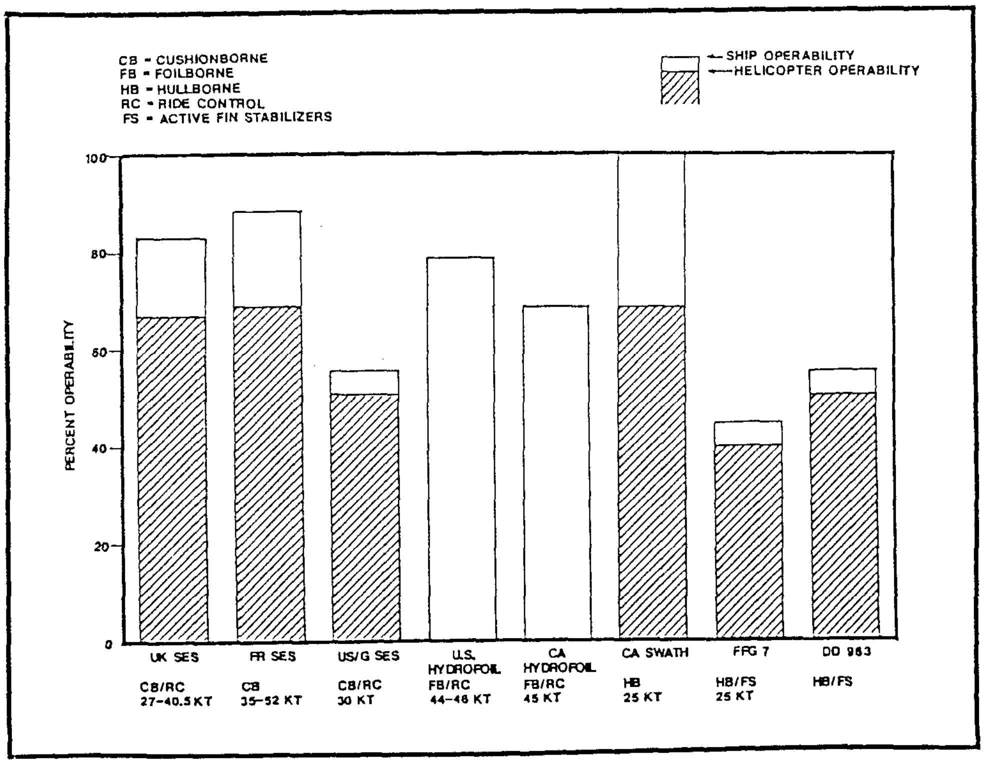


Figure 3.1.2-9. Comparison of Percentage Operability at High Speed in Area 1 of N. Atlantic in Winter

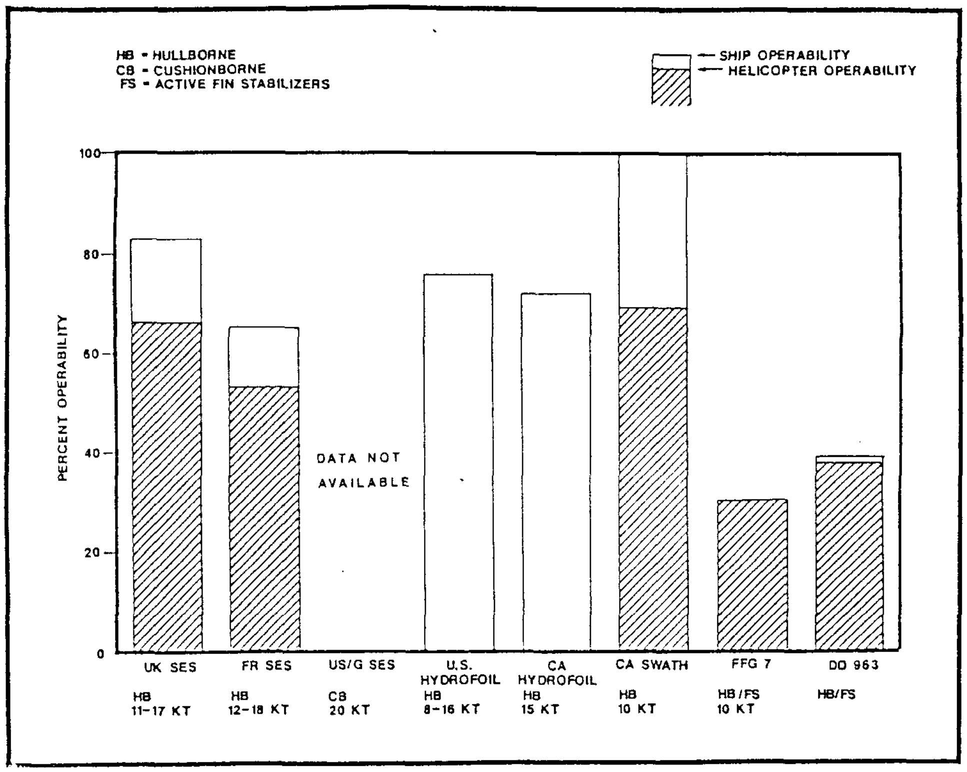


Figure 3.1.2-10. Comparison of Percentage Operability at Low Speed in Area 1 of N. Atlantic in Winter

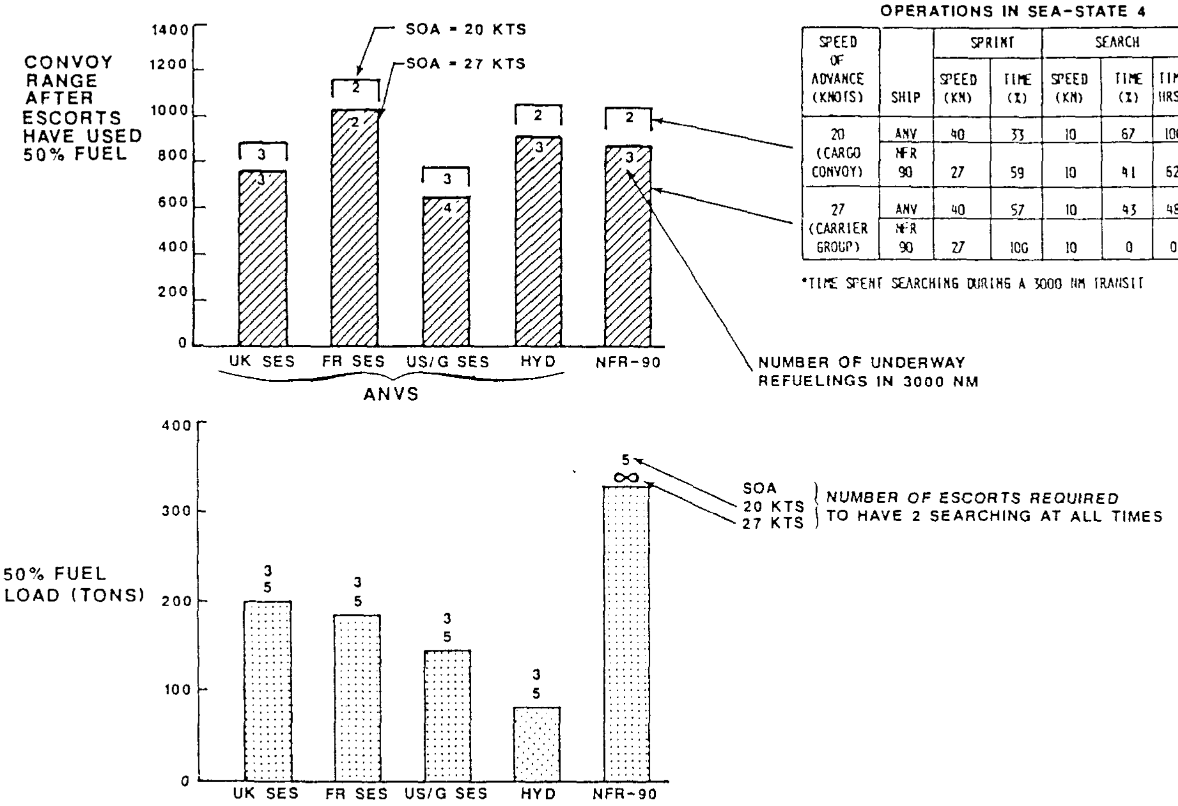
3.1.2.3 Range and Endurance

All of the Point Designs meet the exacting range and endurance requirements that are detailed in Section 3.2.2. The wide range of variation between the three SESs, both in the hull-borne and cushion-borne modes reflects the different approaches of the designers to hull and cushion geometry, and to propulsion and powering schemes. Lift-power requirements also vary considerably from one design to another as explained in Section 3.3.7.2.

The propulsion fuel load to meet the SES range and endurance requirements varies from 280T to 400T. All of the SESs, therefore, are capable of transiting long distances in a reasonably economical and timely fashion. All of the Point Designs can be designed to have range and endurance equivalent to a comparable monohull and have no inherent advantage or disadvantage in this attribute area.

Figure 3.1.2-11 illustrates the implication of the different rates of fuel consumption, the total fuel-load carried and the number of ships required to escort convoys operating at different speeds of advance (SOA).

The top half of Figure 3.1.2-11 compares, for each design, the range segments achieved by a convoy when one half the fuel load of each escort has been consumed, and at which time the escort must be refueled. This fuel load, in each case, is shown in the bottom half of the figure. Range segments are shown, at the top, for two different convoys both transiting a total distance of 3000 nm in sea-state 4. One is a cargo convoy with a 20 knot SOA, the other is a carrier group with a 27 knot SOA.



OPERATIONS IN SEA-STATE 4

SPEED OF ADVANCE (KNOTS)	SHIP	SPRINT		SEARCH		
		SPEED (KN)	TIME (%)	SPEED (KN)	TIME (%)	TIME HRS*
20 (CARGO CONVOY)	ANV	40	33	10	67	100
	NFR 90	27	59	10	41	62
27 (CARRIER GROUP)	ANV	40	57	10	43	48
	NFR 90	27	100	10	0	0

*TIME SPENT SEARCHING DURING A 3000 NM TRANSIT

Figure 3.1.2-11. ASW Surveillance Effectiveness

When escorting the 20 knot convoy the 40 knot SES and Hydrofoil can afford to search at 10 knots (its best search speed) for 67% of the time as compared to only 41% of the time for the 27 knot NFR 90 or SWATH. When escorting the 27 knot carrier group the SWATH or NFR 90 has no time to slow down and search at their best search speeds, while the SES and Hydrofoil can still do this for 43% of the time because of their higher sprint speeds.

Also compared on Figure 3.1.2-11, are the number of refuelings required during the 3000 nm transit. When escorting the 20 knot convoy, the UK and US SES will be required to be refueled three times while the French SES, the US Hydrofoil, the SWATH and the NFR 90 will only need to be refueled twice. The situation is somewhat more demanding for the 27 knot carrier group. For example, the US SES will need to be refueled four times, while the French SES can still get by with only two refuelings.

Also shown in the bottom part of Figure 3.1.2-11 are the number of escorts required in each case to have two searching at all times at their best search speed. To excort a 20 knot convoy, for example, we should need three ANVs compared to five NFR 90s or SWATH ships. For a 27 knot carrier group this increases to five ANVs or an infinite number of NFR 90s or SWATH ships.

From a fleet point of view, therefore, the cost of escorting a 20 knot convoy using Hydrofoils or SES may be reduced by the ratio of 3 to 5 relative to the cost of using monohulls or SWATH. For a convoy proceeding at a 27 knot SOA, the monohull and SWATH cannot search effectively using their own sonar systems but must rely exclusively on their air assets which have limited detection range.

3.1.2.5 Maneuverability

In Section 3.2.4.1 it is shown that the SES point designs, in general, possess maneuvering capabilities comparable to those required for the FFG 7. The acceleration and deceleration performance of an SES will far exceed that of either monohull. The maneuverability of the hydrofoil, when foilborne, accedes that of any platform. The SWATH is less maneuverable than a monohull at high speed. Low speed maneuverability of the SWATH is good because of the widely separated propulsors which can be used to produce differential thrust.

3.1.2.6 Seamanship and Navigation

The seamanship and navigation characteristics and attributes of the SES point designs are discussed in Section 3.2.5. It is concluded that navigational drafts of the SES point designs do not restrict the mobility of the platforms in normal mission areas and ports and that the anchoring systems proposed do not deviate significantly from standard monohull practice. When compared with the FFG 7 and NFR 90, the three SES point designs do exhibit decreased ranges of visibility. However, this is attributed to the specific deck arrangements proposed and is not necessarily inherent in the SES platform type.

3.1.2.7 Combat System Compatability

Combat-system compatability concerns the attributes of the Point Design Platform types which are advantageous, or disadvantageous, to the integration and operation of combat systems and other components of payload. Relative to conventional monohulls, a significant disadvantage of the SES and Hydrofoil in the ASW mission has been shown to be in the integration of advanced sonar hull-mounted arrays. Many of the low frequency transmit and receive arrays being developed to counter future submarine threats are targeted for conventional monohulls. Unless it is possible to develop specific arrays for smaller high-speed ASW ships, the potential weight, size, required "field of fire" achieved with bulbous keels or keel skegs, and required submergence depths of these sonars may be incompatible with the SES and Hydrofoil hullform, size, and high-speed capability. The SWATH has been assessed as having a significant advantage over the conventional ship in integrating the conformal arrays, due to the deep submergence, shape, and size of the lower hulls.

The wide beam and large available deck space aft on the SES and SWATH have been shown to be a significant advantage over conventional ships relative to the handling and storage of multi-line towed arrays and variable depth sonars. This same relatively wider beam and increased deck area also allows for deck arrangements which can enhance the ASW mission in the area of embarked air assets. A significant advantage over the baseline ships is considered to exist for the SES and SWATH relative to helicopter, VSTOL aircraft, and RPV launch and recovery operations. The SWATH can embark considerably more helicopters than the baseline monohull.

All of the Point Designs carry considerably less mission-related payload than their respective baseline monohulls as shown in Figure 3.1.2-12. The SES and Hydrofoil Point Design, have smaller payloads because of their smaller size. Their payload weight fractions, however, are consistent with those of the comparative monohulls. The SWATH, however, has a payload which is some 42% below the trendline established on the basis of full-load displacement.

3.1.2.8 Signatures

Ship signatures which relate to detectability include radar cross section infrared radiation, magnetic, pressure, underwater acoustic and wake. The Point-Design studies have not yet addressed these signatures at a level which would allow for assessment or comparison with the baseline monohulls. However, signatures are a critical concern with respect to the ASW mission and must be addressed in future work.

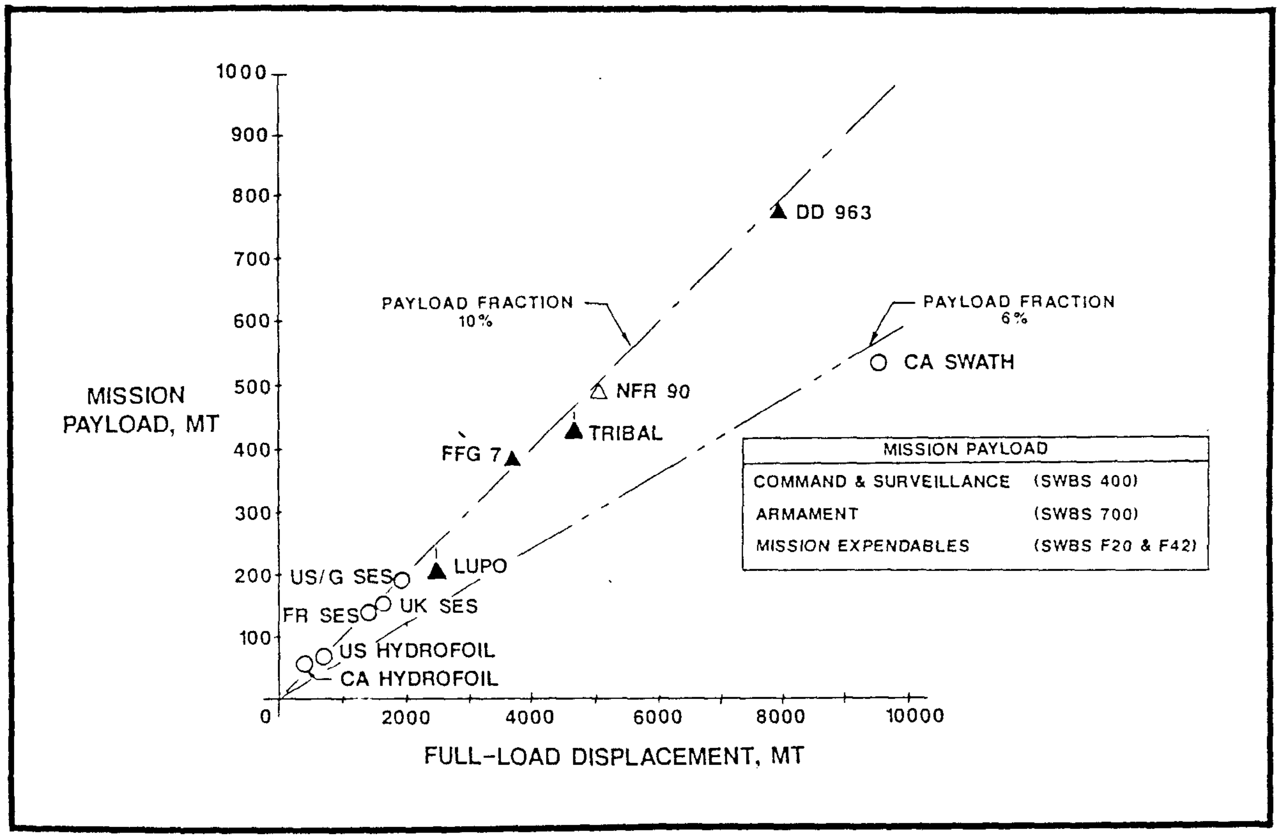


Figure 3.1.2-12. Comparison of Mission Payload

The U.S. Advanced Naval Vehicles Concepts Evaluation (ANVCE) Project was undertaken in the late 1970's to obtain information necessary to recommend a balanced overall research and development program for advanced naval vehicles in the 1980 - 2000 time period. The program assessed the performance and effectiveness of 23 "Point Designs" which included SES, Hydrofoil, and SWATH platforms, similar to the SWG/6 Point Designs, as well as the FFG 7 as a baseline. It is the ANVCE program's detailed analysis of signatures for the SES, Hydrofoil, and SWATH platform types that presently supports the assessments of the SWG/6 Point Designs in this attribute area. The relevant detailed findings of the ANVCE studies are summarized in Appendix D.

The SES, Hydrofoil, and SWATH Point designs are assessed as having very similar radar cross section and infrared signatures to monohulls of comparable size, material, and installed power. Because the Hydrofoil is considerably smaller than the smallest baseline monohull, it is assessed as having lower signatures in these areas. In extreme sea states, all the ANVs are expected to have lower radar signatures because of their superior platform stability.

The ANVCE study assessed two 3000-ton waterjet-propelled SESs as having underwater acoustic signatures equal to the FFG 7 at the maximum speeds of both ships and higher than the FFG 7 at 15 knot speeds for both ships. Tests have been conducted for the Swedish Navy which predict lower underwater acoustic signatures for waterjets as opposed to CRP propellers. The ANVCE study predicted slightly higher underwater acoustic signatures for a 700-ton marine screw propelled Hydrofoil relative to the FFG 7 at maximum speeds and at 15 knots. The ANVCE study predicted very similar underwater acoustic signatures for a 5800-ton SWATH and the FFG 7.

Considerably more analysis will be required in order to completely assess the signature characteristics of each of the SWG/6 Point Designs. Of particular interest in these future studies will be the investigation of how well particular ANVs may integrate design features required to reduce signatures.

3.1.2.8 **Hardness**

The hardness attribute considered for each of the Point Designs and baseline monohulls address those characteristics of the platform which relate to survivability to weapon hits. With the exception of the SWATH Point Design, which studied survivability to weapon hits in order to design a more survivable platform, the SWG/6 Point Designs did not perform analyses on this subject. As with signatures, the current support for these assessments comes from the ANVCE studies in this area.

The ANVCE studies show a significant increase in the survivability of the SES to torpedo hits and semi-armor-piercing missile hits relative to a monohull of similar size. In particular, the complete independence of the two hulls and its capacity to survive by its own means with only one hull intact, gives the SES an important hardness capability. The ANVCE studies also show a significant increase in the survivability of the SWATH to missile hits and an equal survivability to torpedo hits relative to a monohull. The Hydrofoil is assessed by ANVCE as having survivability to torpedo and missile hits similar to that of a monohull of equal size.

Until a detailed analysis can be performed on the survivability to weapon hits for each Point Design, the SES and SWATH are assessed as having an advantage over the respective baseline monohull. The Hydrofoil, due to its smaller size, is assessed as having a disadvantage over the baseline monohull. It must be stressed that this assessment relates only to survivability to a weapon hit. For instance, although the Hydrofoil is less survivable than the FFG 7 because of its smaller size, it is also less likely to be detected, or to be hit, because of its smaller size and higher speed.

A complete study of the vulnerability of ANVs will be required to support the next phase of work. This study should assess the detectability and the survivability to weapon hits and integrate these attributes into an assessment of overall vulnerability. More analysis is also required to develop hardening techniques and signature reduction techniques which are applicable to ANVs and which exploit the unique characteristics of each platform type.

3.2 ASSESSMENT OF MOBILITY

Each of the three types of ships being assessed have a major ASW mission role. Mobility, per se, is therefore significant, primarily with respect to how it contributes to ASW mission performance. An assessment of mobility is made herein with respect to the following parameters:

- Forward speed
- Range and endurance
- Seakeeping and ride quality
- Maneuverability
- Seamanship & Navigation
- Combat-System Capability
- Detectability
- Vulnerability & Survivability.

None of these parameters have great military significance of themselves, but their value lies in their ability to improve mission performance with respect to current capability or to add a new capability not possible with current assets. Forward speed, for example, can improve the capability to prosecute targets, and to maintain station with respect to a moving body of ships such as a battle group, convoy or an underway replenishment group. Speed can also establish a capability to conduct sprint/drift operations as part of an ASW screen; a capability which is not provided with conventional monohull frigates. The potential value of this capability has been identified in a number of studies.

Similarly, seakeeping improvements can have an effect on the capability to perform ASW particularly where helicopter operations are a major element in the ASW system. Conventional monohull frigates are limited in their ability to maintain speed and to deploy and recover helicopters in the sea state environment to which these NATO ships will frequently be exposed. Handling of variable depth sonars (VDS) and towed arrays can also be impeded due to poor seakeeping qualities in high sea states.

Range and endurance must be maintained along with whatever speed and seakeeping capabilities these concepts might provide. If not, the advantages of speed and/or seakeeping in terms of ASW capability, would be degraded by the need to more frequently go off-station to refuel or replenish. Again, the various concepts must retain maneuvering capability consistent with efficient prosecution of the ASW mission role.

Ideally the ASW performance of the various concepts should be assessed by a model which integrates the component performance of the combat system and the mobility performance of the ship, so as to assess the mission performance of the total system. Lack of definition of performance parameters of the respective combat systems, has led to the decision to restrict the assessment to consideration of ship design features.

3.2.1 Forward Speed

One of the principal advantages claimed for advanced naval vessels is their ability to achieve high speeds and their ability to maintain these speeds in relatively high sea states. In a study conducted by Band, Lavis & Associates, Inc., on the potential of SES for the FFX mission, it is pointed out that a faster ship is not necessarily an advantage to the Navy unless it can be proved that it can perform its military mission more effectively or at less overall cost. In assessing the value of speed to an ASW escort, for example, five separate issues are identified as being the real value of speed:

- The potential advantage of sprint-and-search operation in the performance of ASW. The ability of modern sensors and arrays to detect submarines falls off dramatically as ship speed increases as shown in Figures 3.2.1-1. It is, therefore, a considerable advantage to be able to "search" at low speed and then have a sprint capability to be able to rapidly overtake the escorted force before repeating the search.

- Speed is also of value in attacking a submarine once it has been detected. The distance that the submarine can move from its detected position before the escort is in a position to attack is reduced as the escort's sprint speed increases.

- The ability to recover station with respect to a maneuvering force. As the submarine weapons reach longer and longer ranges so must the distance of the escorts from the escorted force increase in proportion. When the escorted force changes direction, the escorts are left out of their intended position ahead of the force, leaving the force inadequately protected. A high-speed sprint capability enables the escort to recover station in minimum time.

- The ability to reduce time off-station for refueling or UNREP, by using its sprint capability to rendevous with the supply ship and to return rapidly to its station.

- The ability to reduce the number of escorts. By being able to reduce time off-station for maneuvers and for UNREP operations, it may be shown that fewer escorts are required to maintain complete coverage at all times.

The advantage of the sprint-and-search mode of operation is illustrated in Figure 3.2.1-2. This figure shows the probability of detecting a submarine as a function of detection range. From this it can be seen that a 15-knot search is more effective than a 20-knot search. Thus, an escort capable of searching at 15 knots and then sprinting at 25 knots to return to station can be shown to be more effective than an escort that can only travel at 20 knots and, therefore, is constrained to search at that speed (if that equals the convoy's speed of advance).

Figure 3.2.1-3 shows the probability of detecting a submarine as a function of the number of escorts. The figure was derived from the French ASW SES-escort effectiveness study presented to SWG/6 in 1985. This report is reproduced as Appendix A. Results are shown for low speed and high speed escorts and also for a range of convoy speeds of advance. The figure shows that, if the escort can sprint at 45 knots instead of 25 knots, then the probability of detecting a submarine increases especially at higher convoy speeds. A 25-knot sprint speed is almost useless if the convoy is moving at 24 knots.

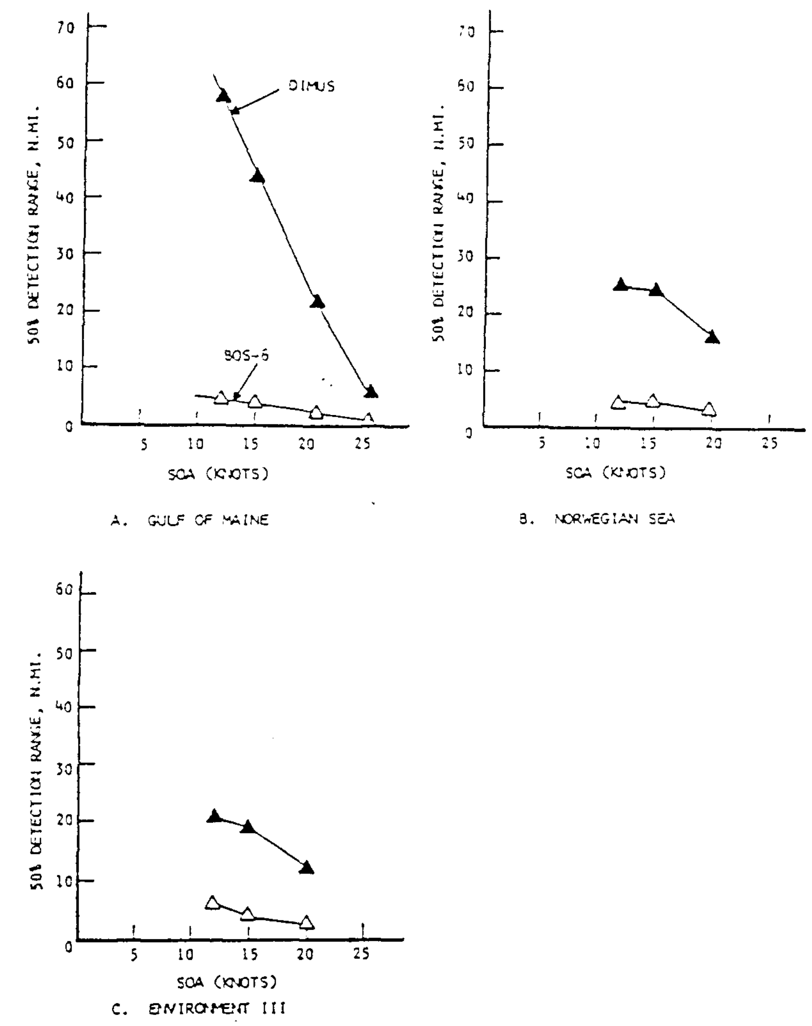


Figure 3.2.1-1. Effects of Changes in Speed on Detection Ranges. Results Relate to Two Different Sonars (DIMUS, BQS-6) for Three Different Acoustic Environments.

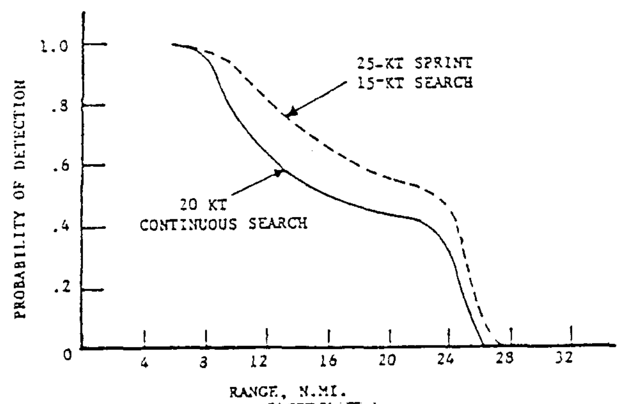


Figure 3.2.1-2. Comparison of Sprint-and-Search Mode of Operation Versus Continuous Search Mode for 20-Knot Convoy SOA.

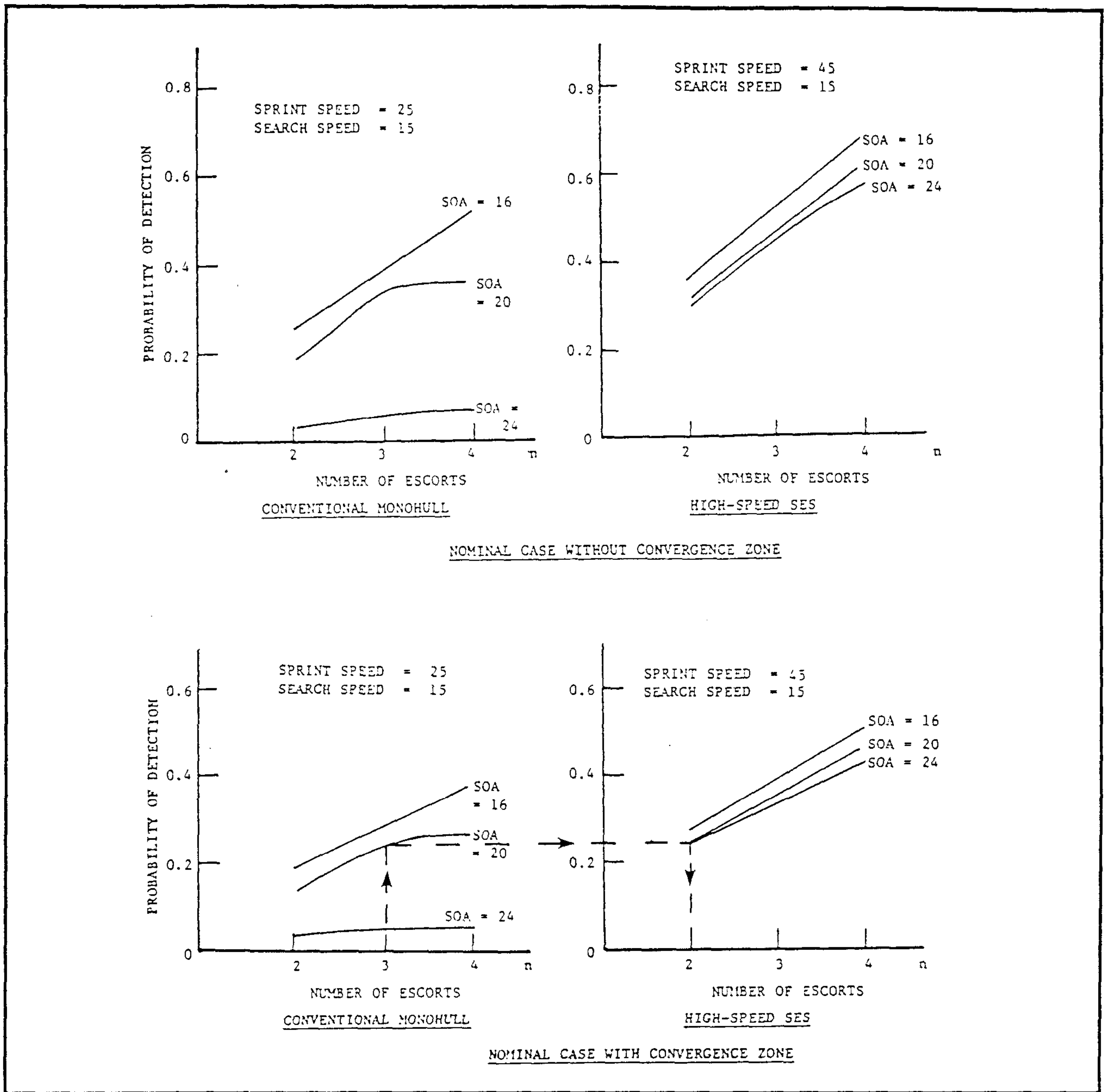


Figure 3.2.1-3. Probability of Success Versus Number of Escorts for Various Force Transit Speeds

A major point derived from Figure 3.2.1-3 is that, for a 20-knot convoy, two 45-knot escorts are as effective as three 25-knot escorts and very nearly as effective as four 25-knot escorts.

Each of the issues identified above are closely tied to a concept of escorting some form of high-value force. The significance of escort speed is closely linked to force speed-of-advance and enemy weapon ranges. The contribution to ASW capability is impacted substantially by assumptions with respect to the ASW sensors, such as the predicted performance capability of the sonar, the need to retrieve and deploy towed arrays and the time required for these operations, the effects of the drag of various arrays on the ship/power characteristics and the extent to which active, rather than passive, sonar might be used in the escort mission. These impacts relate in varying degrees to any of the potential platform configurations, particularly when speeds in excess of the optimal speed for sonar performance are considered. Existing Navy ships can operate at speeds considerably greater than 20 knots and would do so in wartime. Consequently, escort ability to operate effectively at speeds in excess of 20 knots is a realistic requirement. But speed of an escort buys little if vulnerability of the force increases due to degradation of total ASW system performance. Thus, what is needed is a high-speed ASW system capability which includes a platform which provides the speed and support for the sensors, and sensors which are compatible with the high-speed environment. The question revolves around such issues as the time required to deploy and retract towed arrays or alternatively the degree of difficulty in developing the technology to tow arrays at the high speeds required for effective sprint-and-search operations and also the degree of technology required to develop towed or hull-mounted sensors which operate effectively at constant speeds of 20 knots and above.

The predicted variations of ship speed with sea state for the three SESs, the two hydrofoils, the SWATH and the monohulls (FFG 7 and NFR 90) are shown in Figures 3.2.1-4 through 3.2.1-11. For the SESs and for the US Hydrofoil, the speeds are plotted for both the low-speed (hull-borne) and high-speed (cushion- or foil-borne) modes of operation.

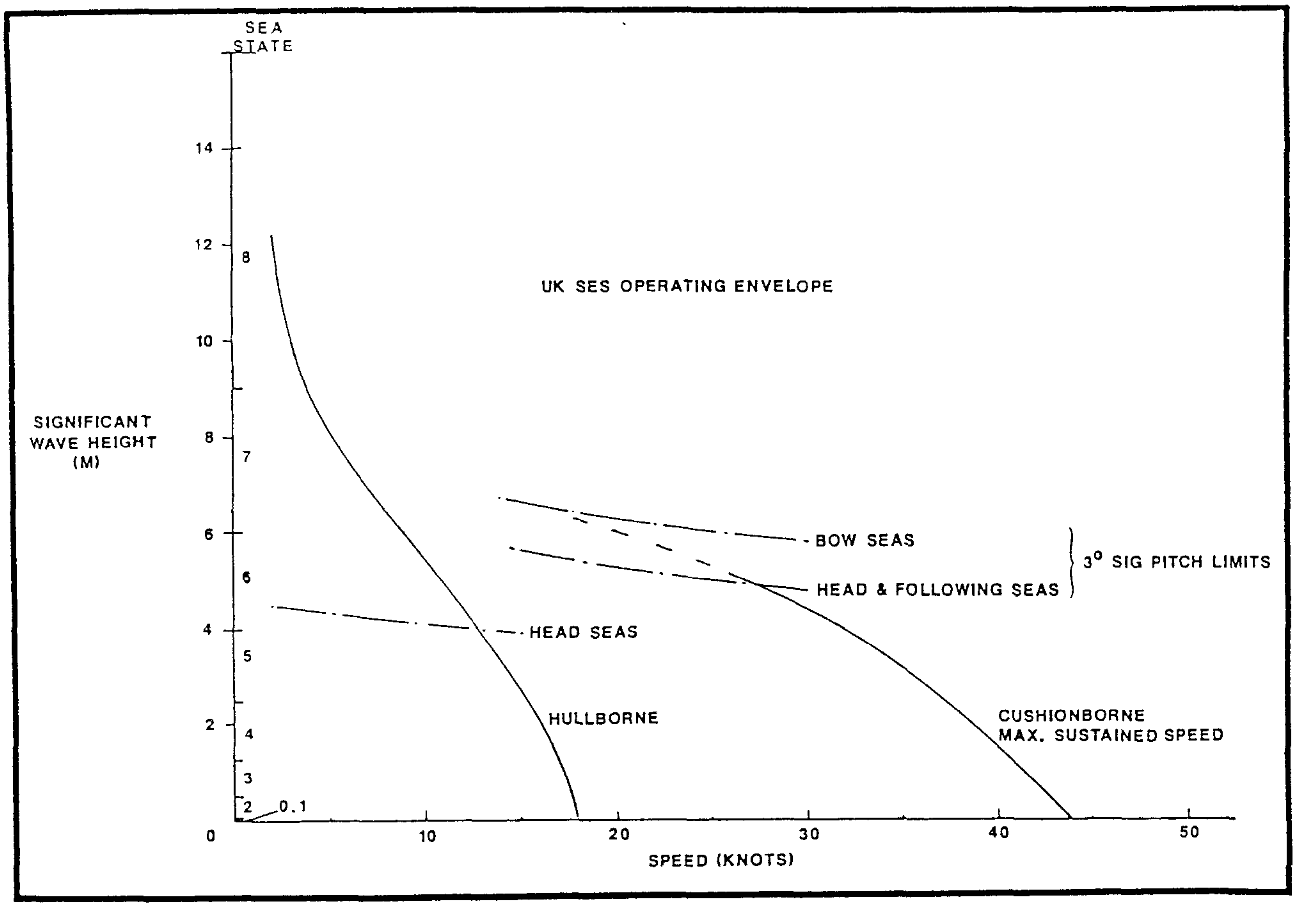


Figure 3.2.1-4. Maximum Sustained Speed Versus Sea State - UK SES

The performance predicted for all three SES designs is very similar. The difference in maximum sustained speed of the three SESs can be attributed principally to their different installed power levels. All have a considerable speed advantage over the larger FFG 7 and NFR 90 in low sea states, but have about the same speed capability as the NFR 90 in 5-meter waves. All of the ships are expected to resort to much lower speeds in wave heights higher than 5 meters due to the increasing probability of excessive motions, sonar-dome emergence, and slamming.

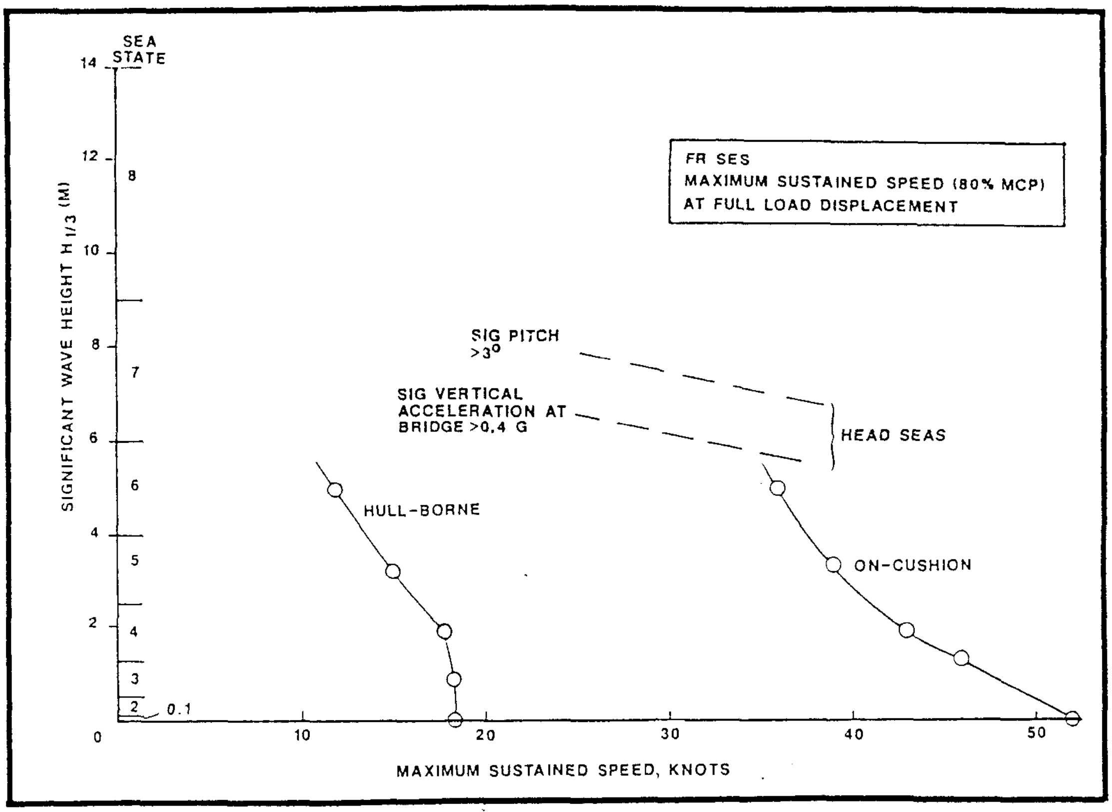


Figure 3.2.1-5. Maximum Sustained Speed Versus Sea State - FR SES

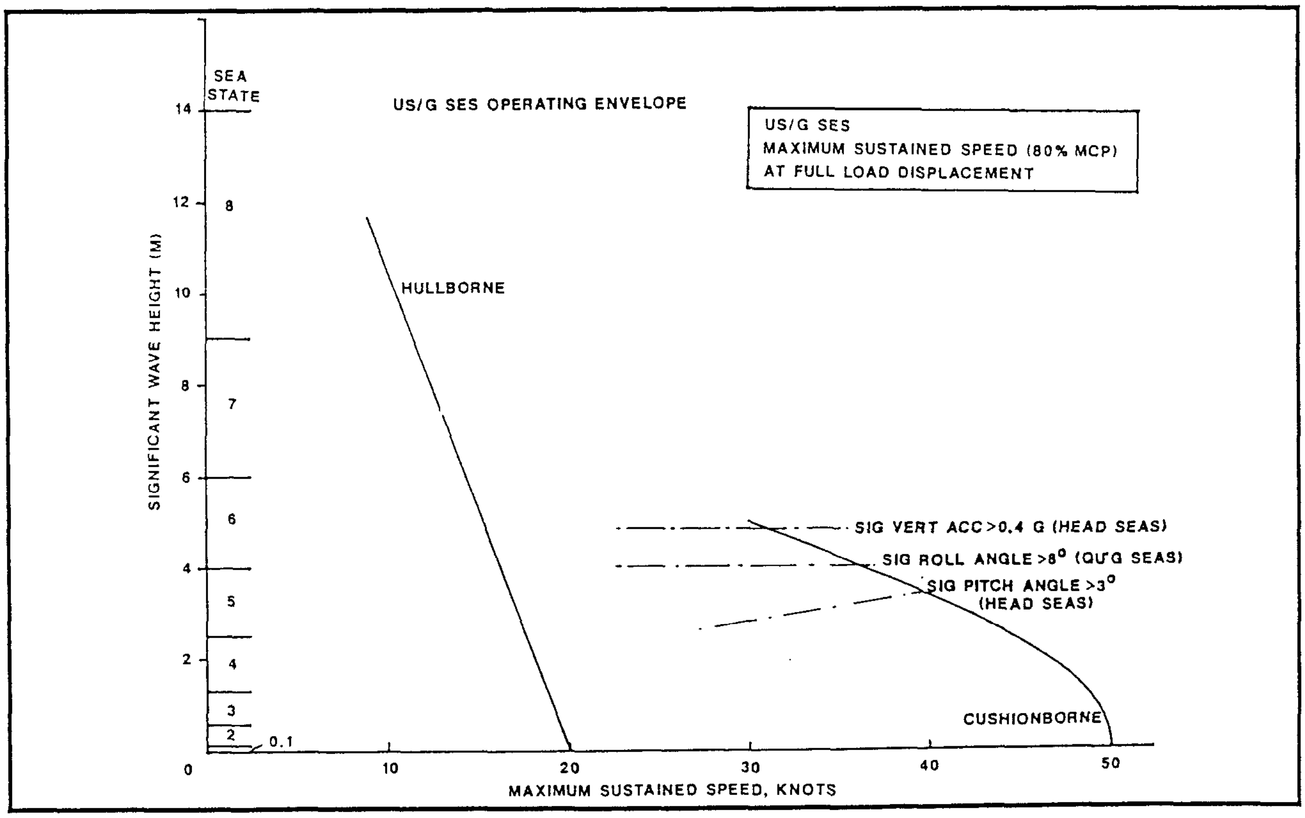


Figure 3.2.1-6. Maximum Sustained Speed Versus Sea State - US/G SES

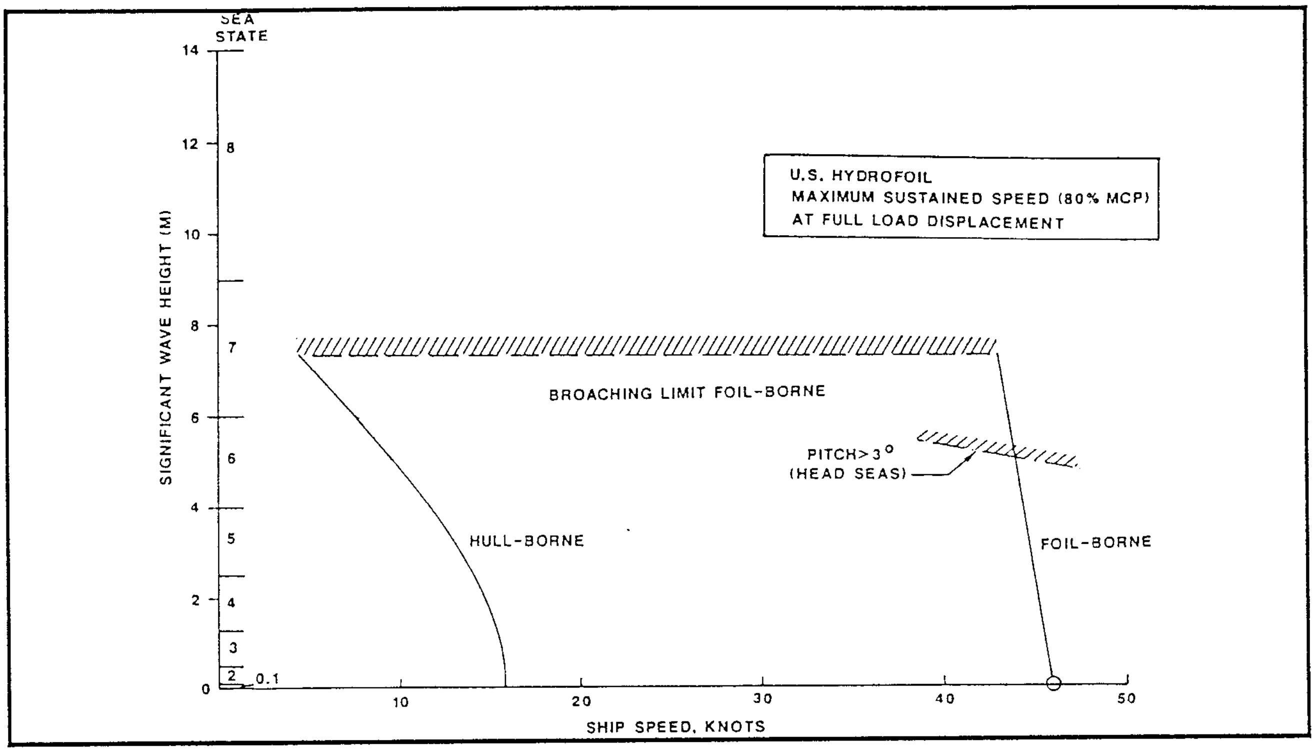


Figure 3.2.1-7. Maximum Sustained Speed Versus Sea State - U.S. Hydrofoil

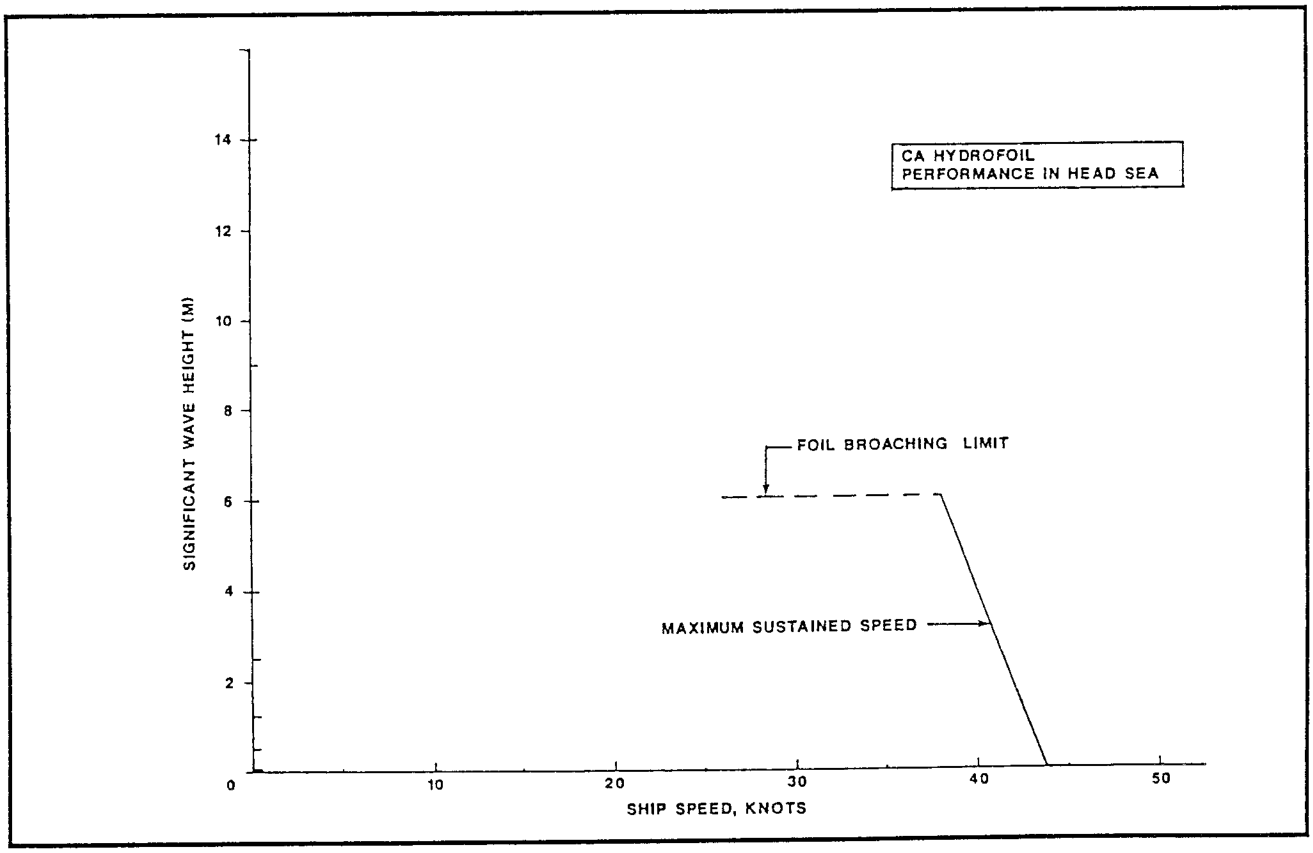


Figure 3.2.1-8. Maximum Sustained Speed Versus Sea State - CA Hydrofoil

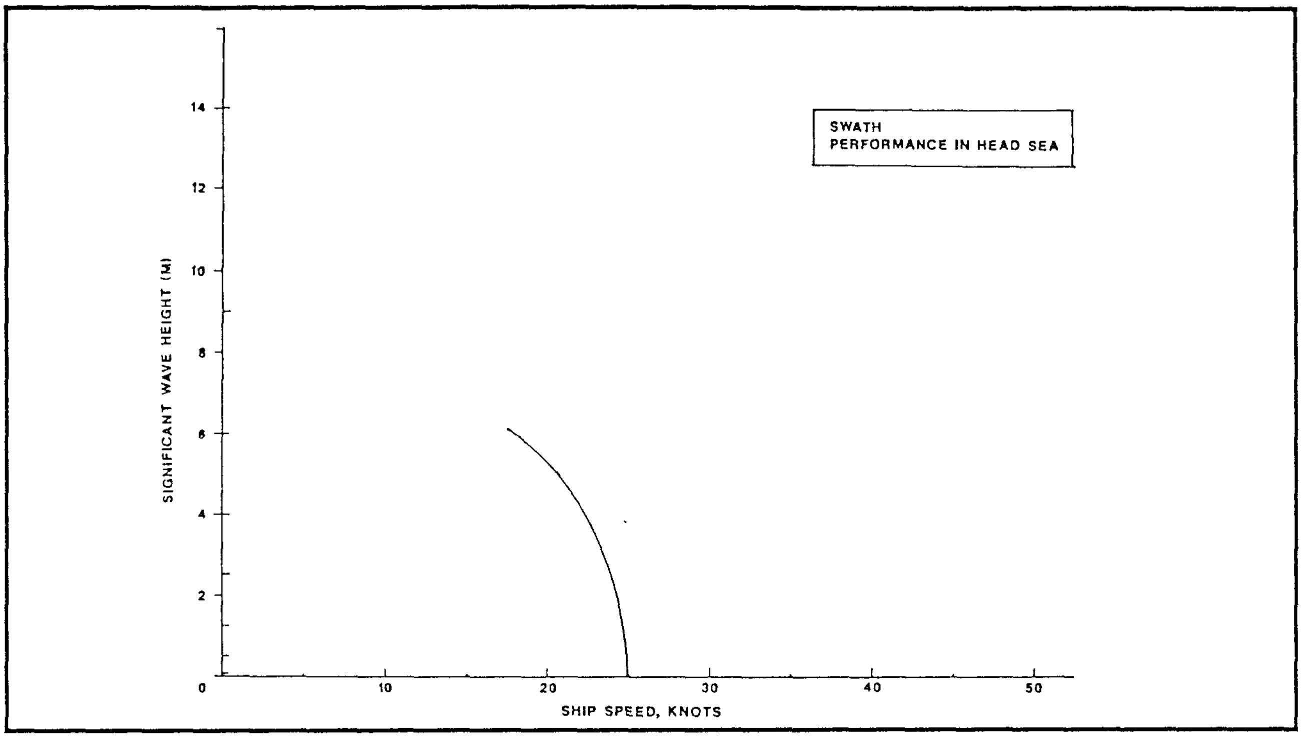


Figure 3.2.1-9. Maximum Sustained Speed Versus Sea State - SWATH

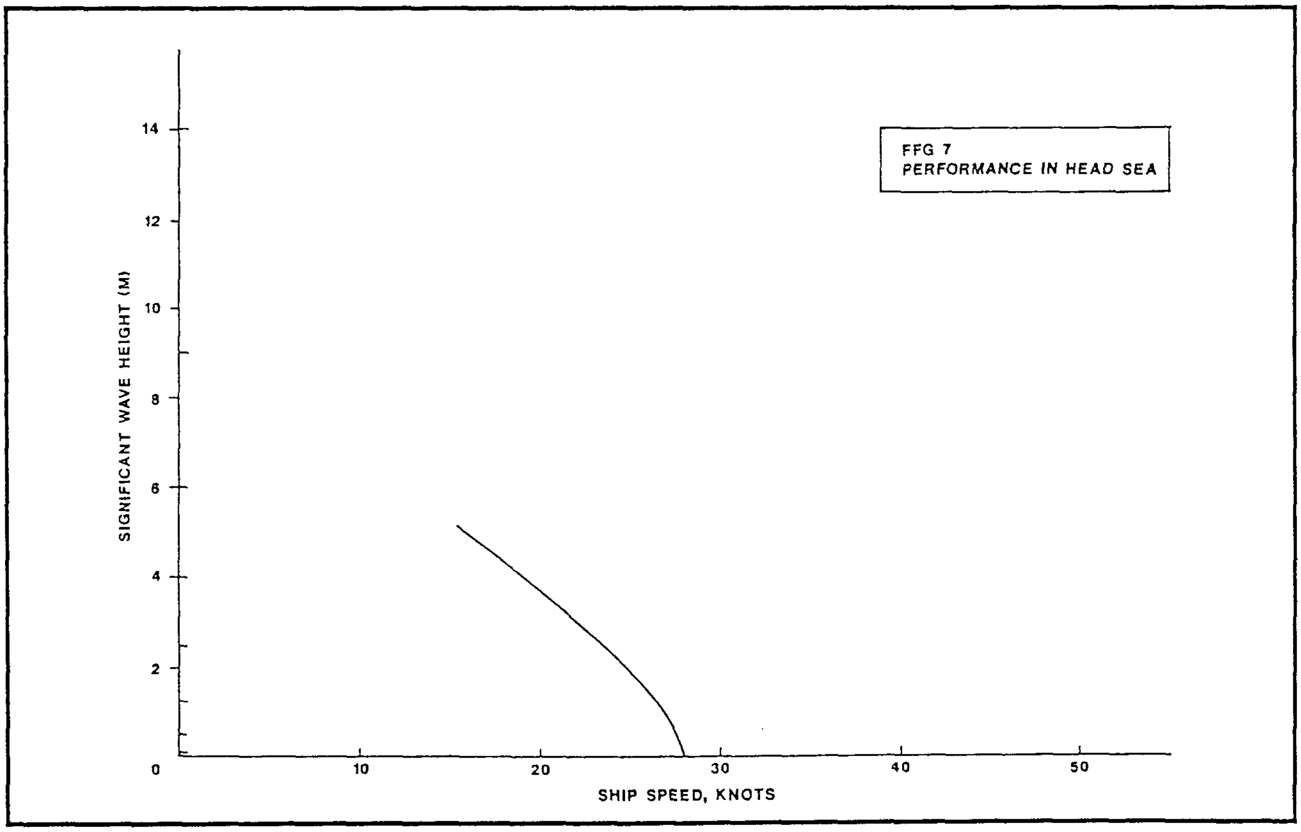


Figure 3.2.1-10. Maximum Sustained Speed Versus Sea State FFG 7

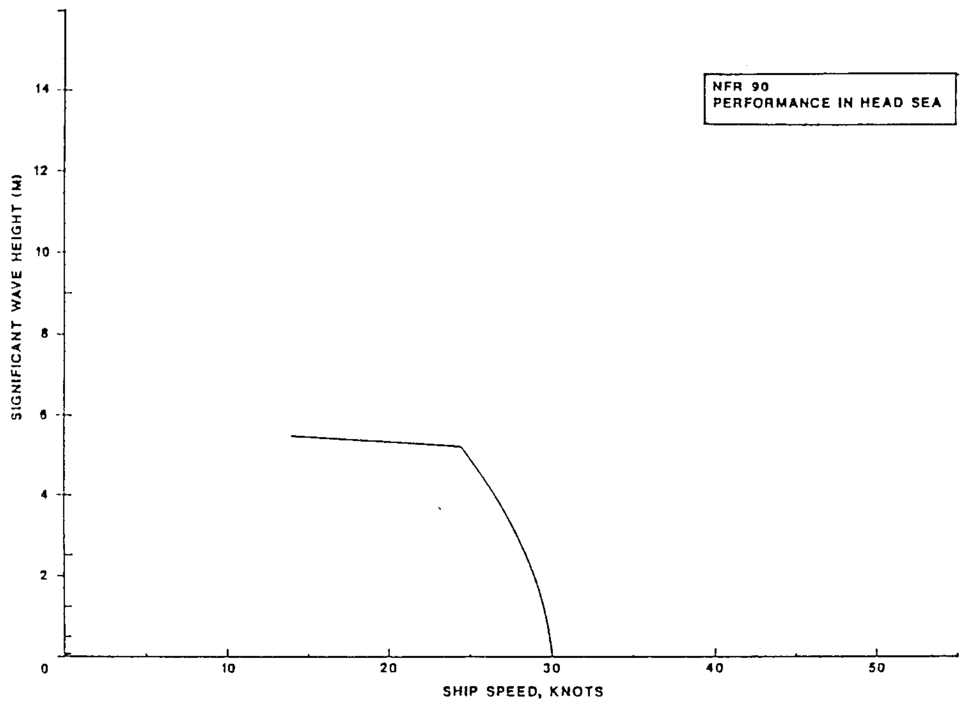


Figure 3.2.1-11. Maximum Sustained Speed Versus Sea State - NFR 90

Most of the SESs and Hydrofoils do not exceed the selected motion limits until the significant wave height exceeds about 5 meters. The US/G SES, however, does exceed the 3^{o} pitch limit in 3-to-4-meter wave heights and exceeds the 8^{o} roll limit in quartering seas in 4 meter waves. Both of these conditions could normally be improved by minor changes in speed or heading.

The US Hydrofoil is predicted to be able to maintain its high speed (above 40 knots) in significant wave heights up to about 6 meters beyond which the onset of foil broaching will begin. Based on current USN Hydrofoil experience, this ship will have to reduce speed and operate in the hullborne mode when the sea condition reaches 7 to 8 meters (low to mid sea-state 7).

The importance of the high-speed capability in the more-prevalent lower sea states is shown in Figure 3.2.1-12, in which the speed-sea-state information from Figures 3.2.1-4 through 3.2.1-11 is converted to days per year versus speed for average North Atlantic conditions (Reference 5). For most of the year the SESs and the hydrofoils have a clear speed advantage over the monohull. A measure of this advantage can be obtained by averaging the sustained speed over a year in the open North Atlantic.

From the data shown in Figure 3.2.1-12, the predicted calm-water speed is compared, in Figure 3.2.1-13 with the annual average sustained speed capability of each ship. The calm-water speed is indicated by the unshaded area of each bar. The average speed is indicated by the shaded area.

The ships are listed from left to right in descending order of average-speed capability. The 10 to 20 knot speed advantage of the hydrofoils and SES is clearly illustrated.

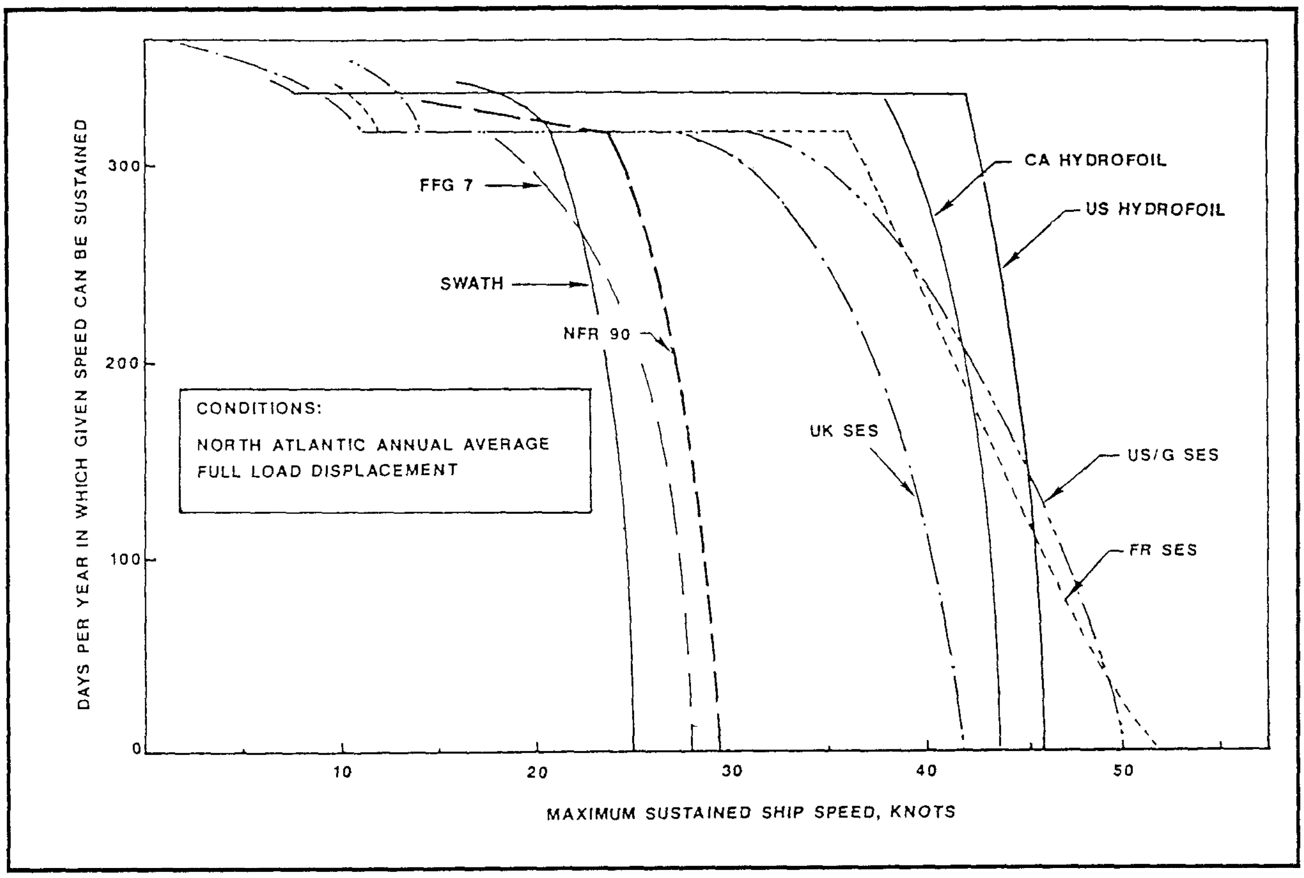


Figure 3.2.1-12. Days Per Year Versus Maximum Sustained Speed for NATO ANVs

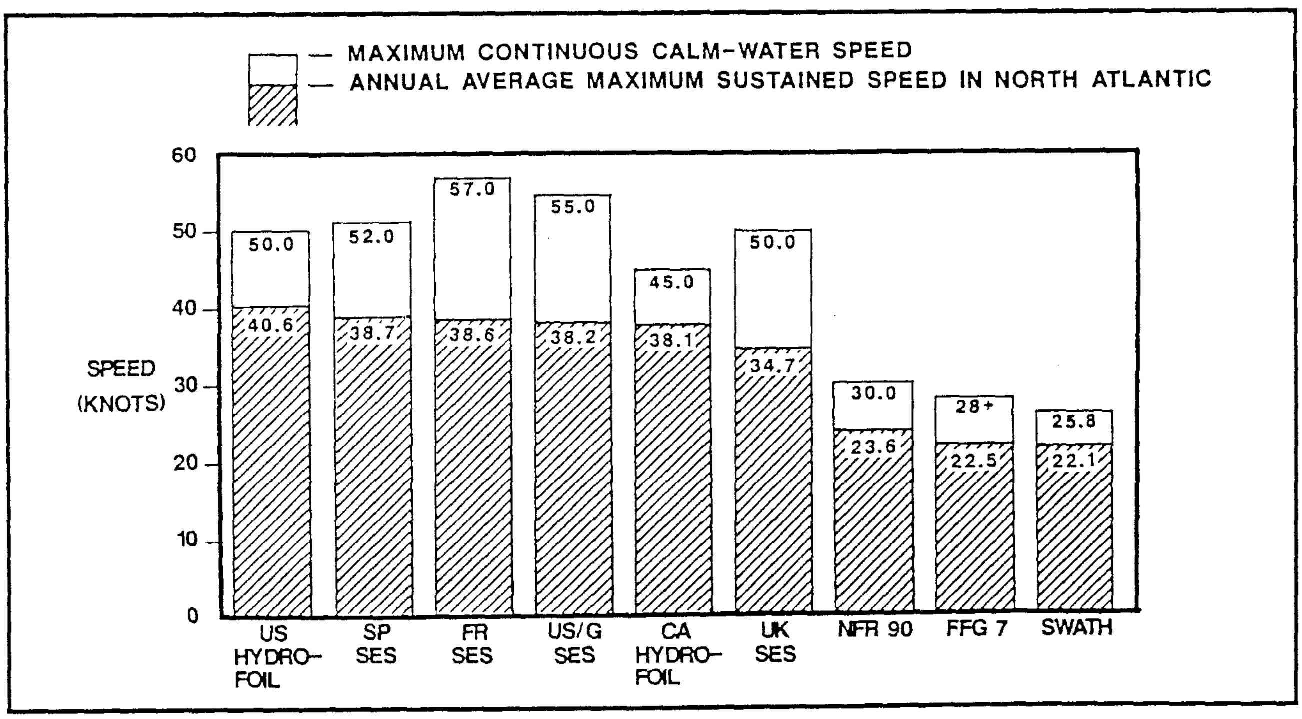


Figure 3.2.1-13. Comparison of Speed Capability

However, the ability to provide a high sustained forward speed in average North Atlantic weather is of limited value if the ship's combat capability is severely degraded by excessive ship motion. Even though the platform, itself, may be able to function without excessive slamming, broaching or deck wetness, high sea states can downgrade the ship's operational capability due to:

- Loss of personnel effectiveness
- Difficulty in launching and retrieving helicopters
- Inaccuracy in operating guns, missiles and decoys, etc., and
- A general downgrade of the ship's surveillance systems.

In many instances, a ship will change speed or heading to improve its situation in this regard. In many other instances, this may not be tactically advantageous. To include these considerations, ship motion criteria used as shown in Section 3.2.3.

3.2.2 Range and Endurance

3.2.2.1 Requirements

The range and endurance requirements for the NATO ANVs are listed in Section 3.1.1. Some are listed at two levels, the lower being the "Minimum Required" and the higher being a "Goal".

3.2.2.2 Fuel Consumption Estimates

The variations of total fuel consumption with forward speed for the SESs, the US Hydrofoil, the SWATH, the LUPO and DESCUBIERTA class monohulls are shown in Figures 3.2.2-1 through 3.2.2-4. Figures 3.2.2-1 and 3.2.2-2 represent the low-speed, diesel-powered, hull-borne mode of operation in sea-states 0 and 6, respectively, and Figures 3.2.2-3 and 3.2.2-4 represent the high-speed, gas-turbine-powered mode of operation which is the cushion-borne mode for the SESs and the foil-borne mode for the US Hydrofoil. The SWATH is shown in both 3.2.2-1 and 3.2.2-3. The Hydrofoil has a low fuel consumption in both modes due to its much lower displacement, conversely the SWATH has very high fuel consumption due largely to its high displacement.

For the low-speed mode, as shown in Figure 3.2.2-1, the LUPO and DESCUBIERTA are shown to have low fuel consumption rates similar to the US/G SES, but which increases significantly as 20 knots is approached.

For the high-speed mode, as shown in Figure 3.2.2-3, the LUPO and DESCUBIERTA exhibit a significant increase in fuel consumption above 20 knots, while the SWATH has a higher consumption rate throughout the speed range.

The UK SES and FR SES have quite similar fuel consumption curves in both modes but the US/G SES claims very much lower fuel consumption in the low-speed, off-cushion mode; its fuel consumption in Sea State 6 is lower than that predicted for either of the other SESs in Sea State 0. In the on-cushion mode, the US/G SES has a fuel consumption rate similar to that of the UK SES and FR SES in Sea State 6 but, again, has a considerably lower fuel consumption in Sea State 0. The US/G SES is shown, in Section 3.3.5, to have significantly lower resistances, despite its much heavier displacement, because of the selection of a high length-to-beam ratio. This, combined with the use of propellers which are claimed to be more efficient (particularly at low speed) than the waterjets used on the UK and FR SES, is an explanation of the low fuel consumption for the US/G SES

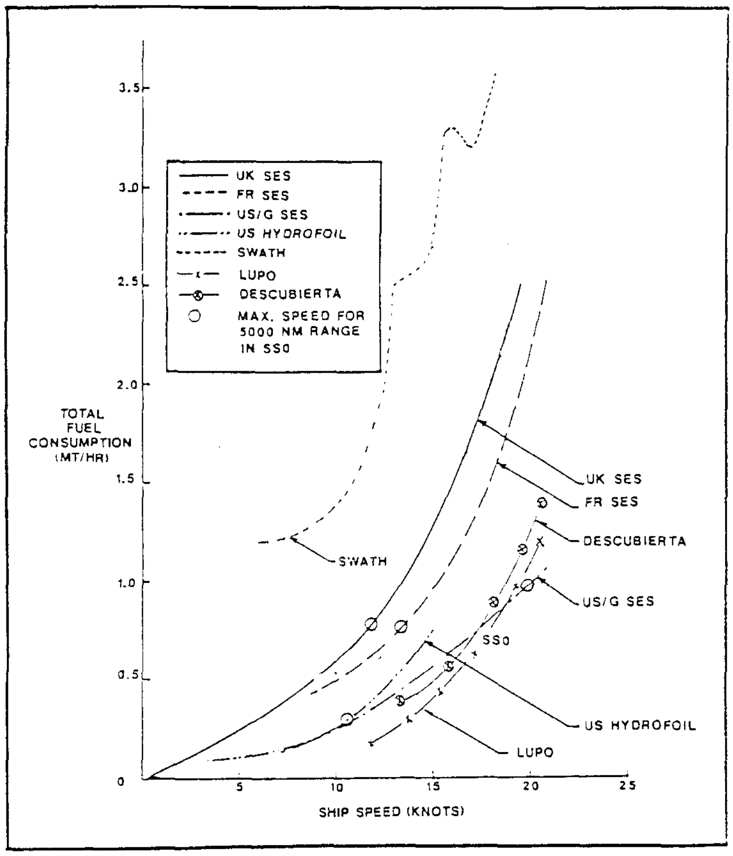


Figure 3.2.2-1. Fuel Consumption Versus Ship Speed - Low-Speed, Hullborne Mode in Sea State 0

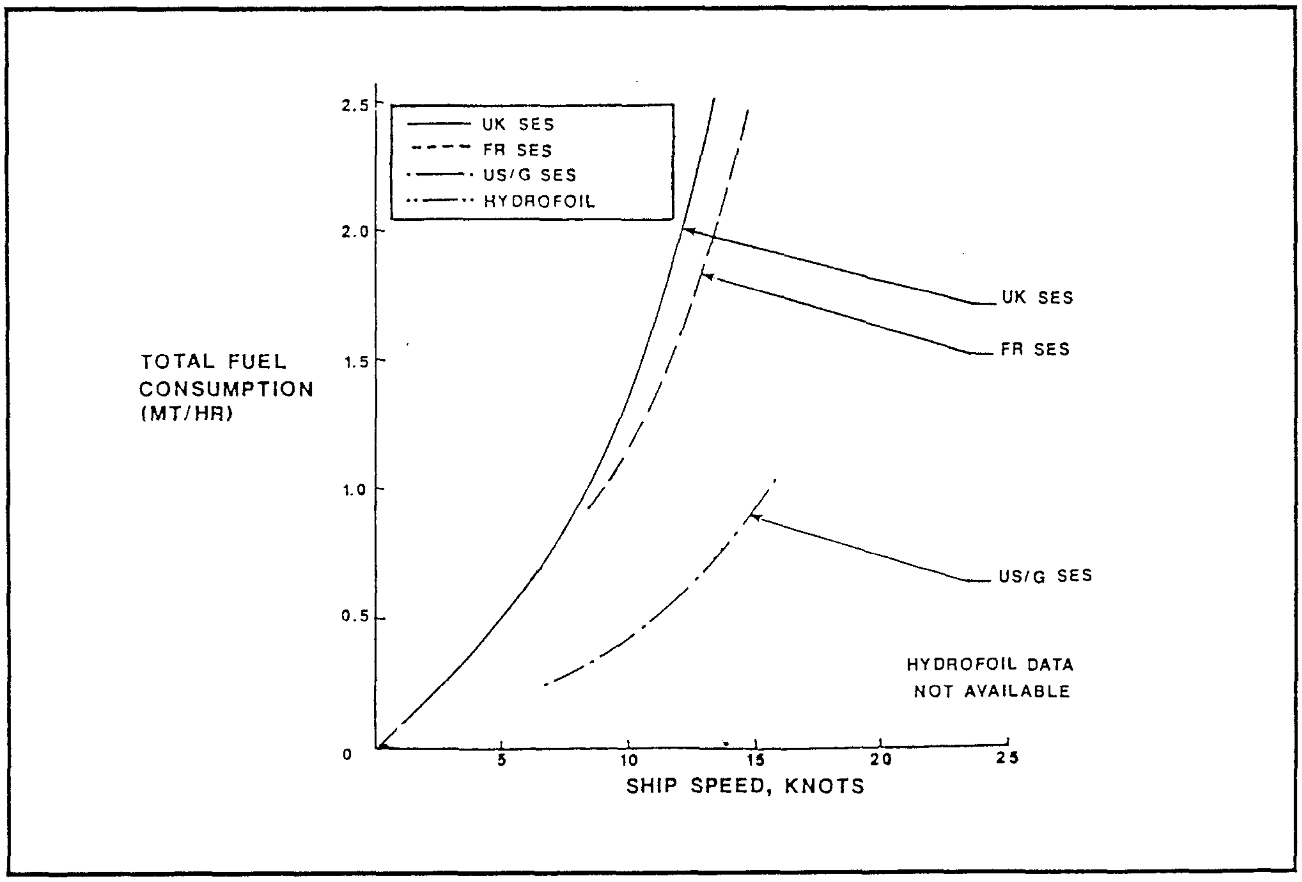


Figure 3.2.2-2. Fuel Consumption Versus Ship Speed - Low-Speed, Hullborne Mode in Sea State 6

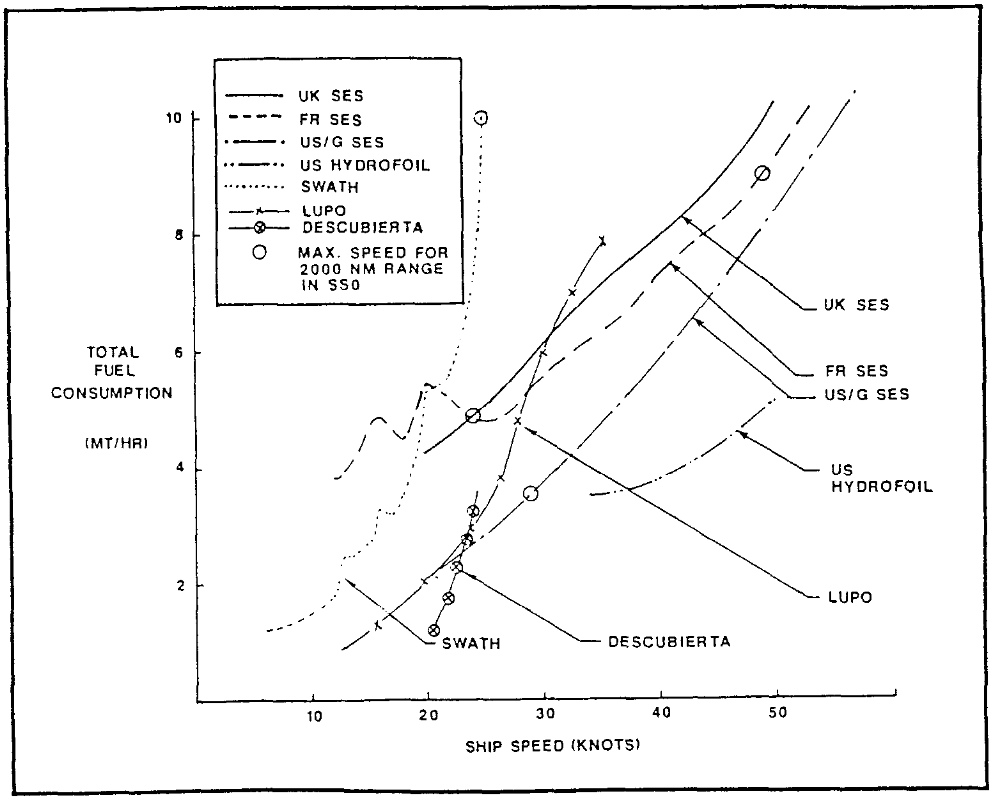


Figure 3.2.2-3. Fuel Consumption versus Ship Speed in the High-Speed, Cushion or Foilborne Mode in Sea State 0

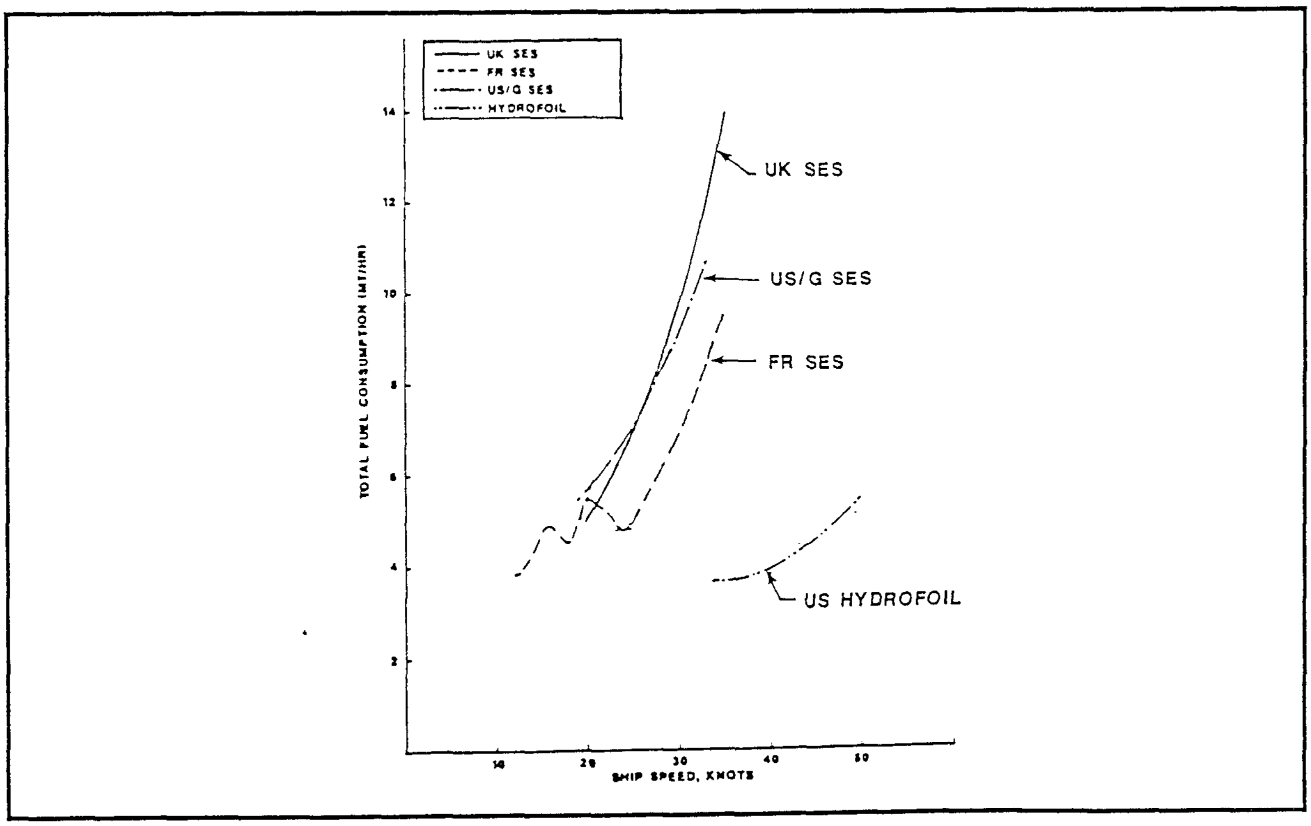


Figure 3.2.2-4. Fuel Consumption Versus Ship Speed - High-Speed, Cushion or Foilborne Mode in Sea State 6

3.2.2.3 Range and Endurance Estimates

The fuel-consumption information provided in Figures 3.2.2-1 and 3.2.2-2 has been used in conjunction with the range and endurance requirements of Table 3.1.1.2-1 to estimate the fuel load required for each ship. These fuel loads and the resulting values of range and endurance achieved are listed in Table 3.2.2-1. It is assumed that appropriate allowances for electric load and for margins were used for all ships but this was not always specifically stated. In accordance with the differences in fuel consumption discussed in the previous paragraph, the fuel load for the US/G SES is considerably less than those for the UK SES and FR SES. The reasons for this are discussed below.

Table 3.2.2-1. Range and Endurance Performance

	UK SES	FR SES	US/G SES	SP SES	US HYD	CAN HYD	SWATH	FFG 7	DD 963	NFR 90
FLD (MT)	1601	1400	1936.5	•	773.3	458	9548	•	•	5059
LOA (M)	92.9	8.9	104.0		66.0	64				140.5
Max. Speed (Knots) for:										
5000 nm SS0 (Goal)	13.6 (H)	16.9(H)	19.8(H)		11.2(H)	12(H)	24	4500 nm @ 20 Knots		19.0(D)
3700 nm (Minimum Required)	17.1(H)	19.3(H)	21.4(H)	•	14.0(H)	16.5(H)	25		•	
2500 nm, SS0 (Goal)	21+(H)	21+(H)	–		15+(H)	20(H)	–			
2000 nm, SS0	24.0(C)	48.8(C)	29.5(C)		–	23	–			28.0(G)
1800 nm, SS0	50.0(C)	57+(C)	38.5(C)	•	–	26	–	•	•	
1500 nm, SS0 (Minimum Required)	50+(C)	57+(C)	50.0(C)		48(F)	45	–			
Max. Range at 10 Knots, SS0 (nm)	7400(H)	7740(H)	11500(H)	•	6000(H)	5800(H)	10200	•	•	•
Max. Range at 10 Knots, SS6 (nm)	2640(H)	3270(H)	6300(D)		?	-				
Normal Fuel Load (mt)	400 445(A)	372 402(A)	286 330	•	160	116	1262	•	•	•
Fuel Tankage (mt)		474	700		250					
Endurance: Maximum Speed for 7 Days Endurance SS3 (Knots)	18.0(H)	19.7(H)	22.0(H)	•	15+(H)	18	24.8	•	•	•

Notes: (A) Includes Aircraft Fuel (C) Cushionborne (D) Diesel (F) Foilborne (G) Gas Turbine (H) Hullborne • Not Available

Figure 3.2.2-5 shows the predicted range distance covered per ton of fuel for each point design as a function of speed. The capability of the SES and Hydrofoil to extend their range by resorting to hullborne operation is seen in the figure to be very considerable. In comparison, the SWATH and the FFG-7 can increase range only slightly be reducing speed.

The right-hand side of Figure 3.2.2-5 shows "productivity" in the form of payload times n. miles per ton of fuel used which puts most of the point designs and the FFG-7 much closer together.

The exception is the US/G SES which remains well above all others. Some reasons for this are:

1. The use of propellers, which are more efficient, particularly at lower speeds than waterjets (which accounts for the shaded area for the US/G SES)

2. The use of a higher L/B than the other SES (thus a longer ship and lower Froude Number for the same speed), and

3. The use of "lenticular" hulls which are claimed to give considerably lower resistance when hullborne.

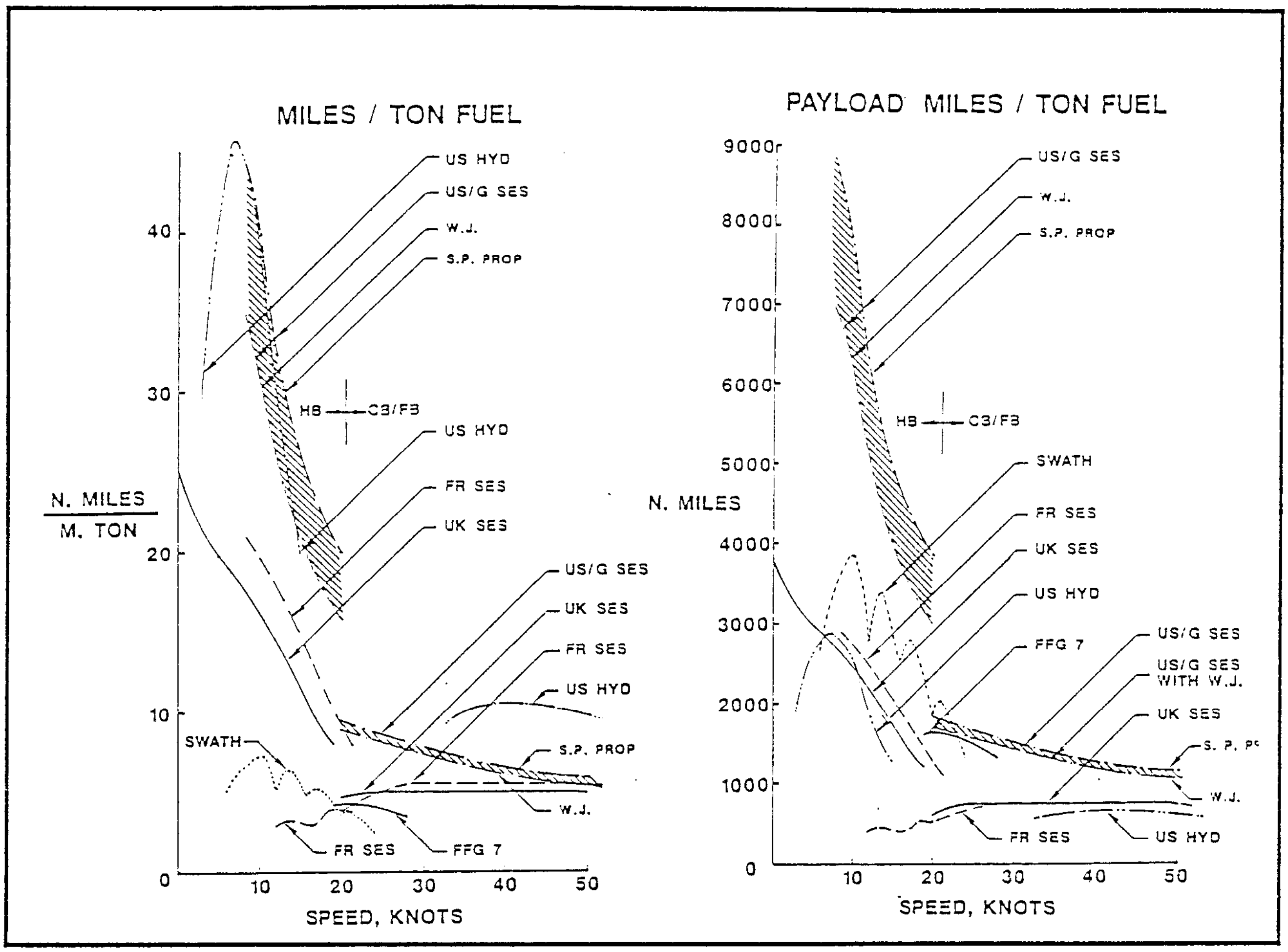


Figure 3.2.2-5. Comparison of Range Per Unit of Fuel

Figure 3.2.2-6 shows the payload-range trade-off for the point designs for a 10 knot speed in calm water. If the total useful load (fuel and payload) remains constant then payload can be increased at the cost of fuel load and range.

The design points for each ship are shown as the square points in each use. The circular points, at zero range, represent the sum of payload and design fuel load in each case.

The SWATH, principally because of its larger displacement, can take the greatest advantage of trading of fuel for payload. The hydrofoils, have the least capability in this regard, while the SES fall between the Hydrofoils and SWATH. Note that the UK and French SES designs have almost exactly the same characteristic curve, while the U.S. SES design is significantly different as explained in the previous figure.

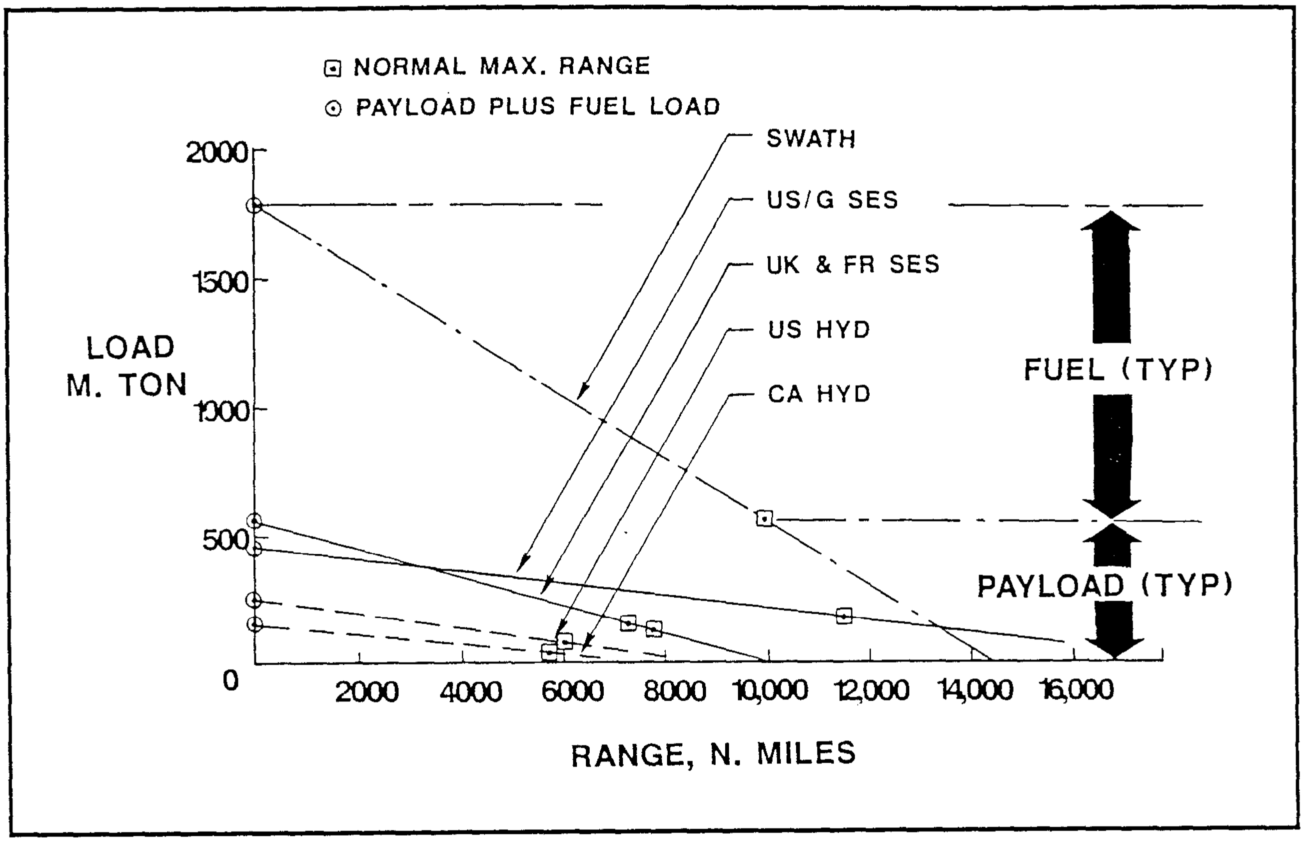


Figure 3.2.2-6. Payload - Range Trade-Off (10 Knots, Sea-State 0)

3.2.2.4 Range Versus Configuration Trade-Off for Hydrofoils

Figure 3.2.2-7 shows the results of the Canadian trade-off study in which four types of foil systems were examined, denoted "A" through "D". Arrows on this figure show the trends, up or down, as the configurations are changed.

Configuration "D" is representative of the Canadian low-cost option and can be compared, here, with an additional configuration which is labeled "E" to represent the configuration of the NATO Point Design.

The trade-off study was completed with all craft at a displacement of only 400 ton, so values of range shown are compared on a relative basis.

Configuration "A", with the least range at low speed, is the best surface-piercing design.

"B" is similar to "A" but has an ability to retract its foils.

At low speed, the weight penalty for retraction gear does not offset the advantage of reduced hullborne drag.

Curve "C" is the best fully-submerged foil design with no retraction, while curve "D", the Canadian low-cost option, is obtained by adding small, low-consumption diesels to configuration "C" and by powering through the main transmission system at low speed.

Configure "E", which represents the NATO Point Design, operates hullborne, in the same way, with foils down, but carries the weight penalty of the retraction gear and a less efficient structure. The shaded area indicates the retraction penalty for low and high-speed operation, respectively.

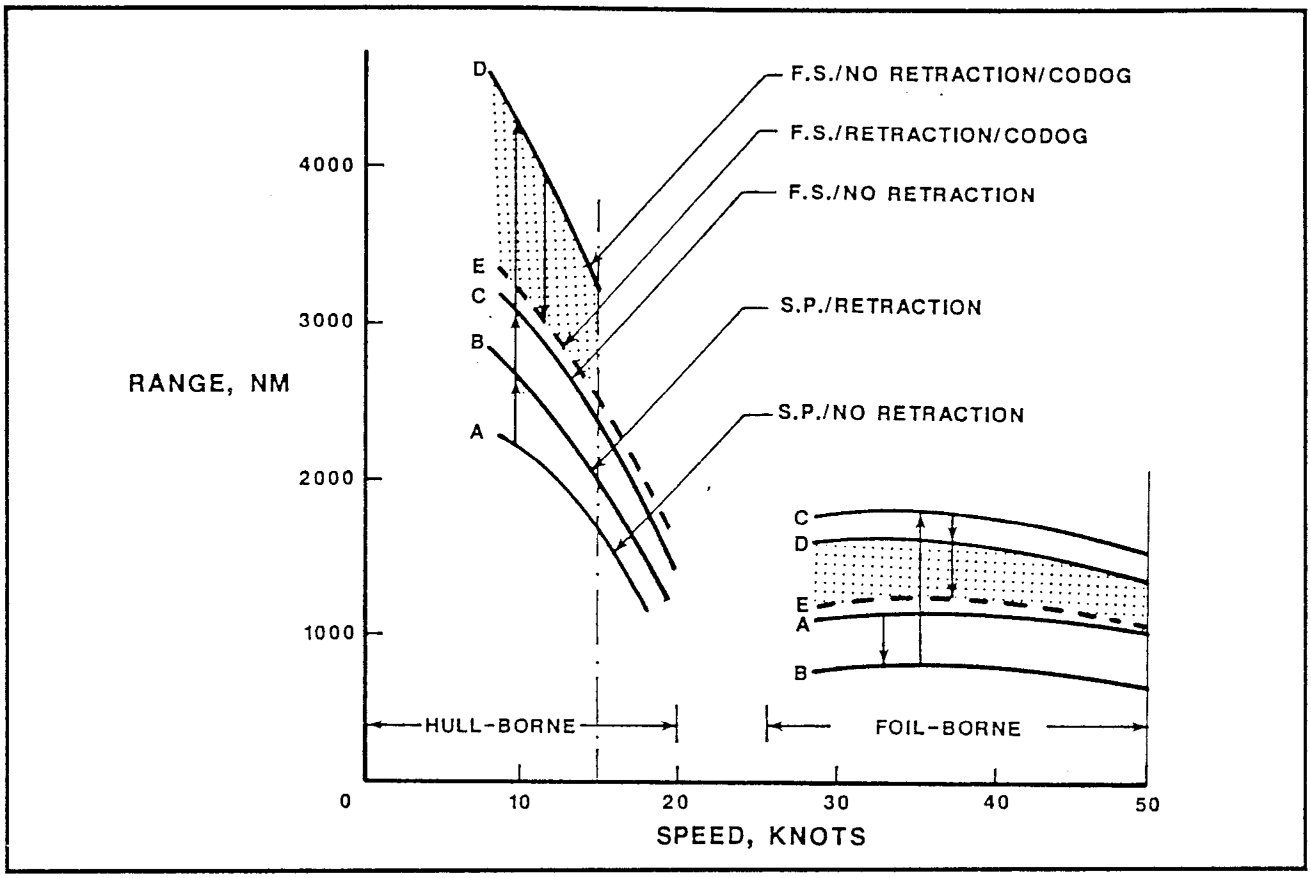


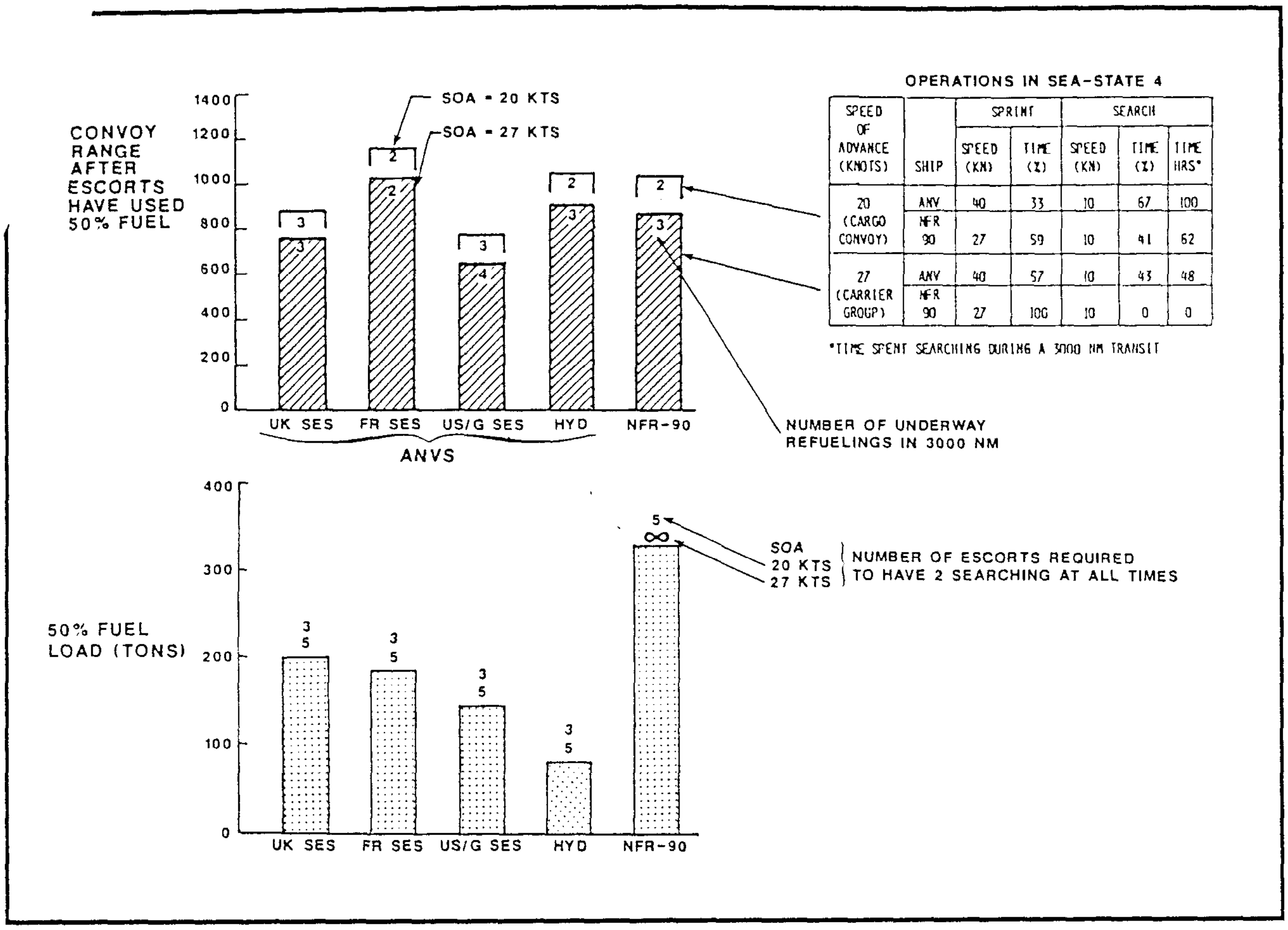
Figure 3.2.2-7. Trade-Off Results Showing Range as a Function of Speed for Various Hydrofoil Configurations

3.2.2.5 <u>Refueling Range Comparisons</u>

Figure 3.2.2-8 illustrates the implication of the different rates of fuel consumption and the total fuel load carried.

The top half of this figure compares, for each design, the range segments achieved by a convoy when one half the fuel load of each escort has been consumed, and at which time the escort must be refueled. This fuel load, in each case, is shown in the bottom half of the figure. Range segments are shown, at the top, for two different convoys both transiting a total distance of 3000 nm in sea state 4. One is a cargo convoy with a 20 knot speed of advance, the other is a carrier group transiting at 27 knots.

Also compared on Figure 3.2.2-8 are the number of refuelings required during the 3000 nm transit. When escorting the 20 knot convoy, the UK and US SES will be required to be refueled three times while the French SES, the Hydrofoil and NFR 90 will only need to be refueled twice. The situation is somewhat more demanding for the 27-knot carrier group. For example, the US SES will need to be refueled four times. While the French SES can still get by with only two refuelings.



SPEED OF ADVANCE (KNOTS)	SHIP	SPRINT		SEARCH		
		SPEED (KN)	TIME (%)	SPEED (KN)	TIME (%)	TIME HRS*
20 (CARGO CONVOY)	ANV	40	33	10	67	100
	NFR 90	27	59	10	41	62
27 (CARRIER GROUP)	ANV	40	57	10	43	48
	NFR 90	27	100	10	0	0

*TIME SPENT SEARCHING DURING A 3000 NM TRANSIT

Figure 3.2.2-8. Range of Convoy Escorts with 50 Percent Fuel Remaining

3.2.3 Seakeeping and Ride Quality

3.2.3.1 Scope of Seakeeping Assessment

The point-design study-guidance document has requested a number of specific seakeeping and ride-quality characteristics to be defined as an output of each point-design study. The approach to ship-motion assessment has been based on these guidelines to the extent to which the data have been made available.

As pointed out in Appendix E it should be understood that the theory of SES seakeeping is in a relatively immature state of development. Much of the extensive SES seakeeping prediction and ride-control system analysis capability that was developed by Aerojet, Bell and RMI to support the US 2K and 3K SES programs is no longer available, although reconstruction of this capability could be accomplished to support subsequent phases of design. A very large number of model tests of various designs have been carried out in towing tanks which are restricted to head-sea testing. Vosper Hovermarine Limited (VHL), in the UK, has also tested a number of free flight models in the open sea, including one manned model. More recently, SES model tests have been conducted by the French and Germans on configurations similar to their respective SES Point Designs. Full-scale tests have been carried out on the US SES 100A, SES 100B, XR-1 (A through E) XR-3, XR-5, BH-110, SES 200, the UK HM527 and HM218 and, more recently, the Norwegian NORCAT. All of these SESs are, however, very much smaller than the proposed SES designs. It is well established that an increase in craft size will have a significant effect on seakeeping performance. For example, the HM527, which is approximately a (1.5/1) scale model of an HM218, has been demonstrated, during trials and operational experience, to have significantly better seakeeping performance - at least as good as, and possibly better than might be expected from the scaled wave conditions. The "comfort limiting" sea state for the HM218 is about 0.75 m whilst that for the HM527 is nearer 1.5 m, (i.e., a 2:1 ratio).

Assessments, therefore, have to be based on the available model data, which have, in most cases, yet to be validated by large-scale correlation. This is not a simple process since there are areas in which modeling and scaling involve a number of uncertainties, particularly those associated with dynamics of the air-cushion.

The assessment of seakeeping is focused on determining to what extent the ship, its crew and combat systems can perform the required operational tasks in the ocean areas of interest to the NATO countries. The goal of this assessment has been to calculate the percentage of time during a typical year that the ship can be expected to adequately perform specific operational tasks such as:

- *Conduct helicopter operations*
- Deploy, tow, operate and retrieve sonar arrays
- Maintain design speed
- Launch missiles and fire guns
- Conduct underway-replenishment operations.

In each case the operational capability has been assessed by defining simple limits in terms of ship motions, accelerations, number of slams per hour, etc. The limits used for the point-design assessment are given in Table 3.2.3-1. The values shown are typical of those which have been used in prior U.S. Navy studies and cover limits for:

- Roll and pitch deck motions for helicopter operations, weapons firing and operating towed sonar gear, etc.
- Wind over the deck for helicopter operations
- Ride quality for the ship's crew
- Slamming of hull bottom or cross structure
- Water over the deck
- Broaching of propellers, waterjet inlets and bow or conformal sonars.

Table 3.2.3-1. Subsystem Performance Limitations for Full Subsystem Performance.

Ship Motion Criteria		Subsystem
	Not to Exceed:	
Roll Pitch Wind Over Deck	8 Degrees* 3 Degrees* 40 to 45 Knots**	• Helo. Operations • Weapons Firing • Deploy/Retrieve Sonar • UNREP
Ride Quality (At Bridge)	0.4 g *Vertical Acceleration 0.2 g *Lateral Acceleration	• Personnel Fatigue
Slams	20 Per Hr	• Structural Damage
Deck Wetness	20 Per Hr	• Deck Operations • Structural Damage
Broaching	20 Per Hr	• Propulsor Limits • Sonar Limits

* Significant, Single Amplitude Values ** Depending on Helicopter

The extent to which the effect of each of these limits has been assessed has depended upon the extent to which the ship-motion characteristics of each design have been determined. Their effects can be determined individually or in combination depending upon the complexity of the mission task to be performed.

3.2.3.2 The Environment

The characteristics of the sea and ocean environments in the NATO area are assumed to be as defined in the "Standardized Wind and Wave Environments for NATO Operations Areas", (STANAG 4194). The probability of occurrence of sea states in various ocean areas and seasons from Reference 3.2.1-4 are plotted in Figure 3.2.3-1. The areas are illustrated in Figures 3.2.3-2 through 3.2.3-4. The highest probabilities of severe sea states occur in the winter in Area 1, which is the area immediately south of Greenland (see Figure 3.2.3-2). The lowest probabilities of high sea states occur in the Baltic Sea (Figure 3.2.3-4). The ability of the various ships to operate in these sea areas is assessed in this section of the report.

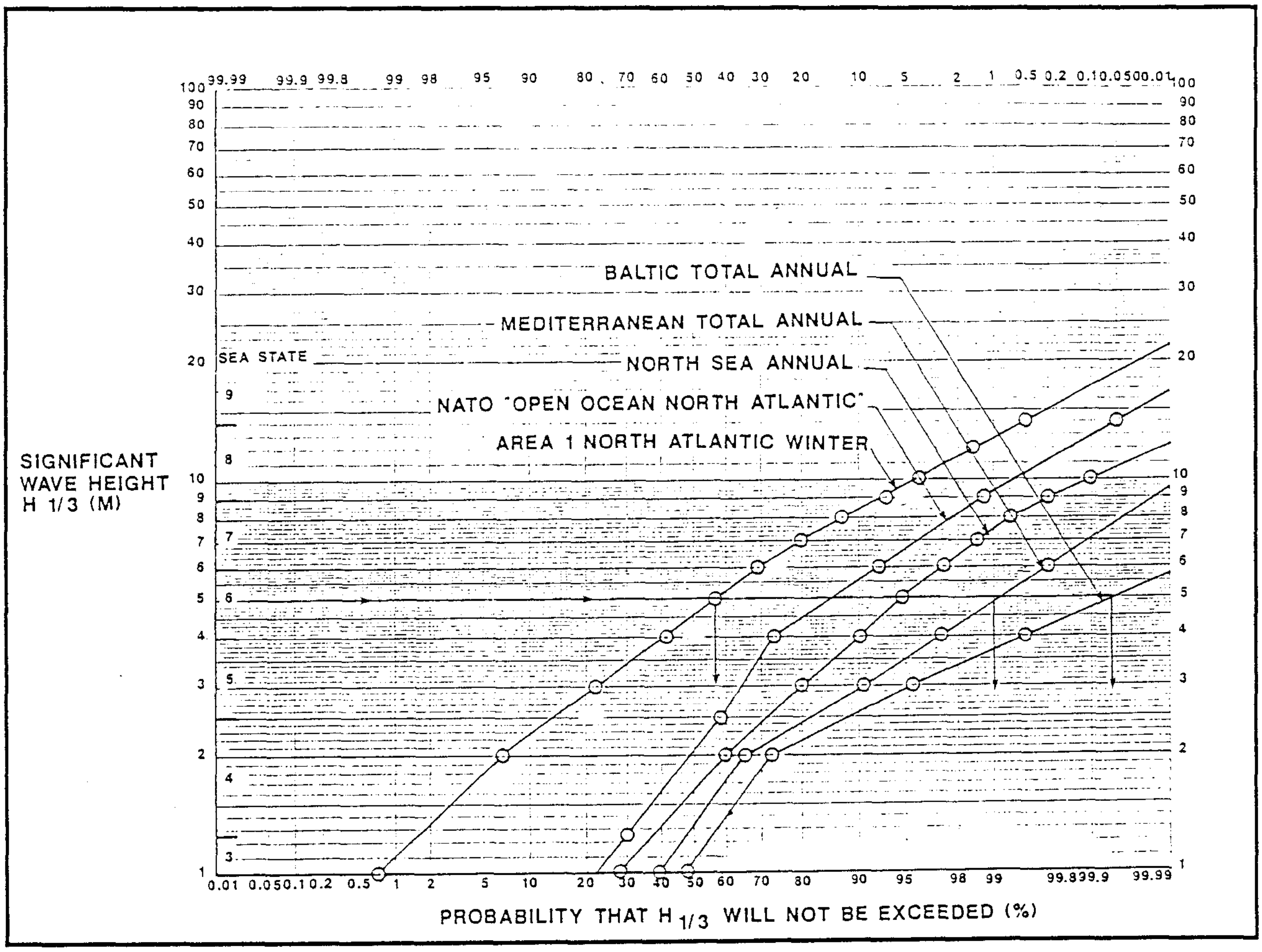


Figure 3.2.3-1. Probability of Not Exceeding Given Sea States for Various Ocean Areas

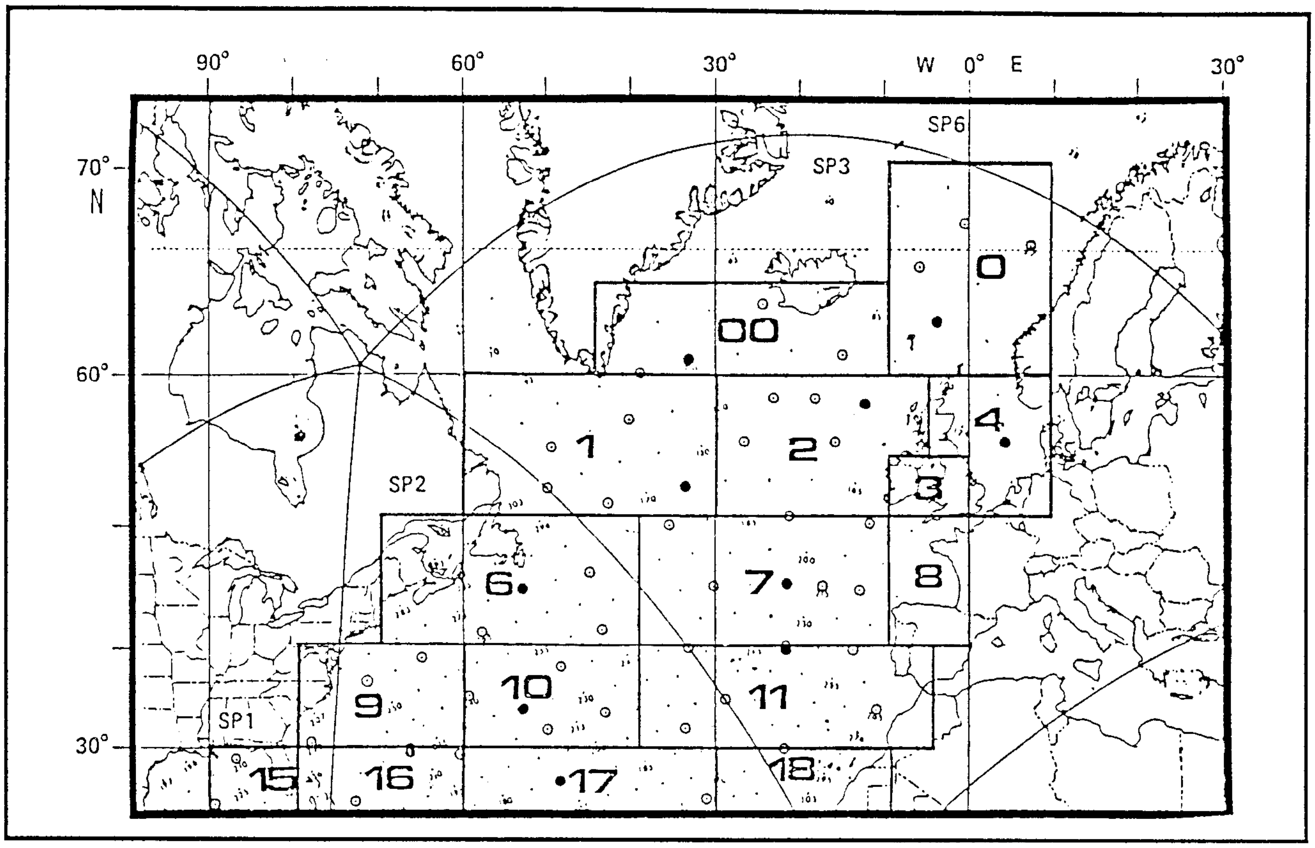


Figure 3.2.3-2. Selection of Representative Areas in the North Atlantic Basin

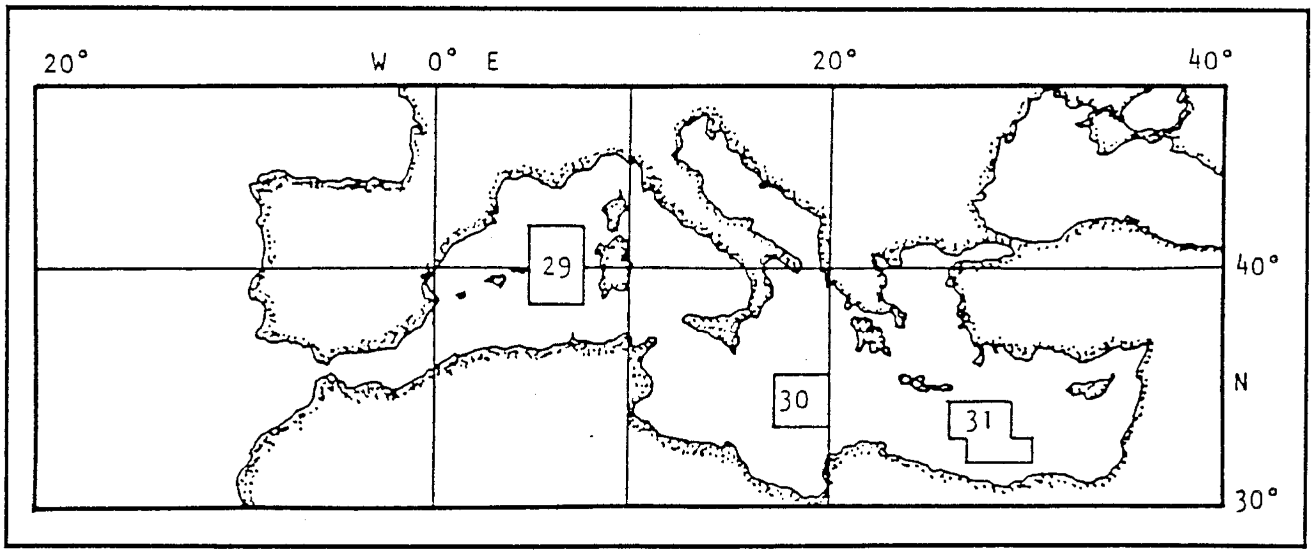


Figure 3.2.3-3. Selection of Representative Areas in the Mediterranean Sea

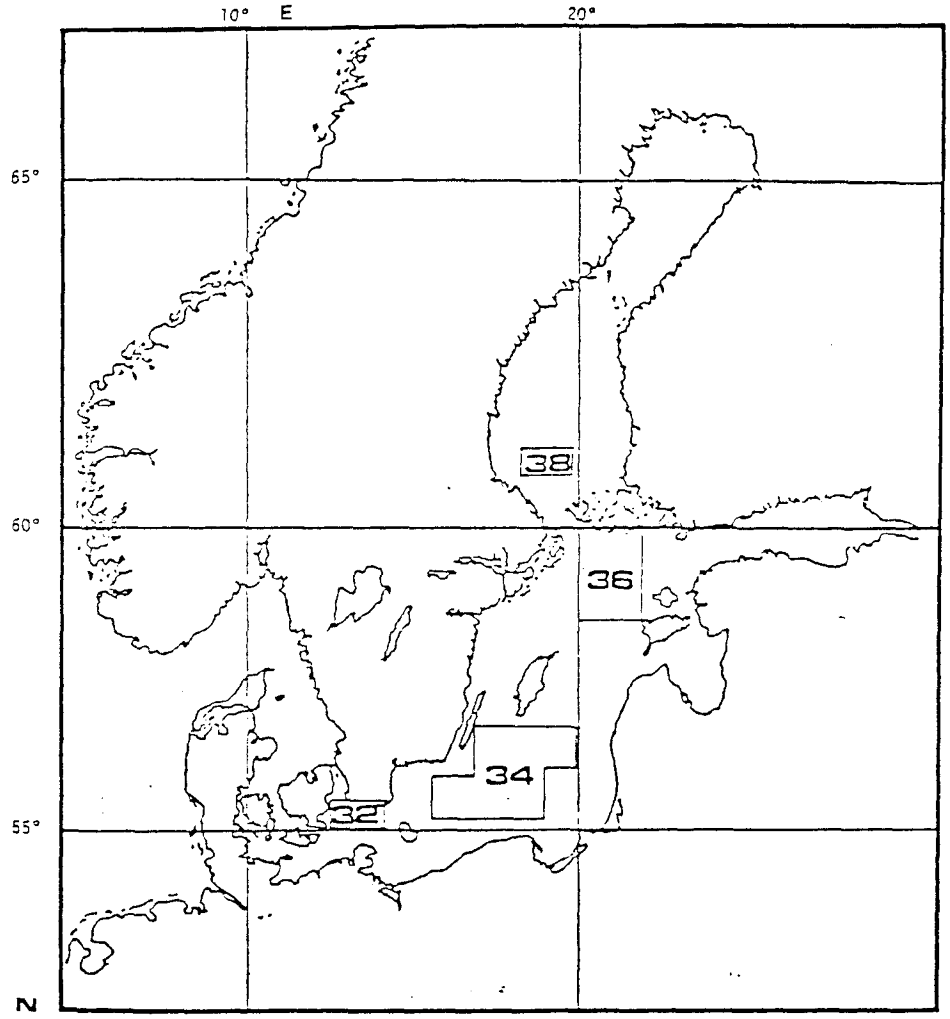


Figure 3.2.3-4. Selection of Representative Areas in the Baltic Sea (Including Gulf of Bothnia)

3.2.3.3 Wind Over the Deck

In Table 3.2.3-1, it is stipulated that the wind over the deck should not exceed 40 to 45 knots for a number of specific operations. This range of relative wind speed is lower than the ship speed in many cases so that the limit will be exceeded under many conditions of operation. This is illustrated in Figure 3.2.3-5 which plots average sustained wind speed against sea state and superimposes the effect of ship motion for a high-speed mode of operation (40^+ knots) and for a 12-knot (hull-borne) mode of operation. When the ship is traveling at 40 knots, the wind speed over the deck can only be less than 40 knots when the wind direction is well abaft the beam. In the hull-borne condition, the relative wind speed will not often be less than 40 knots in Sea States 6 and above. The "sustained wind speed" plotted in Figure 3.2.3-5 is converted to relative wind over the deck for a range of headings and forward speeds in Figure 3.2.3-6. This indicates that normal helicopter operations cannot usually be conducted in wave heights higher than 5 or 6 m. According to current U.S. Navy practice helicopter landings and take-offs are only allowed when the relative wind is forward of the beam and less than 40 or 45 knots. At these higher wind speeds the relative wind direction must be on the bow or dead ahead as the helicopter relies on the shelter provided by the superstructure and hangar. It would be unrealistic to assume, therefore, that high-speed ships could manage to operate helicopters in

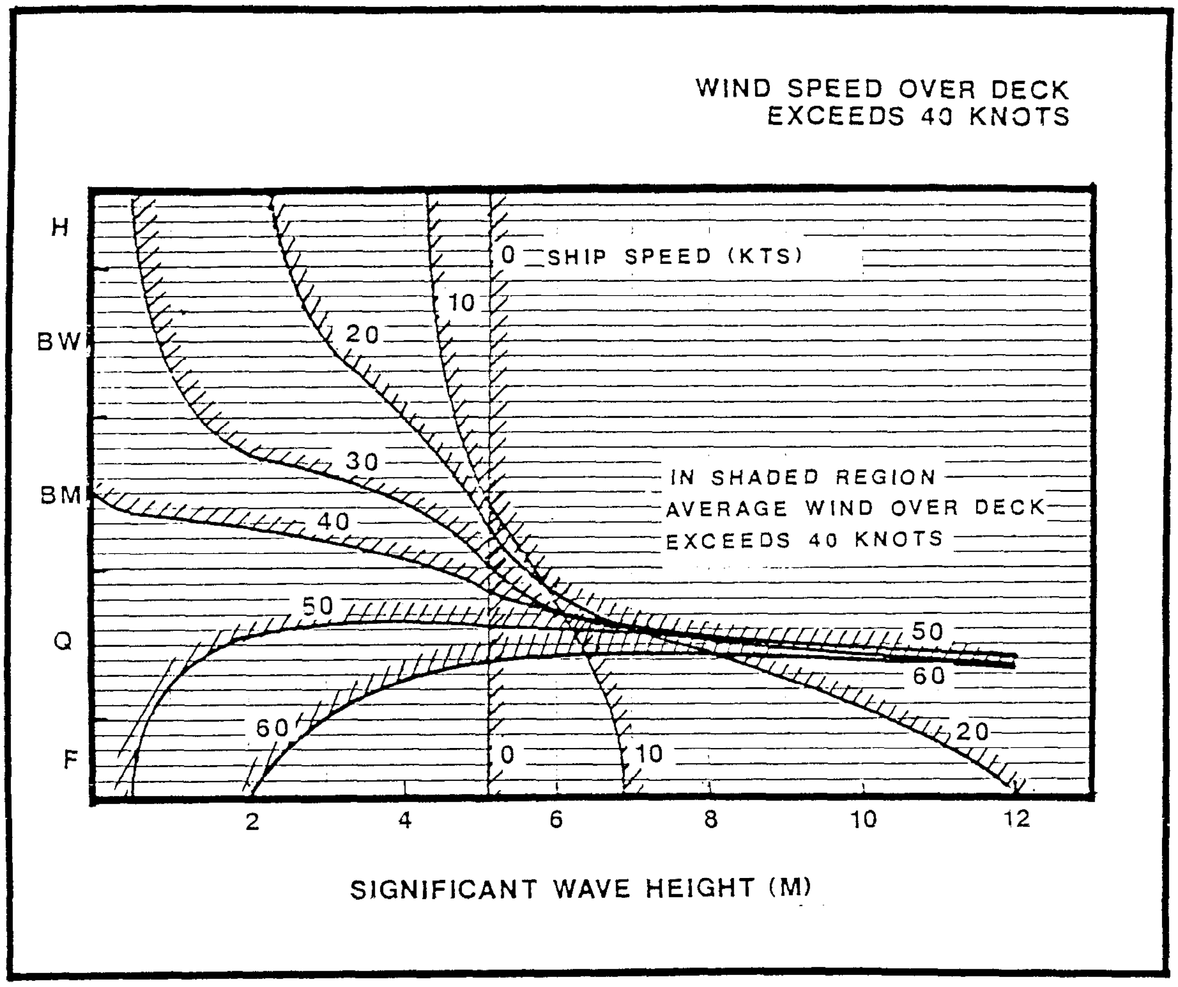


Figure 3.2.3-6. Effect of Ship Speed, Heading to Wind and Significant Wave Height on Average Relative Wind Speed

3.2.3.4 Ship Motions

Predicted motion data are plotted in Figures 3.2.3-7 to 3.2.3-22 for the NATO ANVs and, for comparison, for the FFG-7 and the NFR 90.

These data are derived from the following sources:

UK SES from Reference 6. (Figures 3.2.3-7 through 3.2.3-9)

These data were based on Hovermarine's experimental experience with the DECIDER deep-cushion manned model, extrapolated and interpolated as necessary. Significant values have been assumed to be twice rms values. All on-cushion data are assumed to have been modified by an active ride-control system which is capable of providing the following attenuation:

Angular Motions:	Vertical Accelerations:	
Pitch Amplitude 25%	GG and Stern	50%
Roll Amplitude 50%	Bow	25%

true wind speeds higher than ship speed by running close to down wind to achieve lower relative wind speeds as the direction of these relative winds would be unacceptable by current standards. Wind speeds and directions bear no fixed relationship to wave height and wave directions so this analysis can only be regarded as approximate.

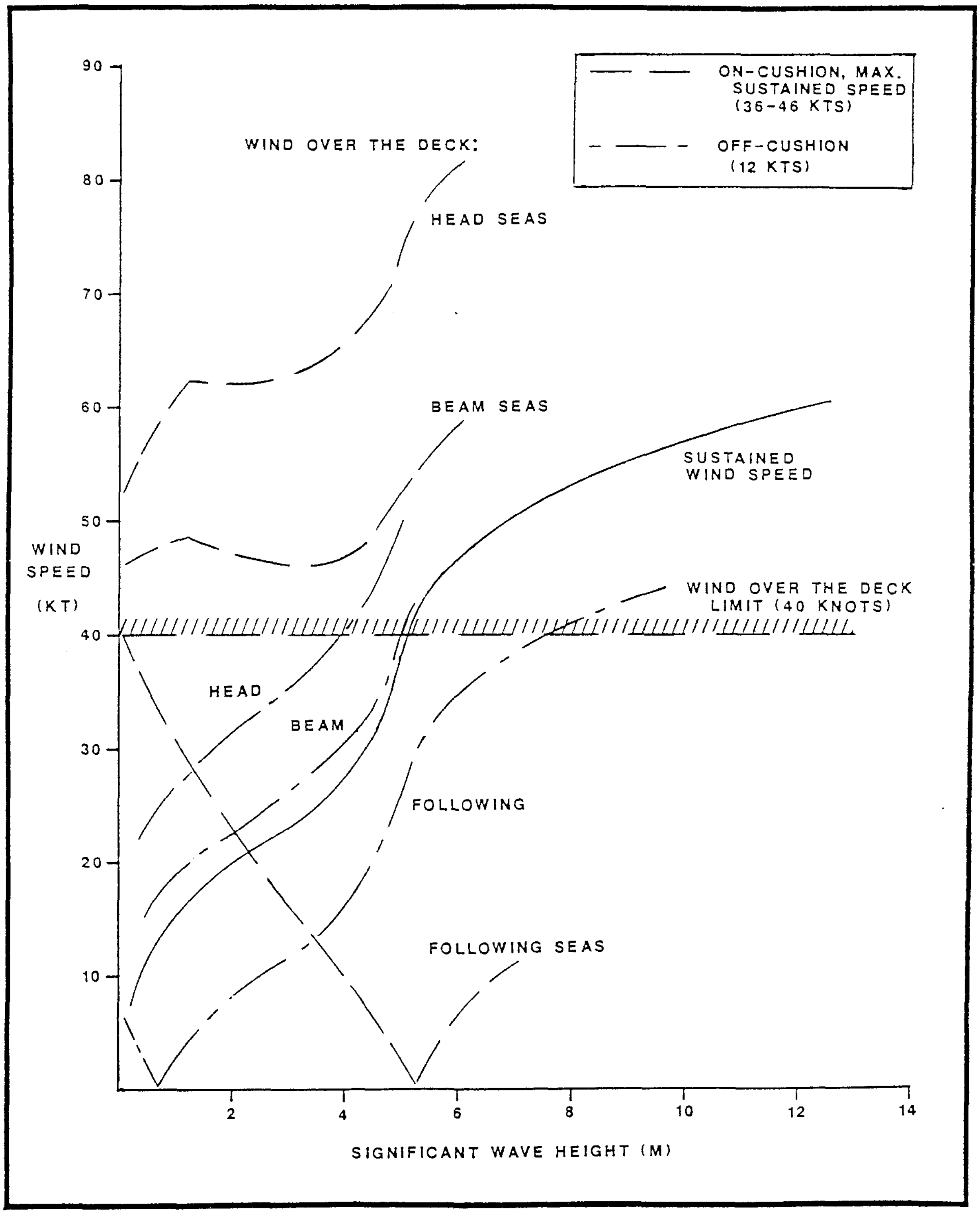


Figure 3.2.3-5. Average Relative Speed Over the Deck for an SES at Maximum Sustained Speed and at 12 Knots as a Function of Wave Height.

Compared with current experience, these attenuations seem to be ambitious, especially in high sea states. This is discussed further in Section 3.3.14 Ride Control Systems, and in Reference 6.

The UK SES data includes hullborne and cushionborne modes for a full range of speeds, sea states and headings.

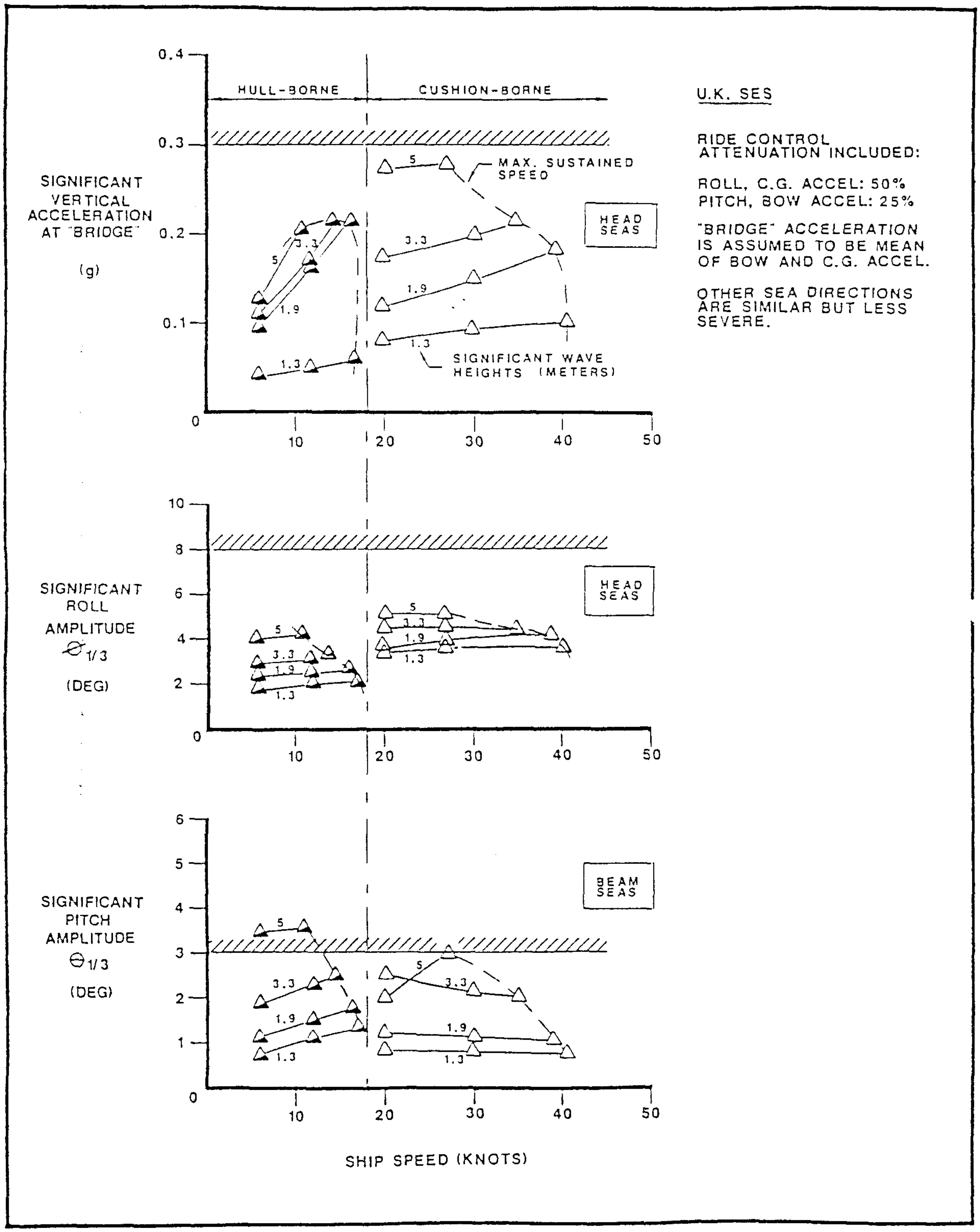


Figure 3.2.3-7. Predicted Variation of Motions and Accelerations With Sea State and Ship Speed for UK SES

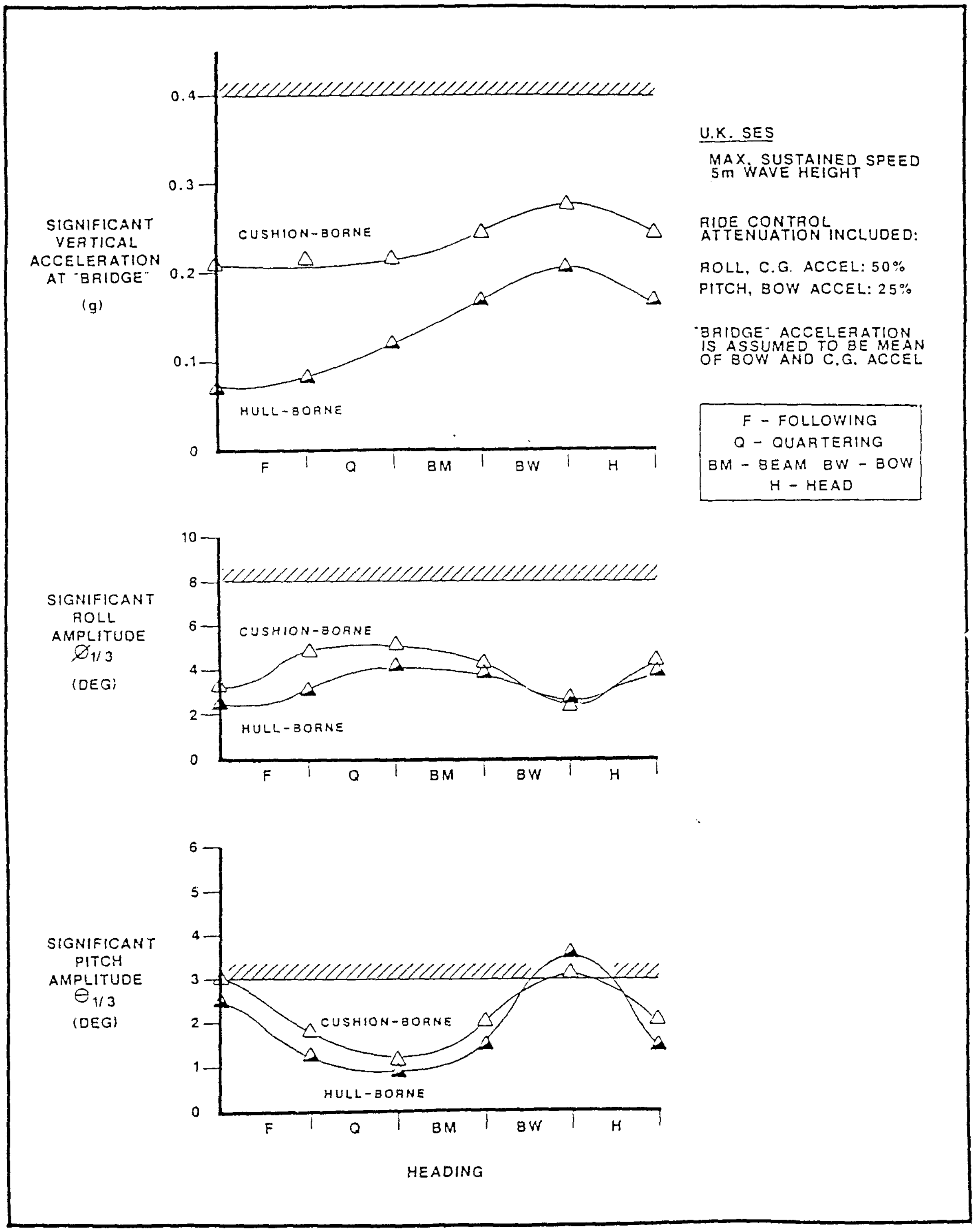


Figure 3.2.3-8. Predicted Variation in Motions and Accelerations With Heading Angle; UK SES at Maximum Sustained Speed in Waves With 5 Meter Significant Wave Height

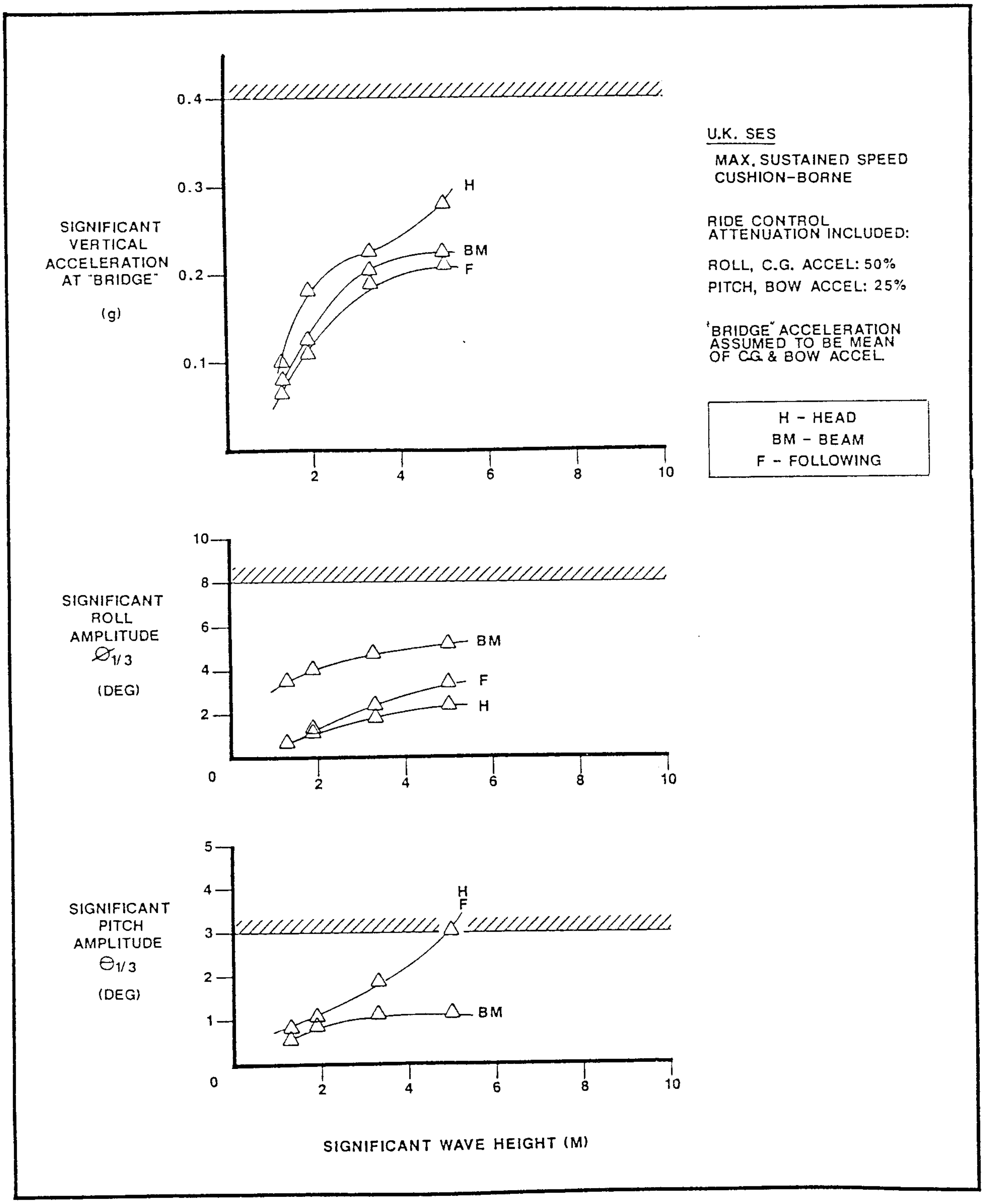


Figure 3.2.3-9. Predicted Variation of Motion and Acceleration Data With Sea State for UK SES at Maximum Sustained Speed, Cushionborne

FR SES from Reference 7. (Figure 3.2.3-10)

The predicted data is based on theoretical analyses, model and sub-scale full-scale tests.

The FR SES data includes hullborne operation at 12 knots and cushionborne operation at maximum sustained speed for a range of sea states and headings.

US/G SES from Reference 8. (Figures 3.2.3-11 through 3.2.3-14)

The US/G SES data is provided by an analytical prediction based on SES 200 experience. The data is provided for two cushionborne speeds (20 and 30 knots) in 5-meter waves for a range of headings. No cushionborne information is provided.

In Figure 3.2.3-15, some of the UK SES and US/G SES data are compared with data available from full-scale trials of the NORCAT. The NORCAT data has been scaled up to represent a 1900 LT SES at about 16-24 knots in seas of approximately 5 meters. In view of the very different sources of these three sets of data the agreement is surprisingly good. Both the UK SES and the NORCAT data are derived from open-sea tests and show much less sensitivity to heading than the US/G SES data which is derived largely from analytical results. The greater roll sensitivity of the US/G SES may be explained by its higher length-to-beam ratio.

The assumed operability limits listed in Table 3.2.3-1 are identified on each data plot. All three SES operate well within the operability limits in seas up to 5 meters except for the following cases:

- The UK SES, in spite of the attenuation assumed to be provided by the ride-control system, exceeds the 3° pitch limit in 5-meter head seas in both the hullborne and cushionborne modes of operation at maximum sustained speed.

- The US/G SES exceeds both the vertical acceleration and pitch limits in head seas, with or without an operating ride-control system. The roll limit is also exceeded in quartering seas at 20 knots.

SP SES

Reference 9 includes no seakeeping data.

US Hydrofoil from Reference 10. (Figure 3.2.3-16)

Some predicted motion and acceleration data is provided for the foilborne mode of operation for all headings and two sea states. None of the reported motions exceed the proposed operability criteria. The hydrofoil is not expected to operate foilborne in wave heights above 5 meters.

CA Hydrofoil from Reference 14.

The Canadian Hydrofoil is predicted to remain within the operability limits for 80% of the time at 40 knots. No details of the derivation of this percentage are given. A speed of 43 knots can be sustained in calm water.

SWATH from Reference 15. (Figure 3.2.3-17)

A limited amount of predicted seakeeping data is provided in the reference. Vertical accelerations are reported for a number of locations on the ship, two speeds and all headings. No motion or acceleration data are expected to exceed the operability limits at 30 knots at any heading in 5.5-meter waves, the only wave height reported (the ship has a maximum calm-water speed of 25 knots).

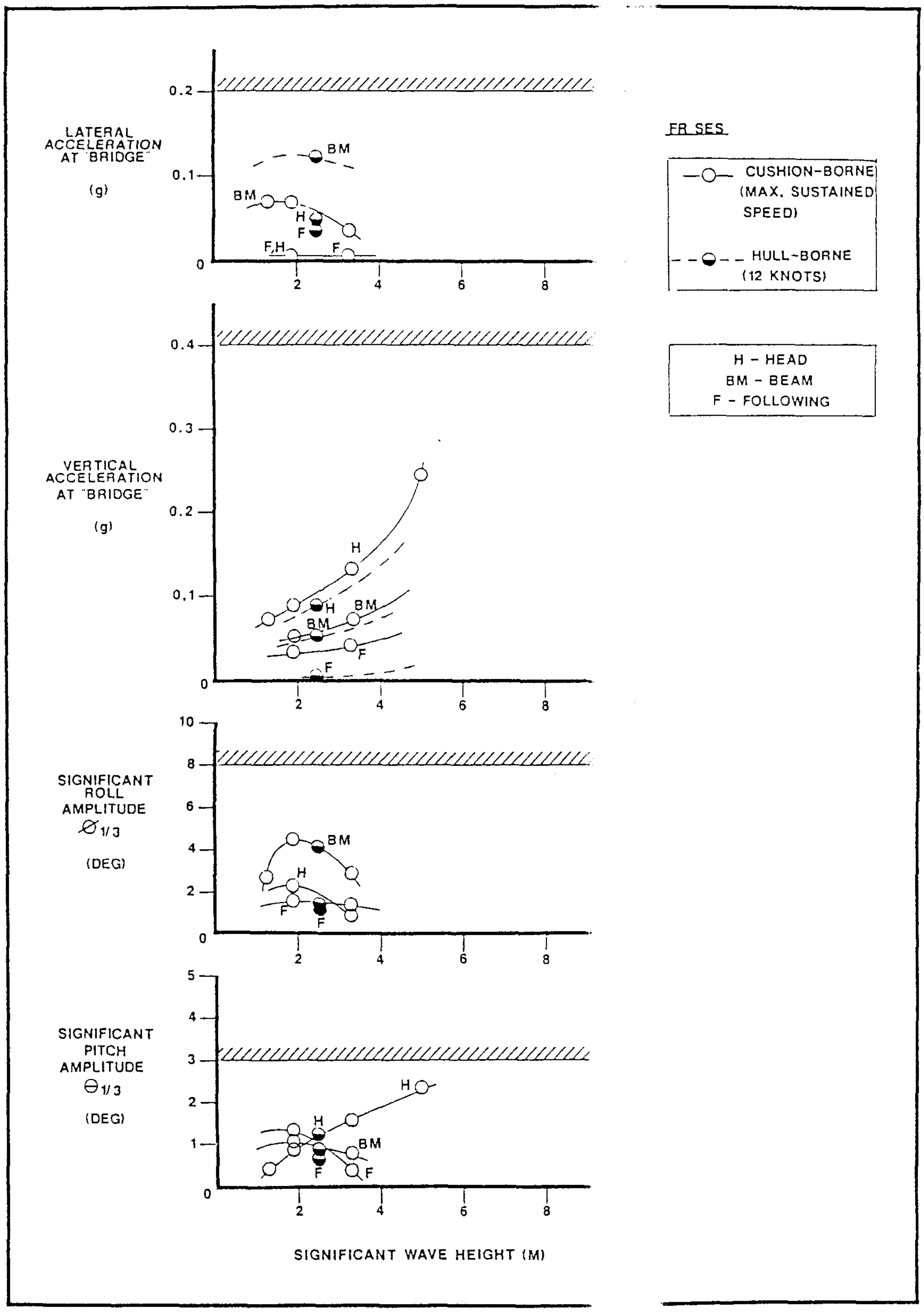


Figure 3.2.3-10. Predicted Variation of Motion and Acceleration D: Wave Heights for the FR SES and Maximum Sustained Speed

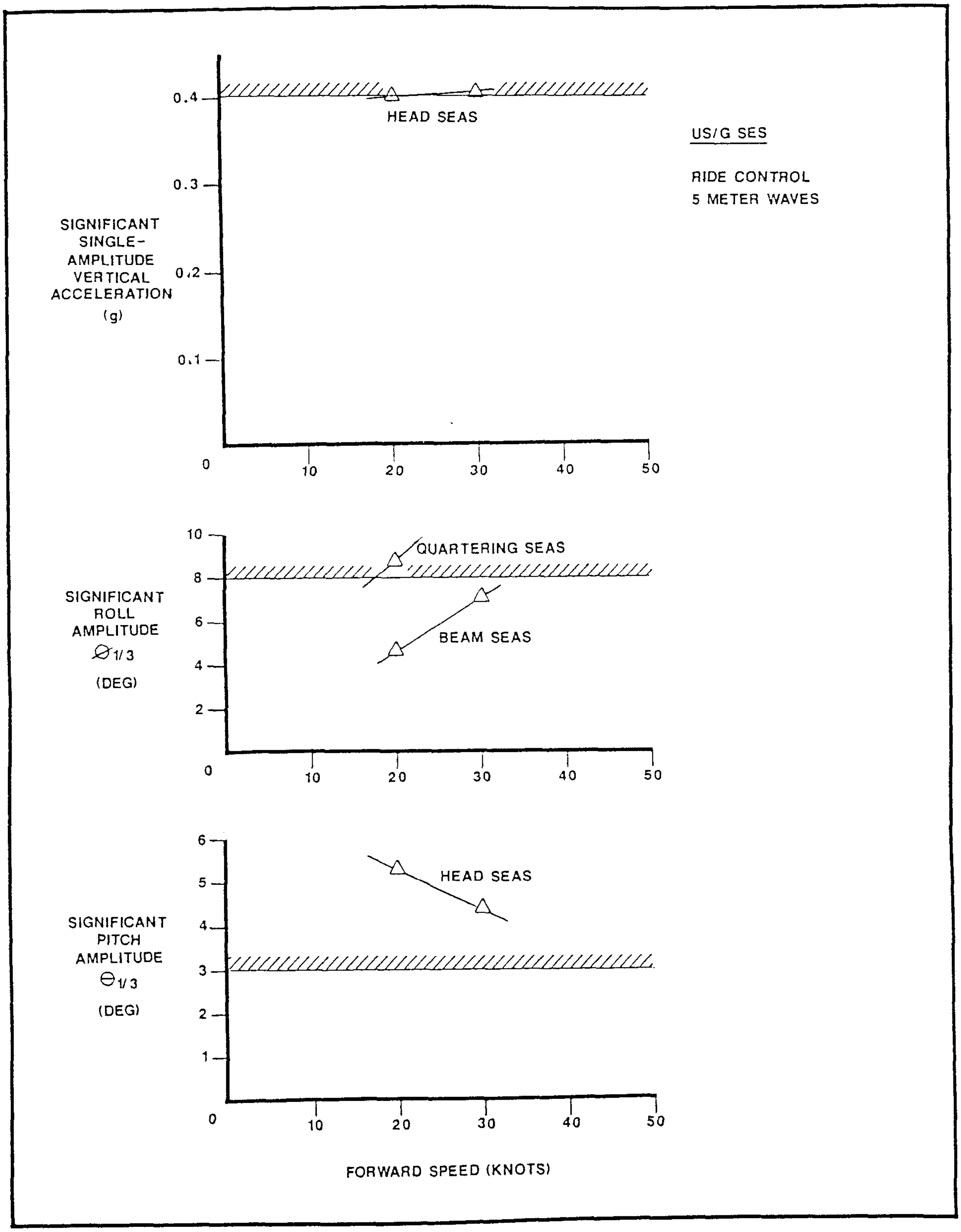


Figure 3.2.3-11. Predicted Variation of Motions and Accelerations With Forward Speed and Heading for US/G SES (With Ride Control)

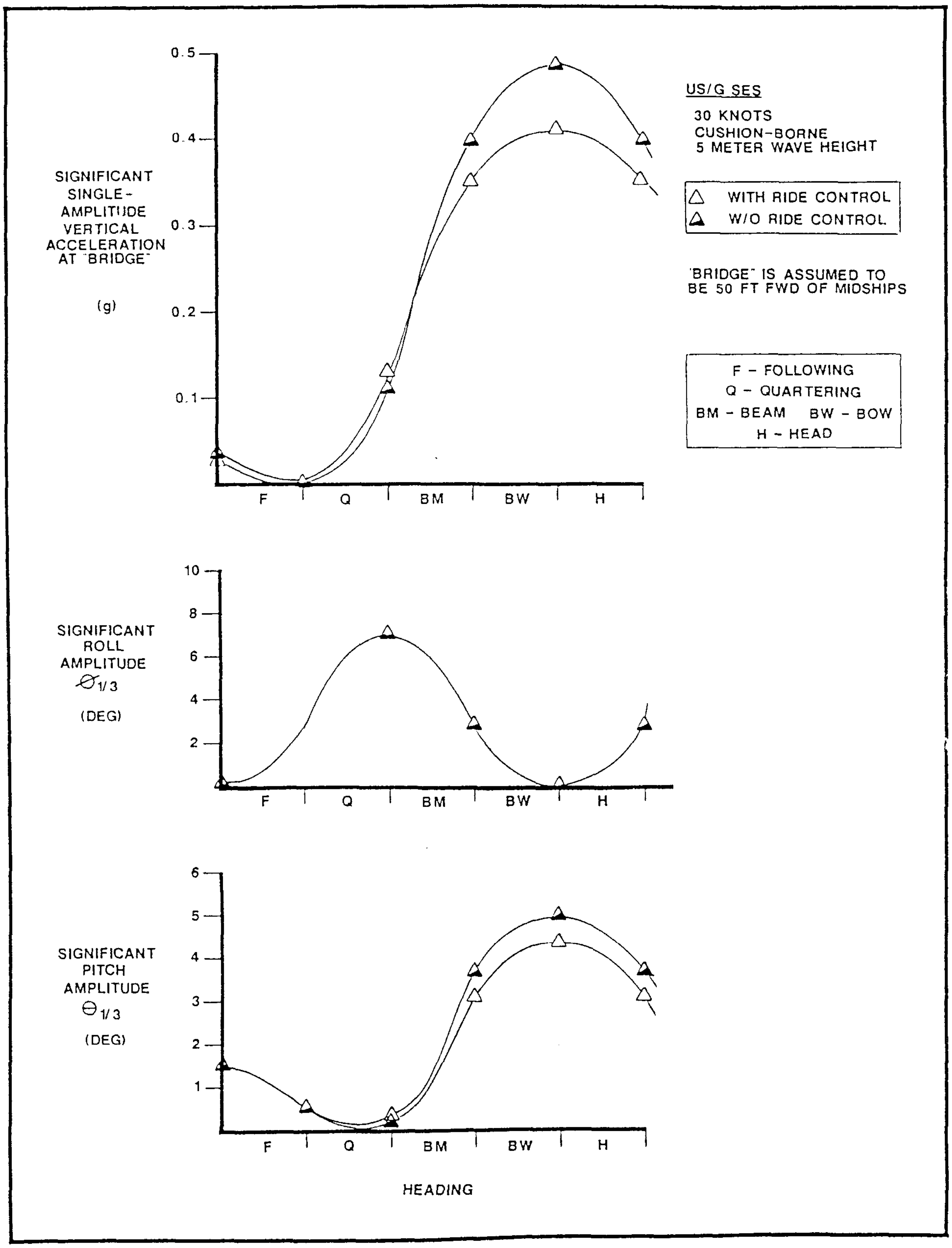


Figure 3.2.3-12. Predicted Variation of Motions and Accelerations With Heading for US/G SES at 30 Knots in 5 Meter Waves

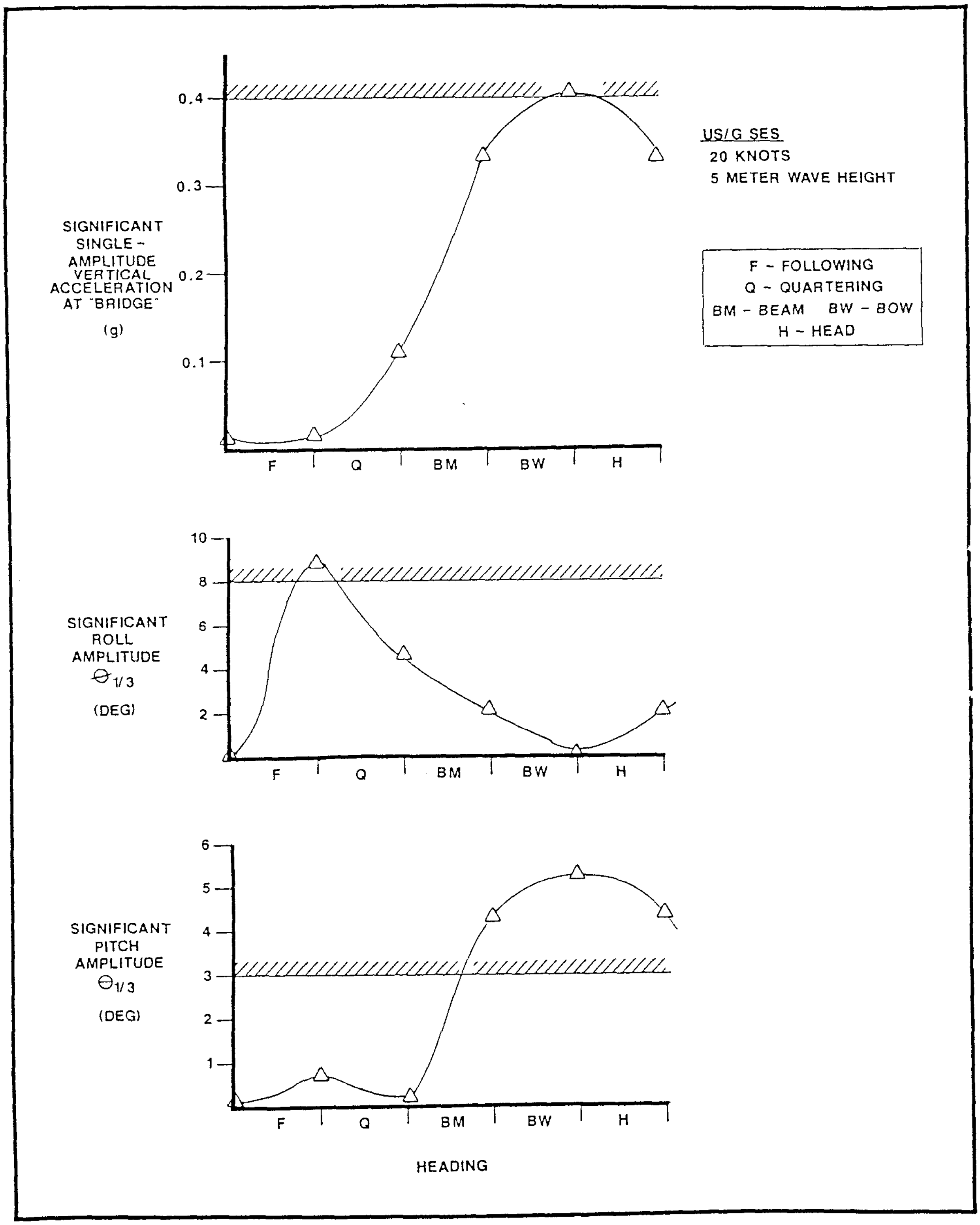


Figure 3.2.3-13. Predicted Variation of Motions and Accelerations With Heading for US/G SES at 20 Knots in 5 Meter Waves

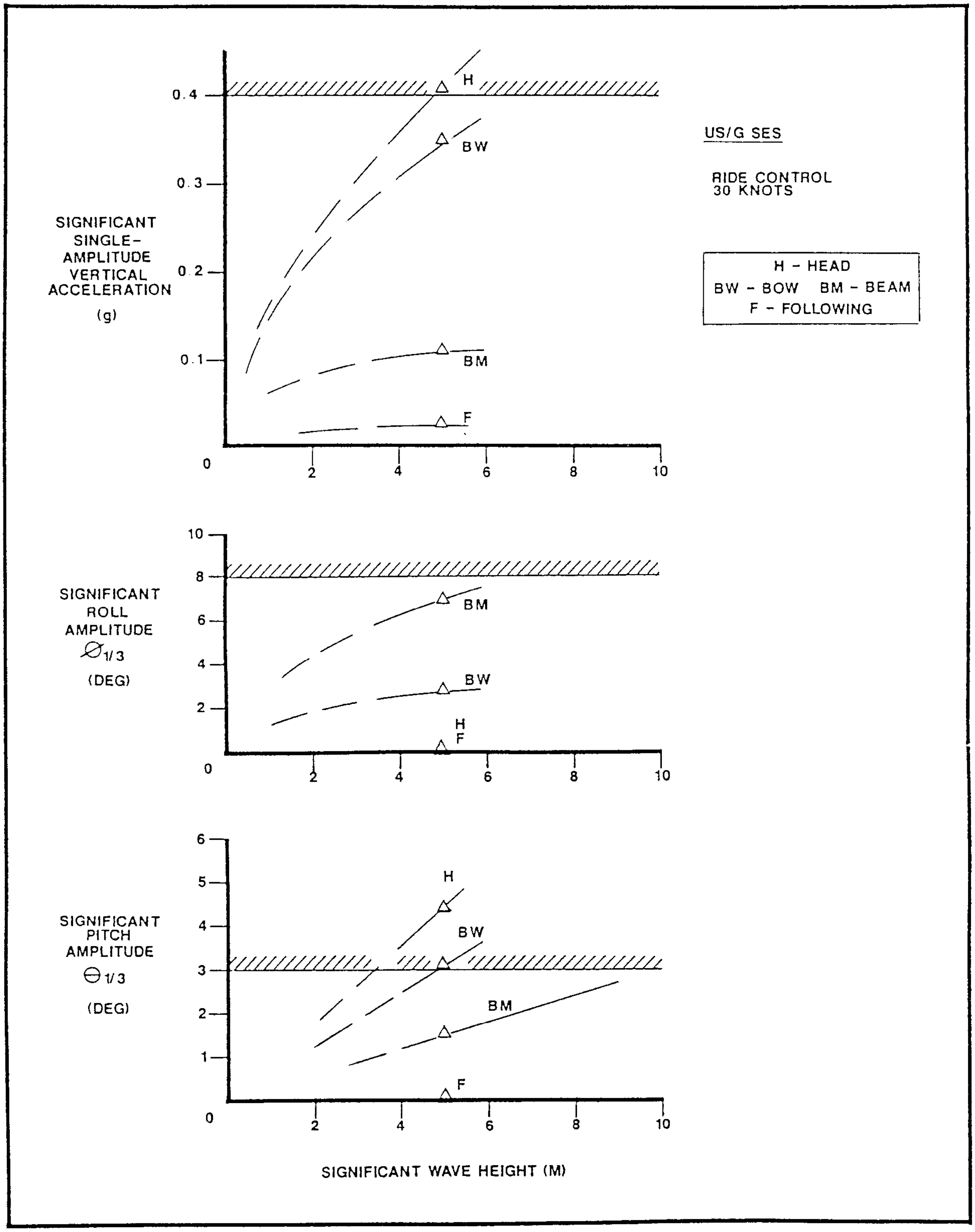


Figure 3.2.3-14. Predicted Variation of Motions and Accelerations With Significant Wave Height for US/G SES at 30 Knots

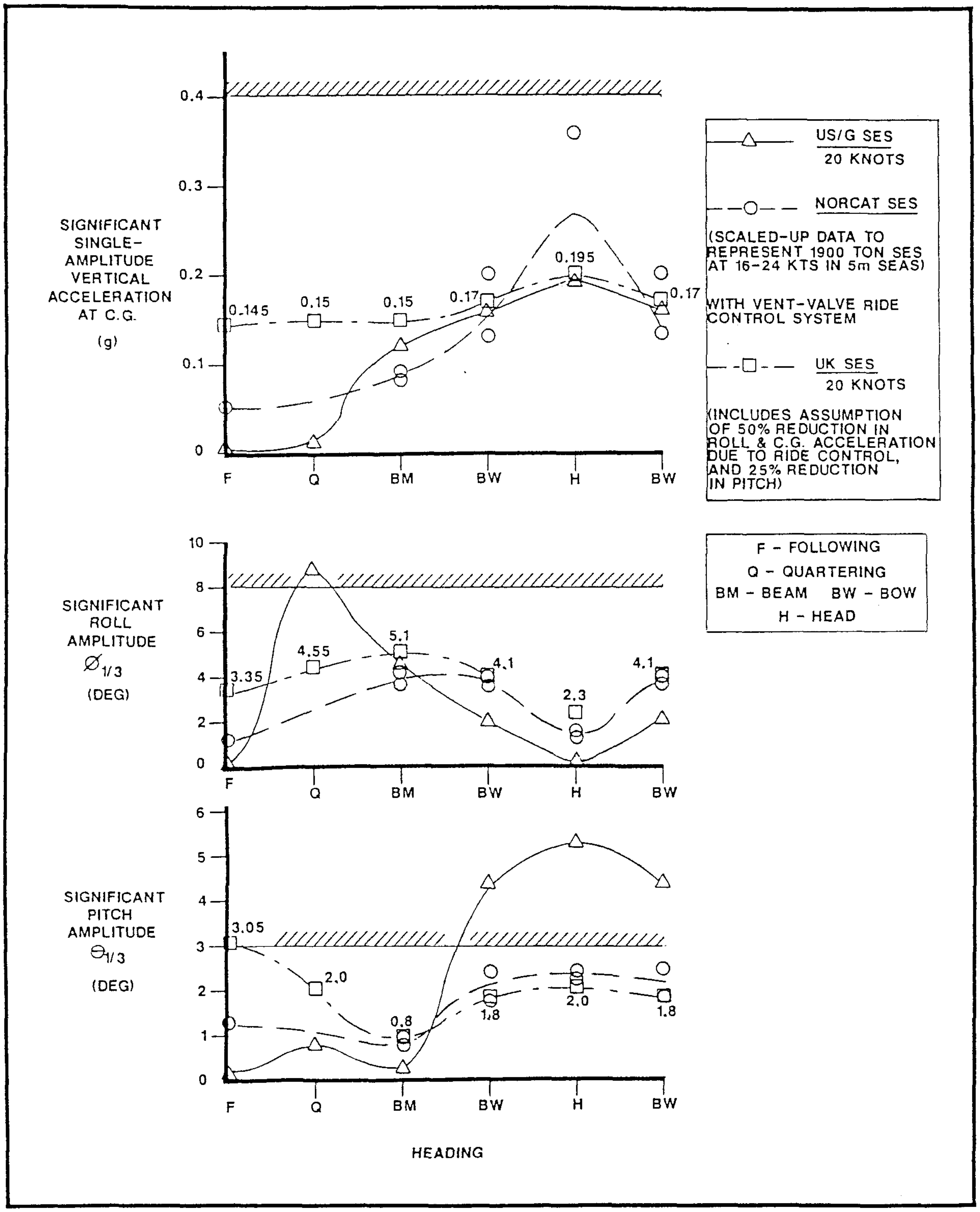


Figure 3.2.3-15. Comparison of Motions and Acceleration for UK SES, US/G SES and NORCAT

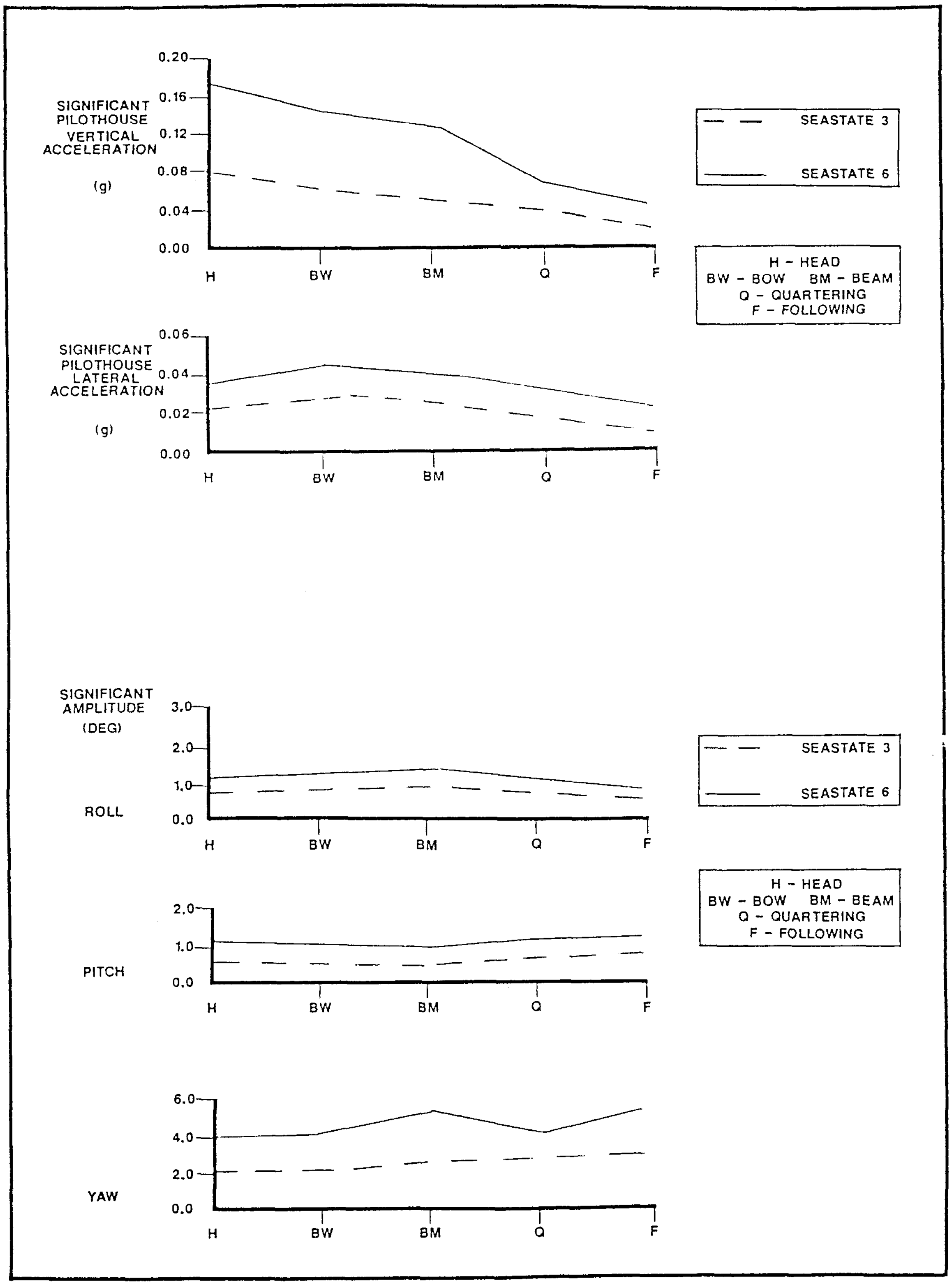


Figure 3.2.3-16. U.S. Hydrofoil Foilborne Motions and Accelerations as a Function of Heading

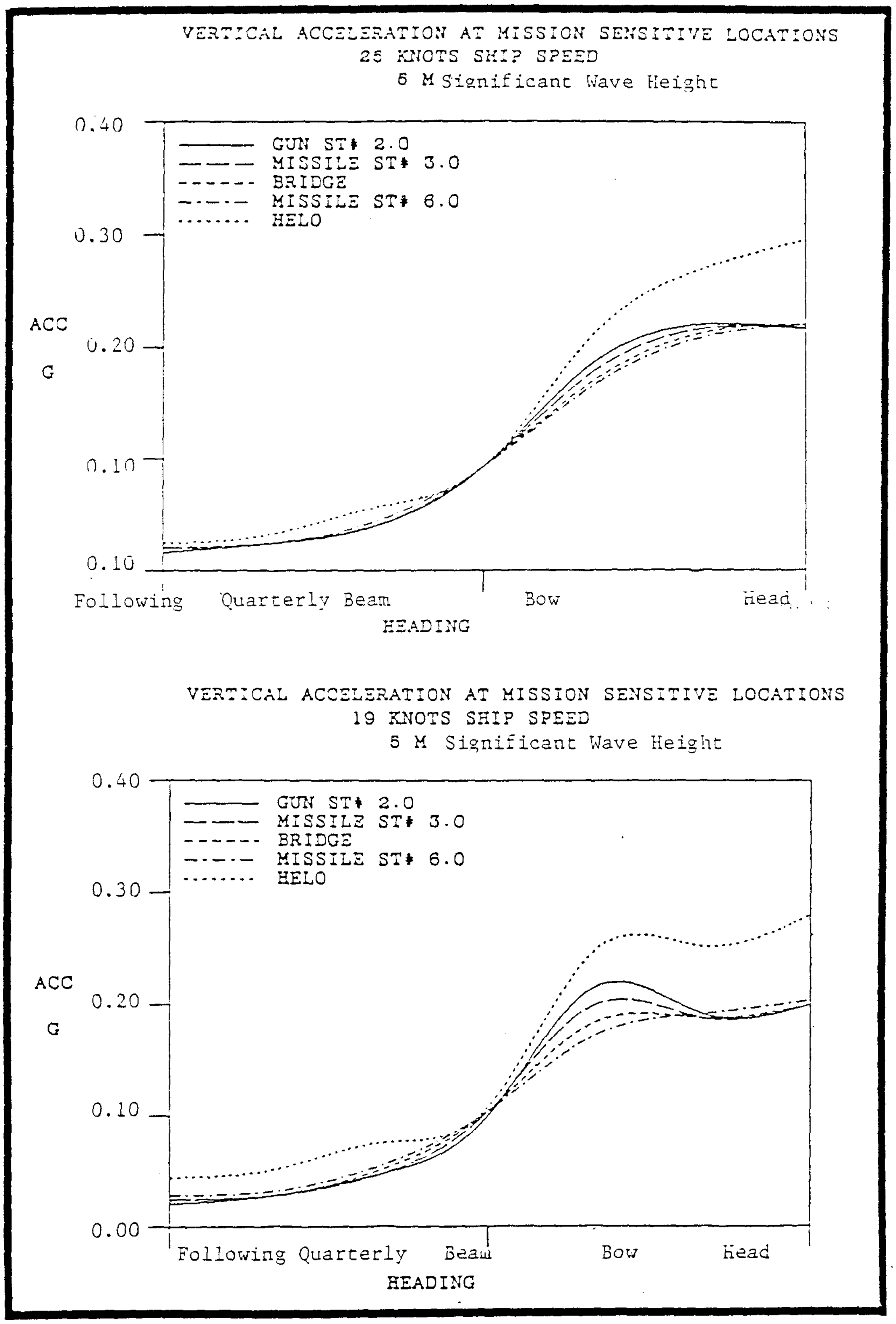


Figure 3.2.3-17. SWATH Vertical Acceleration at Worst Modal Period of Reference 15

It has been observed that the SWATH design will have a roll natural period that is approximately double the heave period. This combination may result in adverse seakeeping behavior such as hull emergence and subsequent slamming. An increase in strut thickness could be considered as a method to decouple heave and roll.

FFG 7 from References 16 and 17. (Figures 3.2.3-18 through 3.2.3-22)

A very limited amount of FFG 7 seakeeping data is contained in the references. Full-scale test results are reported for a full range of headings in 6 to 8 ft (1.8 - 2.4 m) seas at two forward speeds (10 and 25 knots).

Figures 3.2.3-18 and 3.2.3-19 show full-scale pitch and roll data from the FFG 7 and FFG 1079 running at a number of speeds and headings in a sea with significant wave heights between 2 and 3 meters. The highest pitch angles shown in the figure are not necessarily in head seas, in fact at 25 knots the FFG 7 displays the lowest pitch response in head seas. The largest roll angles, in Figure 3.2.3-19 are consistently found in beam or quartering seas.

Some of the pitch and roll data plotted in Figures 3.2.3-18 and 3.2.3-19 have been compared, in Figure 3.2.3-20, with similar data for the Italian frigate LUPO (2400T) (Reference 11), the French frigate CASM 70 (4000T) (Reference 12) and the Spanish Corvette DESCUBIERTA (1500T) (Reference 13). The data for the CASM 70 and for DESCUBIERTA are computed. Data for the other ships are from full-scale trials. The plots show the significant pitch and roll angles per meter of significant wave height.

The roll characteristics of the five ships are quite similar. All display a maximum tendency to roll when the sea is between the beam and the quarter. The FFG-7 rolls and pitches considerably more than the slightly larger FF 1079.

The three full-scale measurements of pitch behavior are quite similar but the calculated pitch values for the DESCUBIERTA and for the CASM 70 are much larger in head and following seas.

The FFG-7 data have been used to project variations of pitch, roll and vertical acceleration as functions of sea state in Figures 3.2.3-21 and 3.2.3-22. For lack of other information a linear relationship has been assumed for each parameter. Model FFG 7 data are also plotted on Figure 3.2.3-21. The model data confirms the linear trend of roll and pitch angular displacement variation with wave height but the values are very different from the full-scale trials. These differences are presumably due to the two-dimensional nature of model tank waves which will cause pitch to be exaggerated and roll to be under estimated in head and bow seas. The full-scale data was used in the subsequent analysis. From this rather limited data on the FFG 7 it appears that it will roll more than 8^{o} in 5-meter seas at all headings except head seas at 25 knots. This situation is similar, but a little less severe, when speed is reduced to 10 knots.

NFR 90 from Reference 23.

The reference provides predicted seakeeping data for the NFR 90 in sea state 6 at a range of speeds and headings.

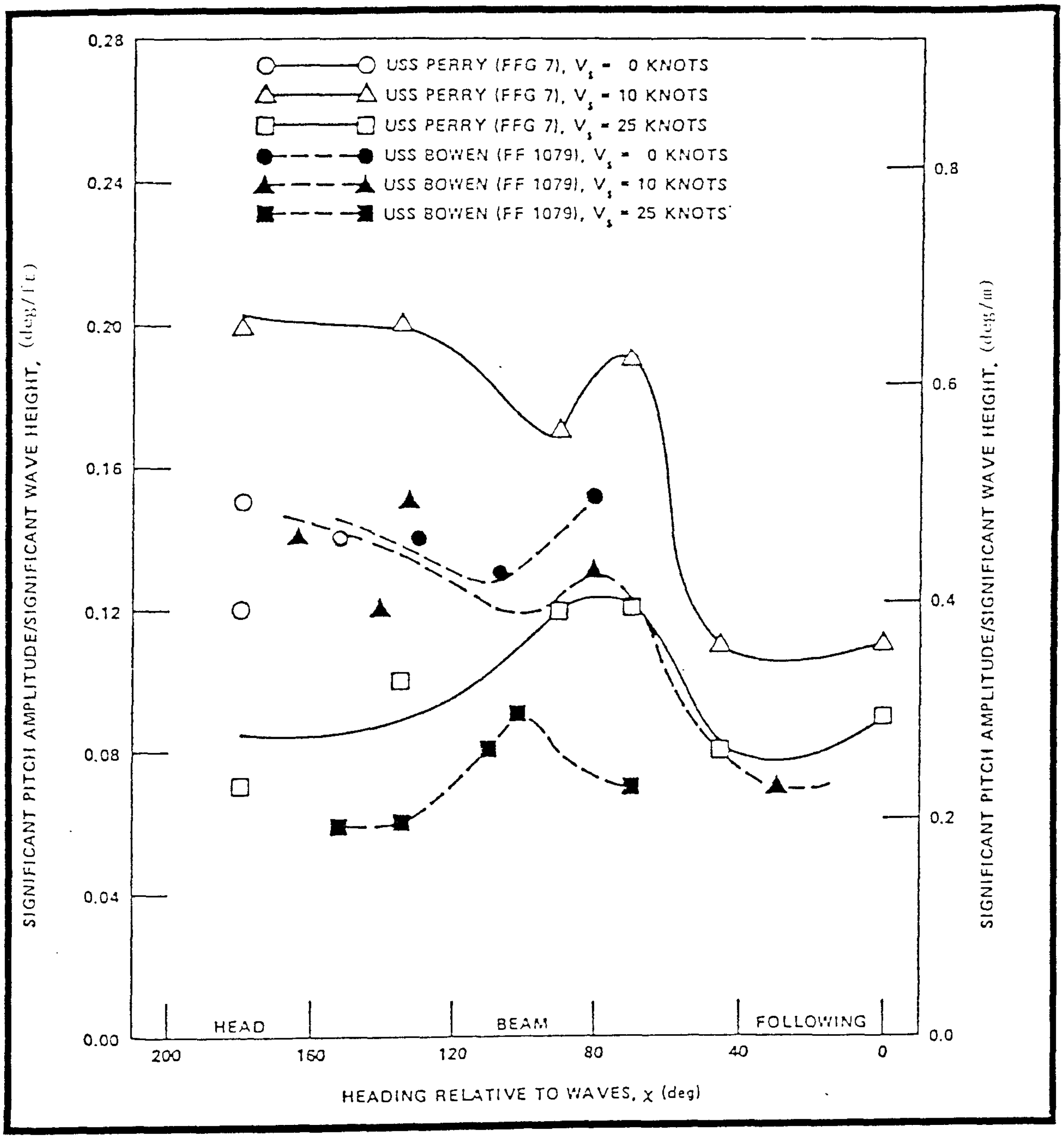


Figure 3.2.3-18. Significant Pitch Amplitude Per Unit Significant Wave Height Versus Heading Relative to Waves from the Trials Conducted on the USS PERRY (FFG-7) and the USS BOWEN (FF 1079) at Ship Speeds of 0, 10 and 25 Knots (Reference 17)

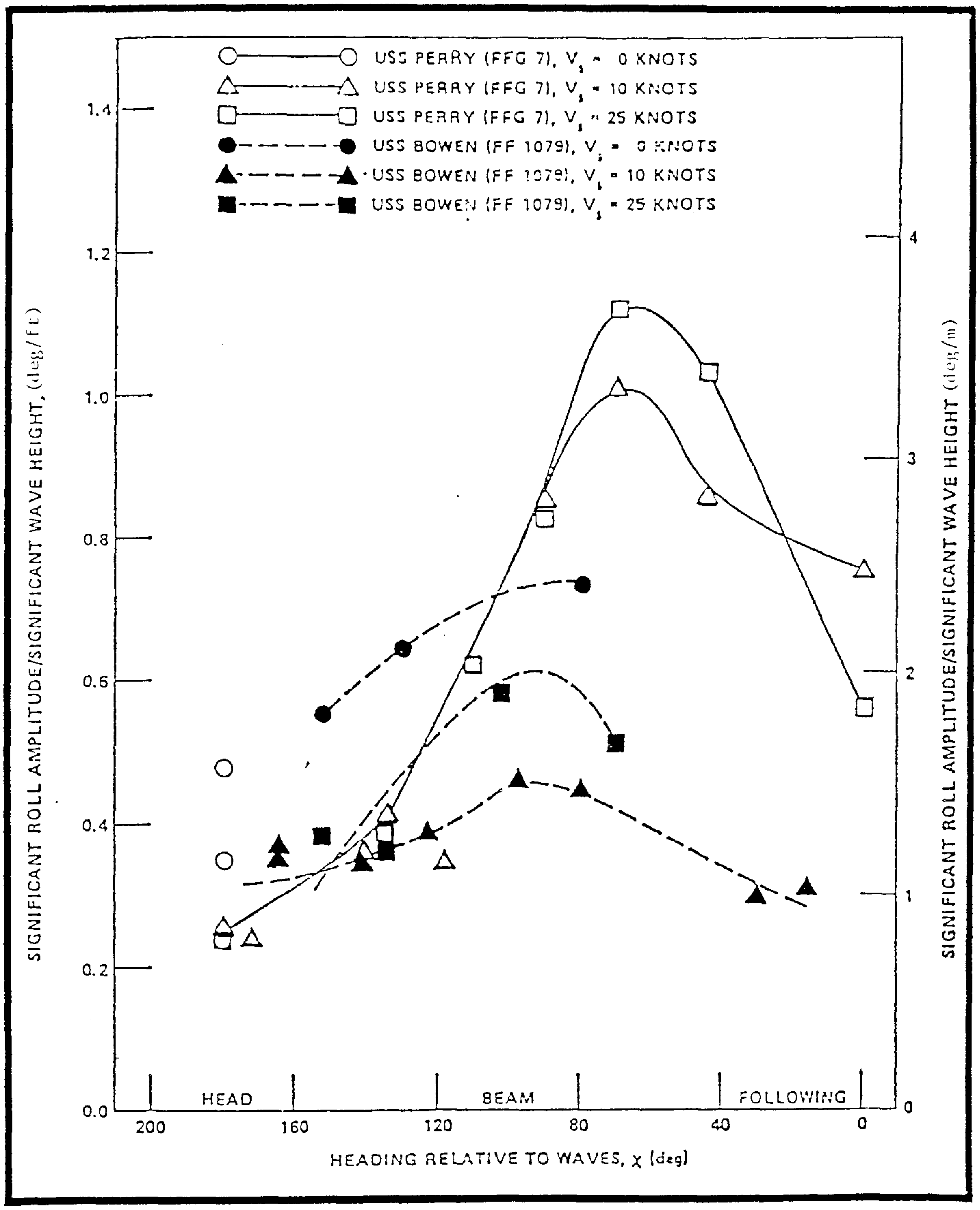


Figure 3.2.3-19. Significant Roll Amplitude Per Unit Significant Wave Height Versus Heading Relative to Waves from the Trials Conducted on the USS PERRY (FFG-7) and the USS BOWEN (FF 1079) at Ship Speeds of 0, 10 and 25 Knots (Reference 17)

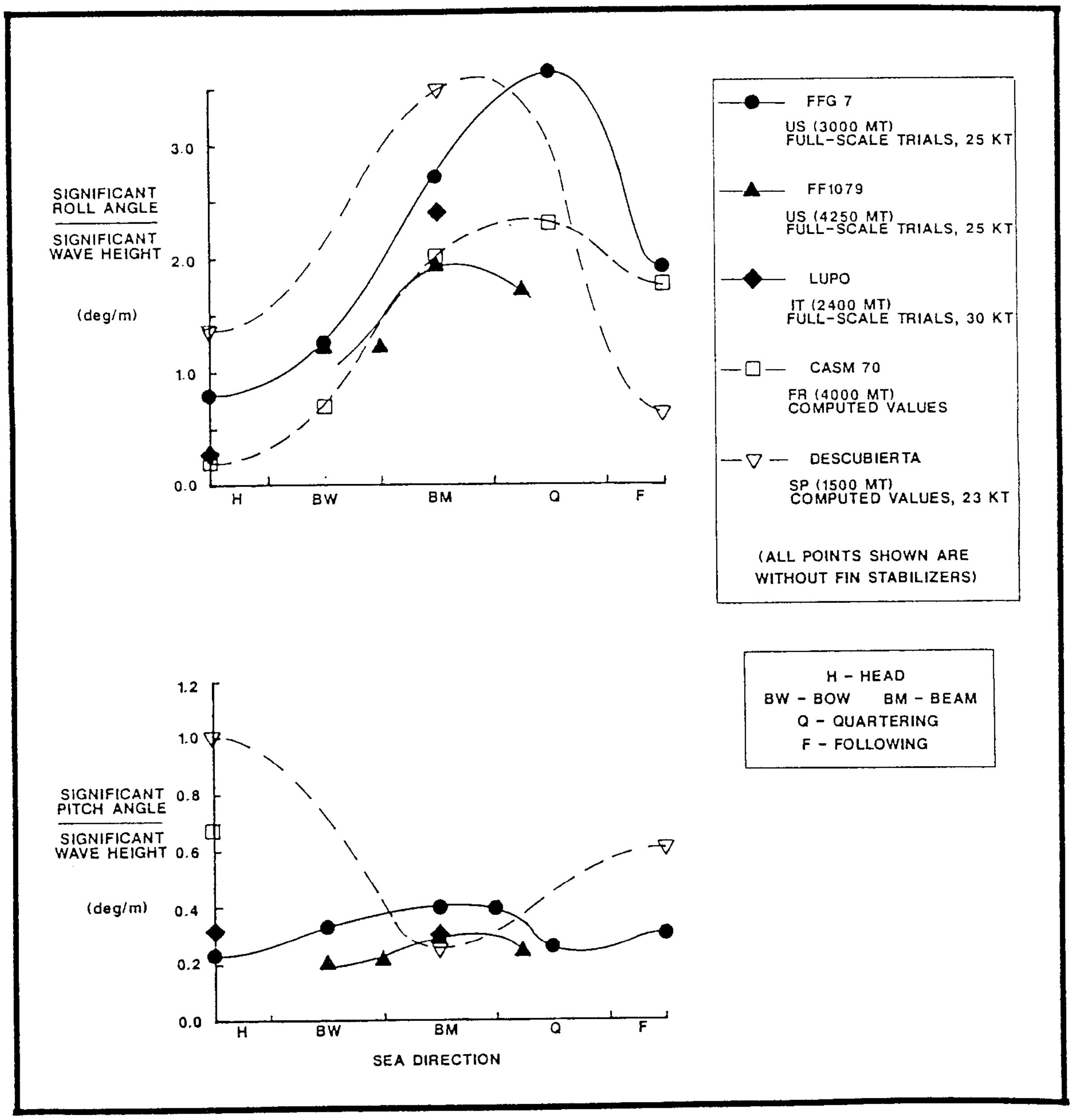


Figure 3.2.3-20. Comparison of Monohull Frigate Seakeeping Data

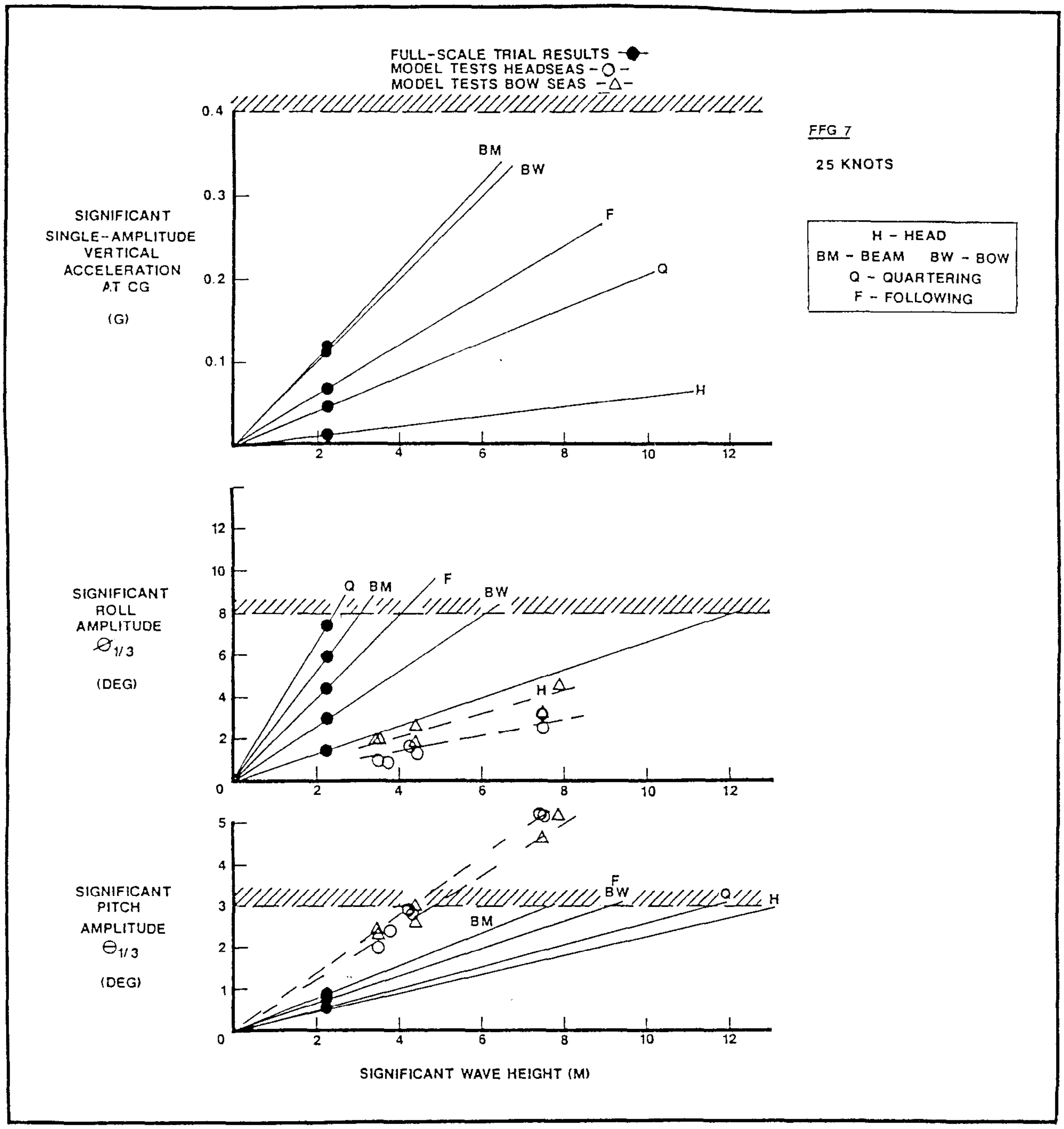


Figure 3.2.3-21. Predicted Variation of Motions and Accelerations With Significant Wave Height for FFG-7 at 25 Knots

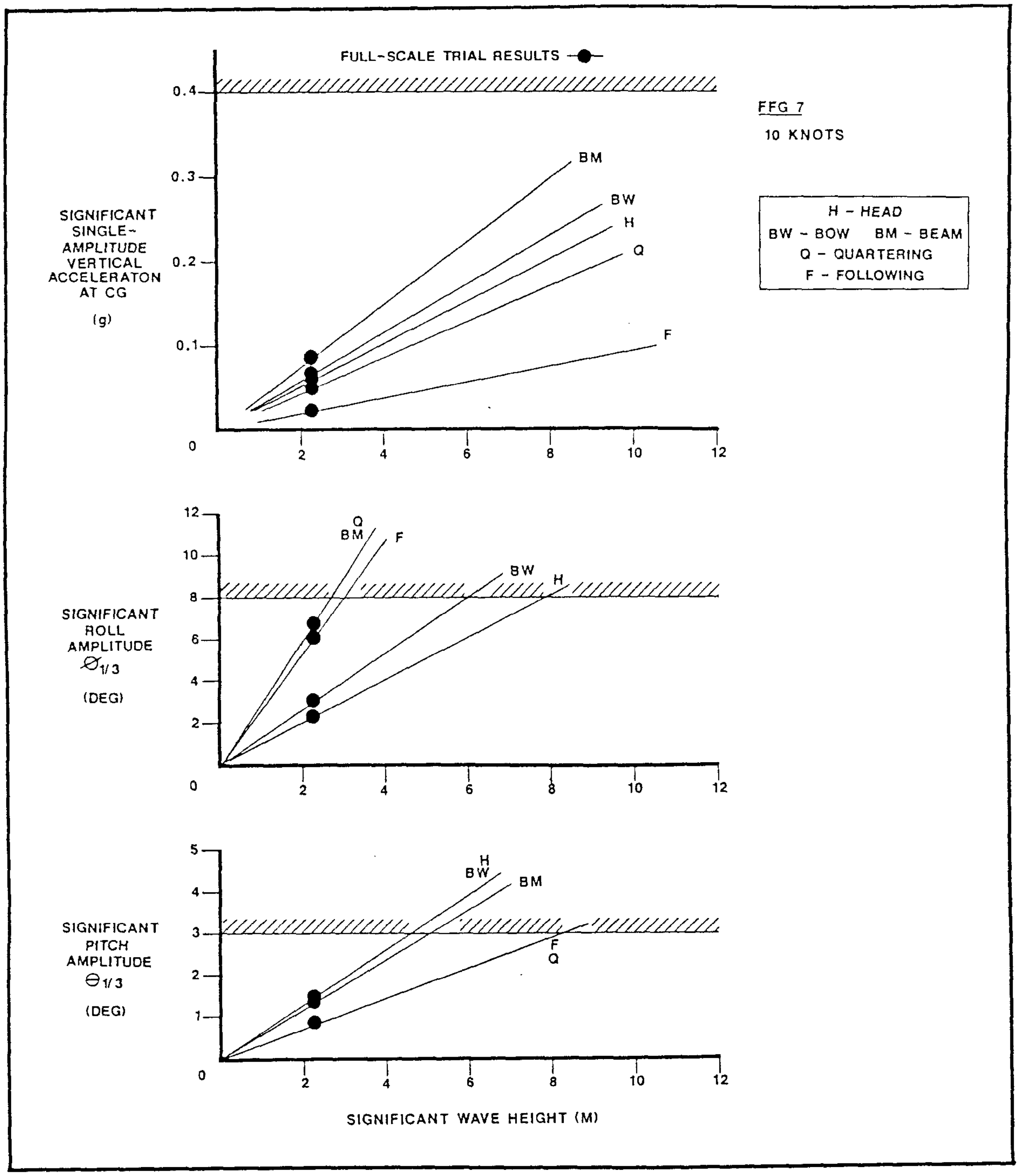


Figure 3.2.3-22. Predicted Variation of Motions and Accelerations With Significant Wave Height for FFG-7 at 10 Knots

3.2.3.5 Operability Limits

In Figures 3.2.3-23 through 3.2.3-31 an attempt is made to establish ranges within which the ships can and cannot operate in an unrestricted fashion at their maximum sustained speeds.

Where applicable, this information is provided for cushion- or foil-borne modes and for hull-borne modes. For the UK SES represented in Figure 3.2.3-23, for example, the upper diagram represents operation at maximum sustained cushion-borne speed. The figure represents the full range of headings plotted against significant wave height. The windspeed over the deck is a limitation, as mentioned in Section 3.2.3-3, at all headings except following and quartering seas. A pitch limitation is also plotted for head and following seas. A vertical acceleration limit is also plotted but is not critical in this case. In the lower figure the hull-borne mode of operation is represented. In this case the pitch is again the limiting factor and the wind-over-the-deck limit takes on a different form.

For the US Hydrofoil (Figure 3.2.3-26) the first limit reached is the foil broaching limit which is expected to occur at a significant wave height of about 6 meters. In any case, windspeed over the deck will not be so restricting to the Hydrofoils as they are not equipped with helicopters.

The limited data for the NFR 90 in Reference 23 is represented by Figures 3.2.3-31A, B and C. The variation of behavior with ship speed is not addressed for the other ships.

3.2.3.6 Operability Contours

Figure 3.2.3-32 shows, for a typical ANV, the most critical operability limits from Figures such as 3.2.3-23 through 3.2.3-31. Also included in these figures are the percentages of time (p_{oh}) that each ship can operate without restriction within each range (h) of significant wave height. It is assumed that all headings to the waves are equally likely to occur so that the percentage values quoted for each range of wave heights represent the proportion of that area of the figure that is free of limitations.

At the bottom of each of the three figures, the probability of occurrence (p_{wh}) of each wave height range is quoted for average annual North Atlantic conditions.

The total proportion of time, P_t, in a year in which the ship can operate in an unrestricted manner is given by:

$$P_t = \sum_{h=o}^{h=16} (p_{oh} \cdot p_{wh})$$

It is unnecessary to continue the summation beyond a significant wave height of 16 meters as no wave heights above this value are reported in Reference 5.

It was further assumed that helicopter operations would not be conducted in wind speeds higher than 45 knots which correspond approximately to significant wave heights of 6 meters. This assumption is based on the fact that the NATO limits for helicopter operations on frigate-sized ships do not allow fleet helicopter operations in relative winds that exceed 45 knots and that this figure is used only for relative wind directions from ahead or on the bow. With the wind coming from this direction the helicopter is, to some extent, sheltered by the hangar and the superstructure as it touches down. The percentage of time that a helicopter is assumed to be able to operate, therefore, is given by:

$$P_{t_h} = \sum_{h=0}^{h=6} (P_{o_h} \cdot P_{wh})$$

The probability of occurrence of various wave heights for twenty-one regions of interest to NATO operations are quoted in Reference 5. In most cases the information is provided for four seasons (winter, spring, summer and fall) and for an annual average. The total operating probability for each of the ships was computed for the annual average and for each of the four seasons in each of the twenty-one areas.

The results of these computations have been converted to contour plots in Figures 3.2.3-33 through 3.2.3-56. All except for the last four of these figures ignore the relative wind limitation so that they may be considered as defining ship operability capabilities but not helicopter operability capabilities.

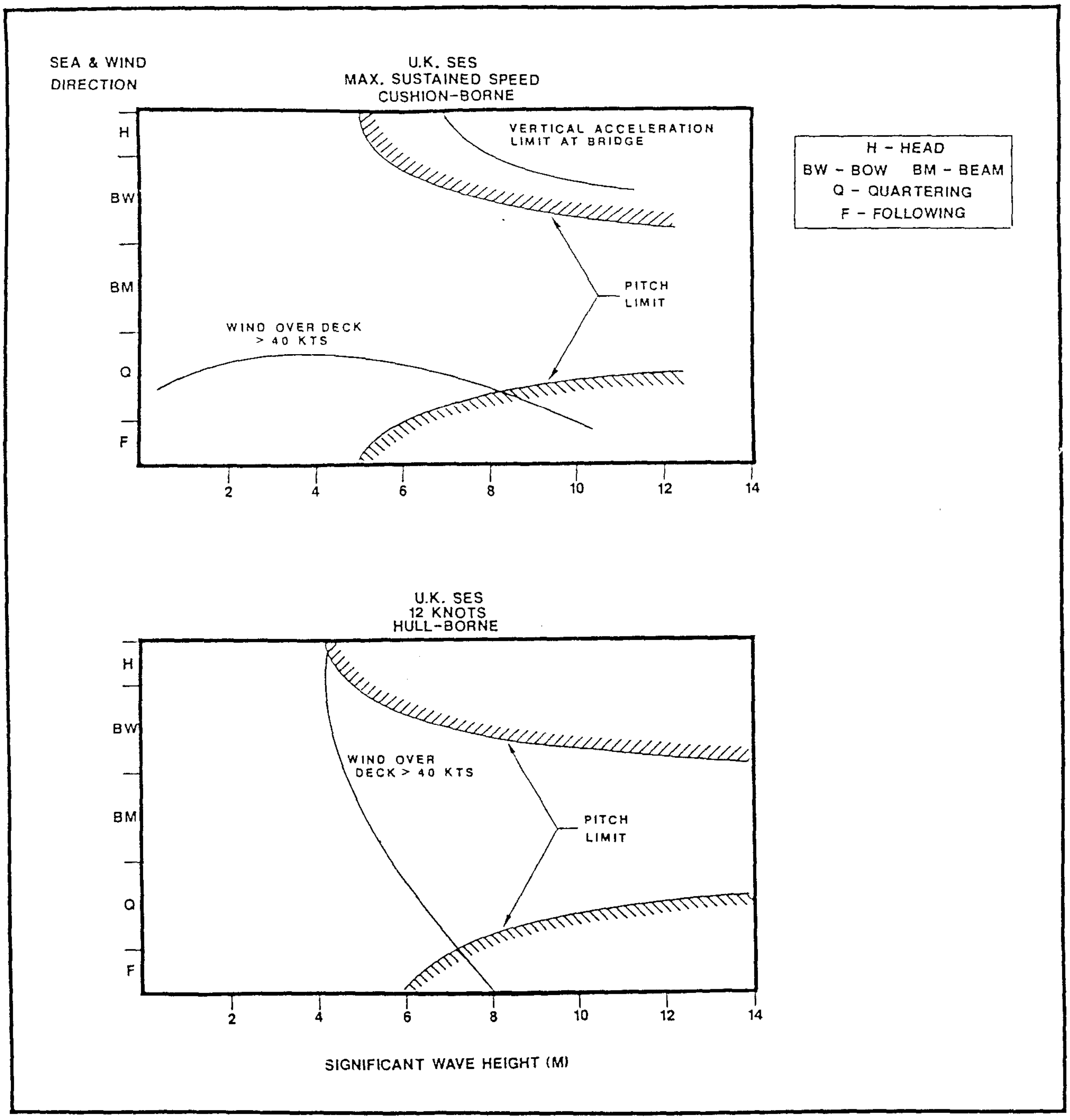


Figure 3.2.3-23. UK SES Seakeeping Limits - Effect of Wave Height and Heading

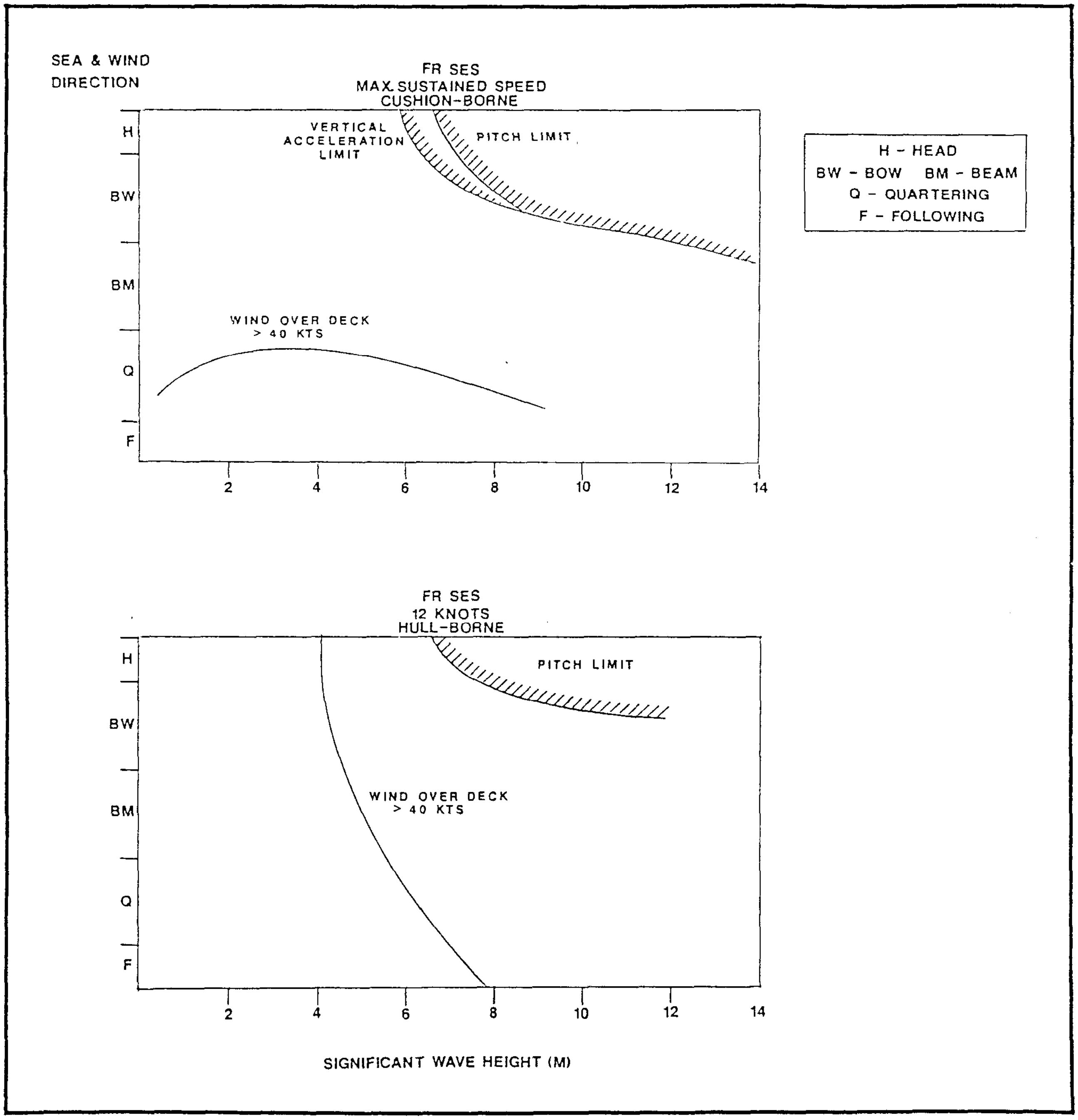


Figure 3.2.3-24. FR SES Seakeeping Limits - Effect of Wave Height and Heading

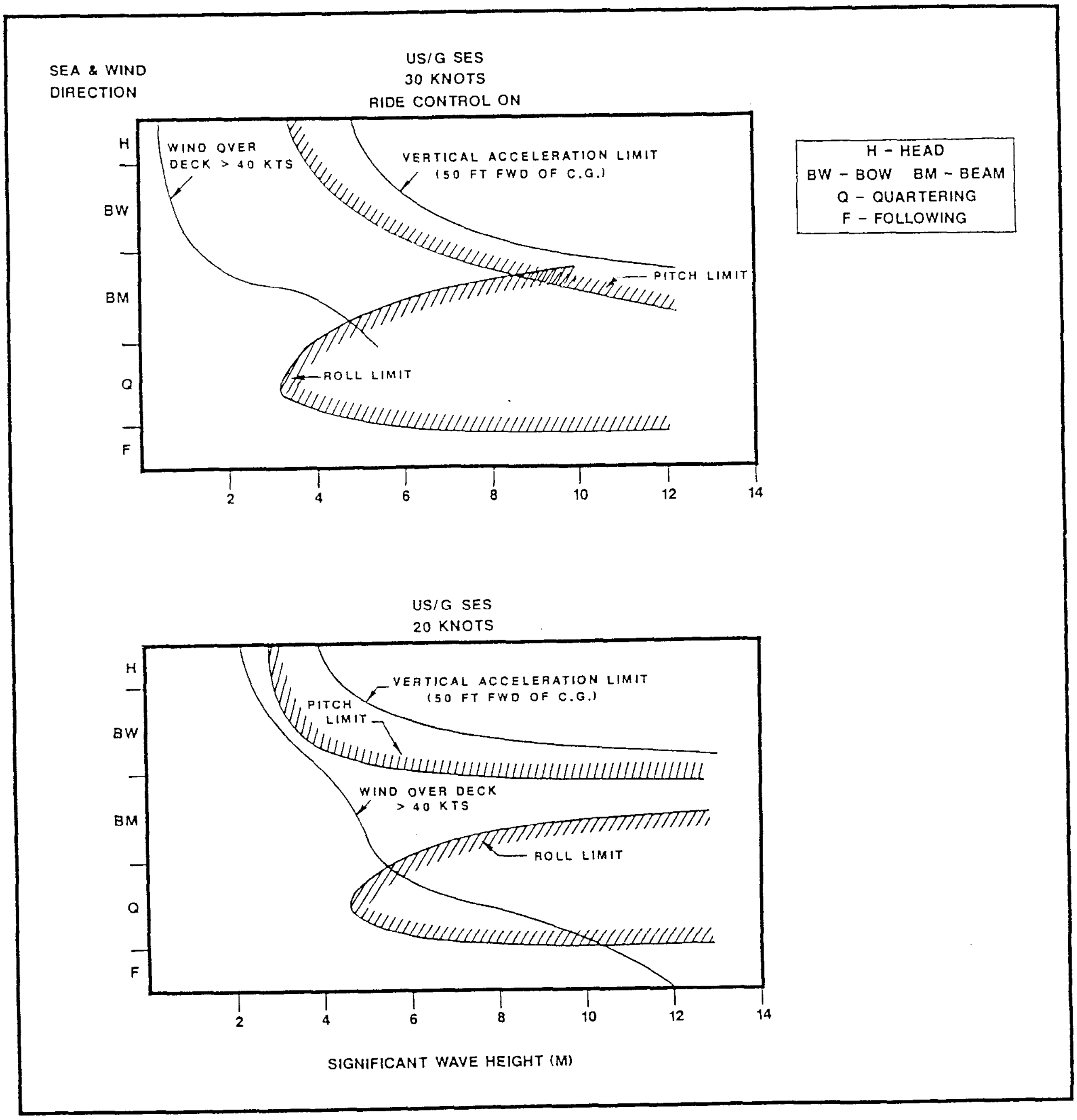


Figure 3.2.3-25. US/G Seakeeping Limits - Effect of Wave Height and Heading

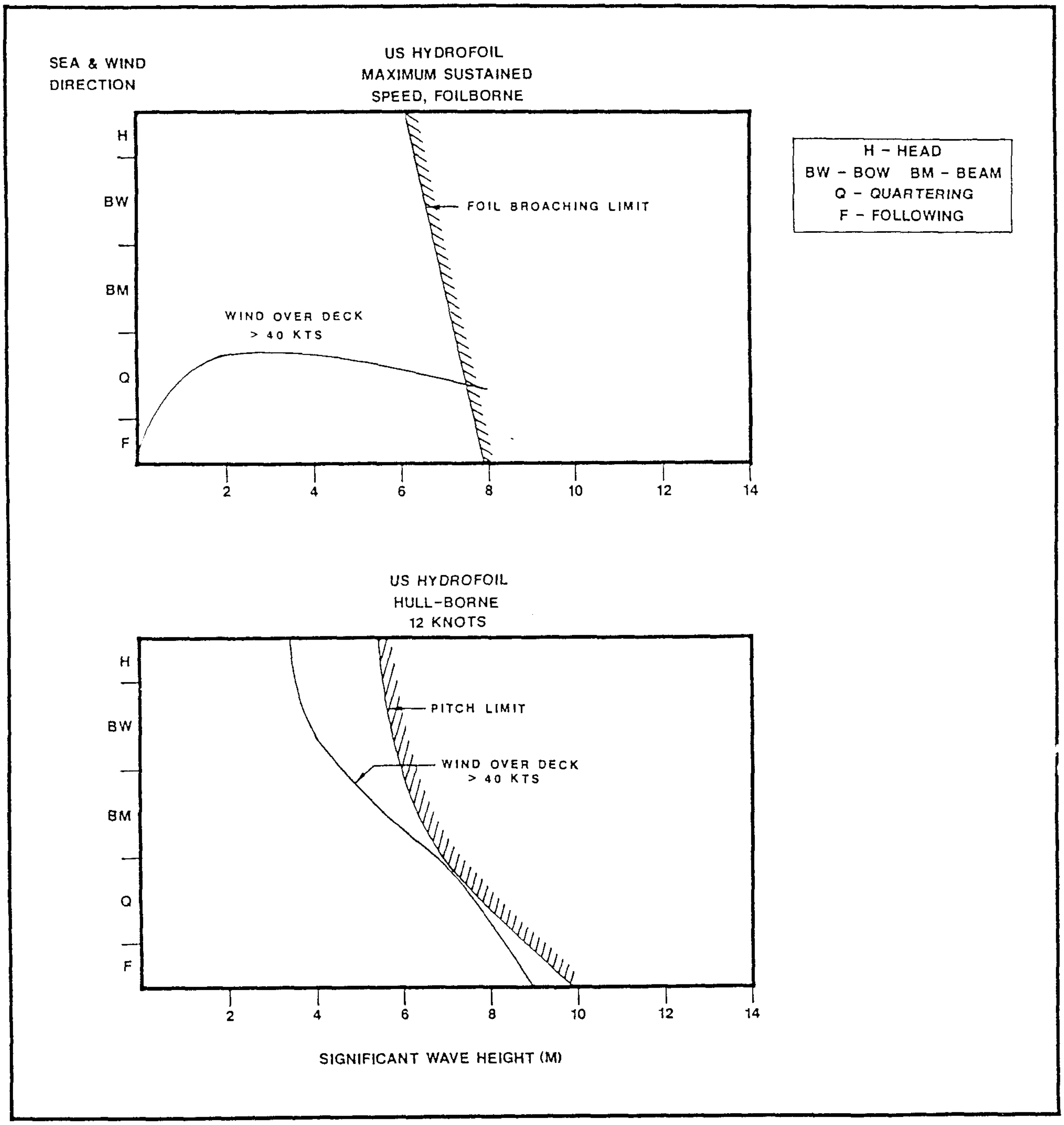


Figure 3.2.3-26. U.S. Hydrofoil Seakeeping Limits - Effect of Wave Height and Heading

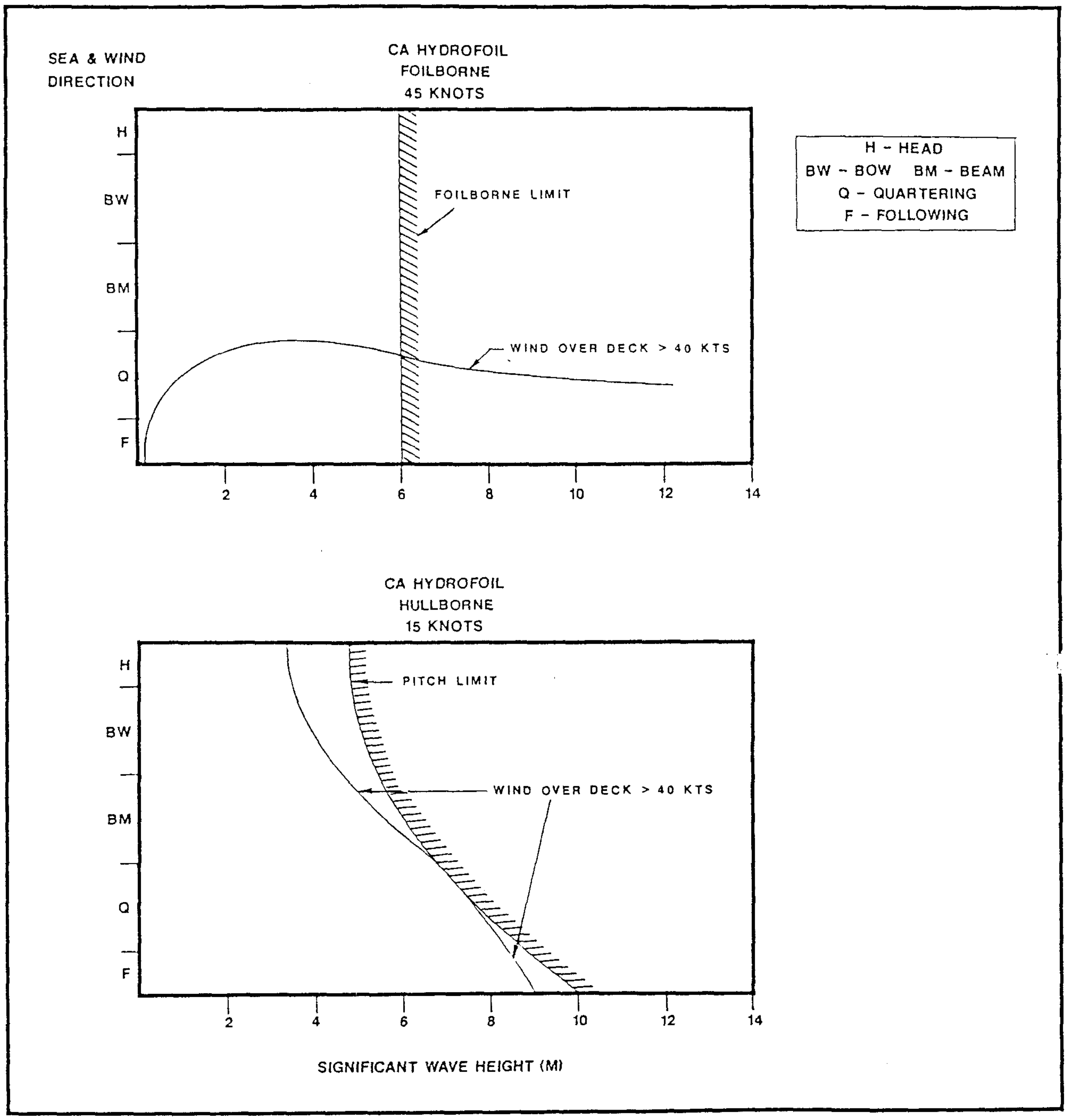


Figure 3.2.3-27. CA Hydrofoil Seakeeping Limits

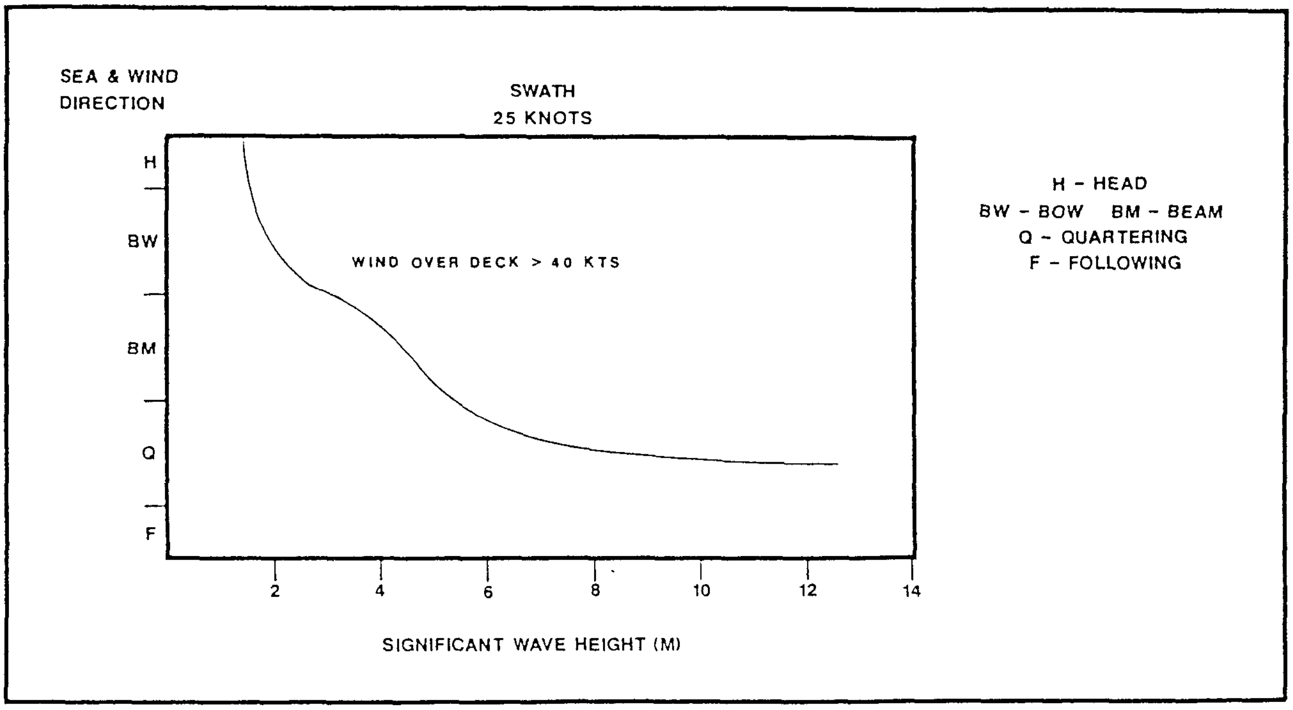


Figure 3.2.3-28. SWATH Seakeeping Limits

The Figures 3.2.3-33 through 3.2.3-47 represent the ship operability contours for eight different platforms in winter conditions. For each ship except the SWATH two speed conditions are included. In the case of the SESs and hydrofoils these two speeds are usually the maximum sustained cushion or foilborne speed and a hullborne speed between 10 and 15 knots.

Figures 3.2.3-48 through 3.2.3-53 show the operability of one of the ships (the UK SES) under a range of different conditions. Figures 3.2.3-48 and 3.2.3-49 show the annual average operability at high cushionborne speeds and at hullborne speeds, respectively. Figures 3.2.3-50 through 3.2.3-553 show the operability of the UK SES's helicopter at the same two speeds for annual average (Figures 4.2.3-50 and 4.2.3-51) and for winter conditions (Figures 4.2.3-52 and 4.2.3-53).

Figure 3.2.3-33, for example, shows that the UK SES can operate in all areas of the North Atlantic in winter at its maximum sustained speed on-cushion without exceeding the motion limits for at least 80% of the year. Figure 3.2.3-34 shows that its performance off-cushion is very similar. Figure 3.2.3-48 and 3.2.3-49 show that, on an annual basis these operability figures increase to at least 90%.

Figures 3.2.3-50 through 3.2.3-53 show helicopter operability limits for the "annual average" and the "winter" cases in the cushionborne and hullborne modes. On an annual basis a helicopter can operate from the UK SES for more than 90% of the time and during the winter months the helicopter can operate for more than 65% of the time. These figures for the UK SES (the FR SES and US/G SES are similar) are significantly better than those for a conventional frigate such as the FFG 7 which is illustrated in Figures 3.2.3-44 and 3.2.3-45.

The SWATH does not expect to exceed the motion or acceleration limits at any time, as illustrated by Figure 3.2.3-43. It is however limited in a manner very similar to the UK SES as far as helicopter operations are concerned due simply to the wind-speed-over-the-deck limit discussed above. The helicopter operability contours when operating from a SWATH are shown for comparison in Figure 3.2.3-56. In fact, this plot shows the probability of encountering 6-meter waves in the North Atlantic in winter as this is the only restriction considered.

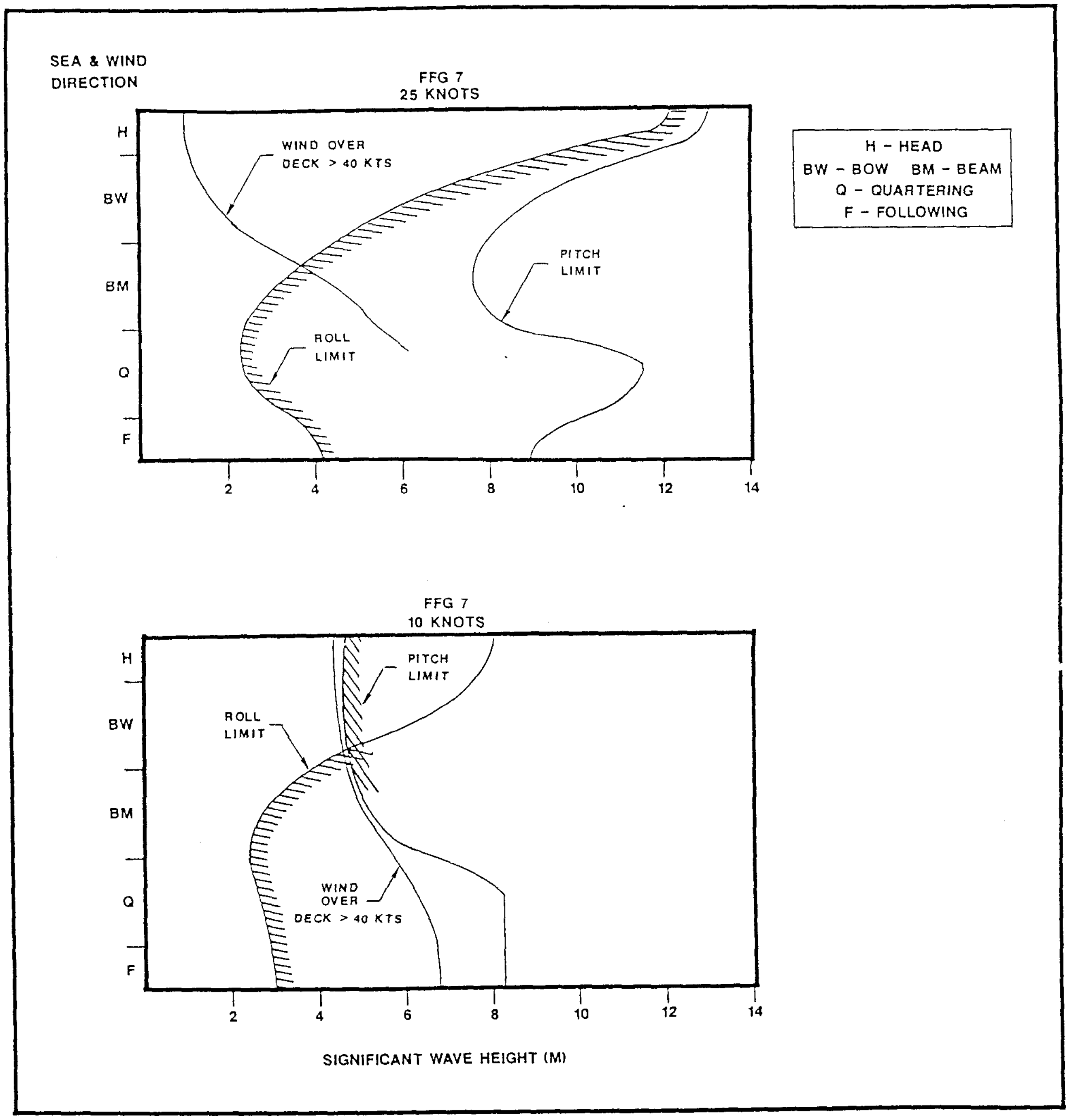


Figure 3.2.3-29. FFG-7 Seakeeping Limits

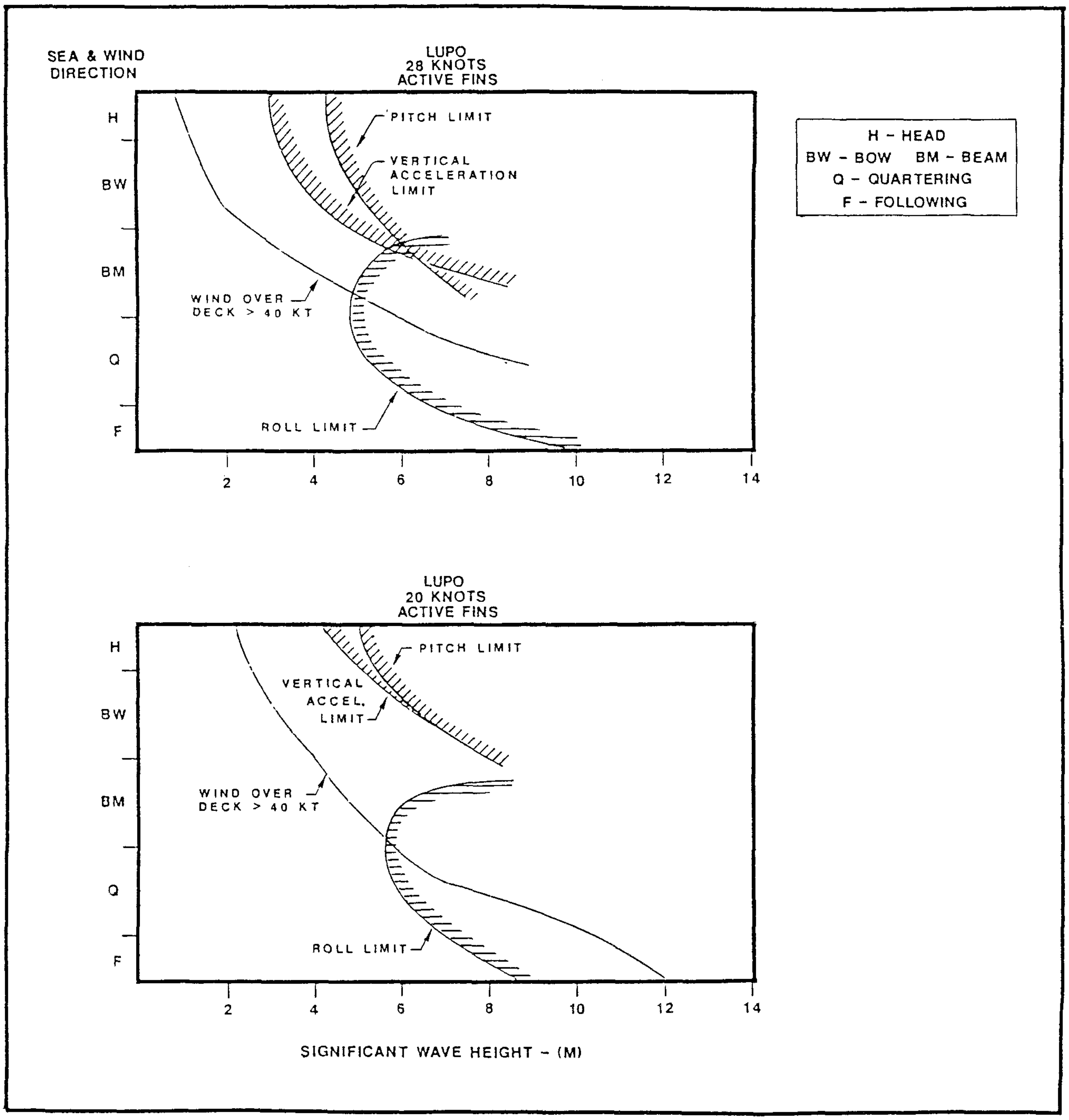


Figure 3.2.3-30. LUPO Seakeeping Limits

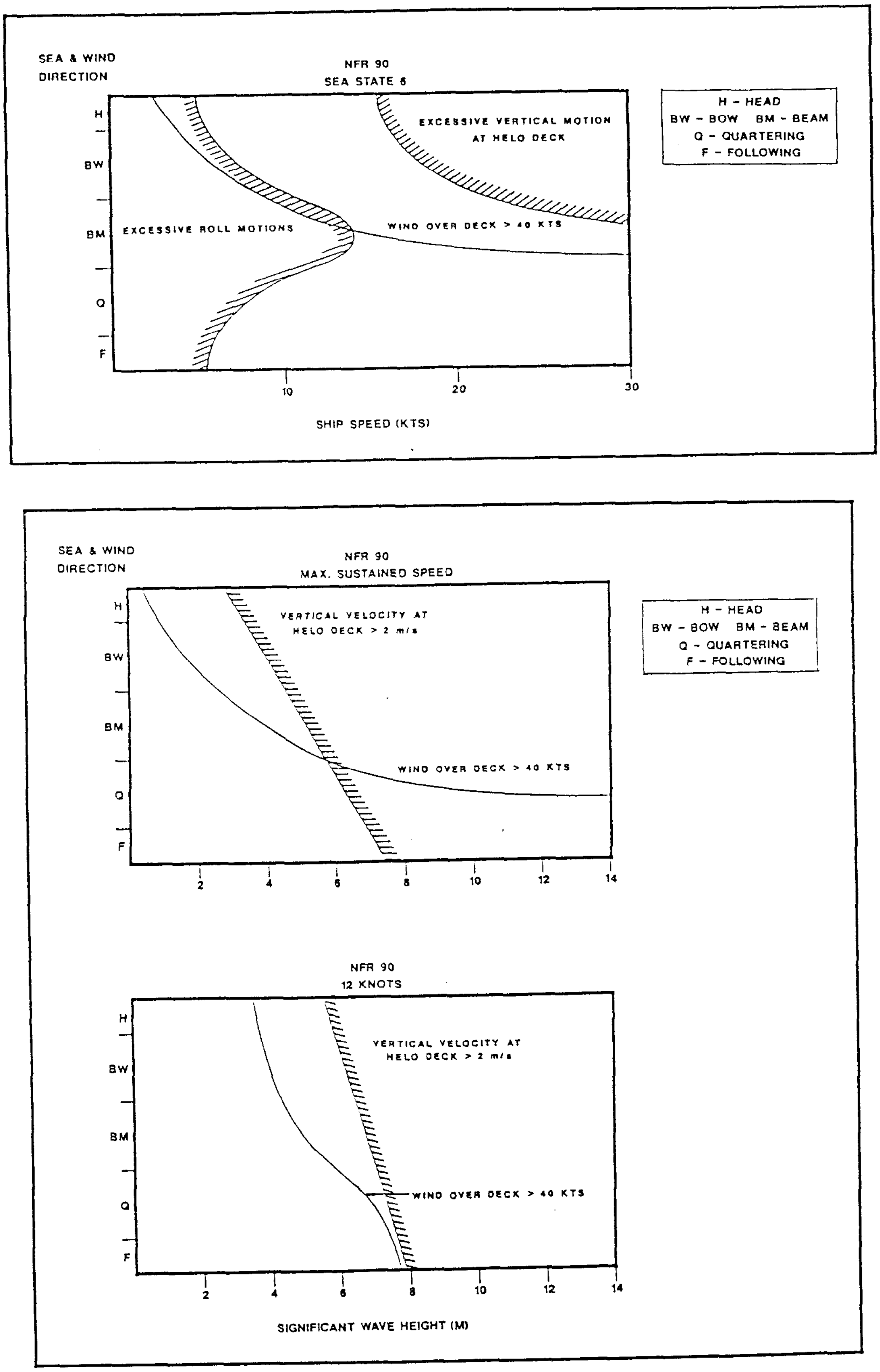
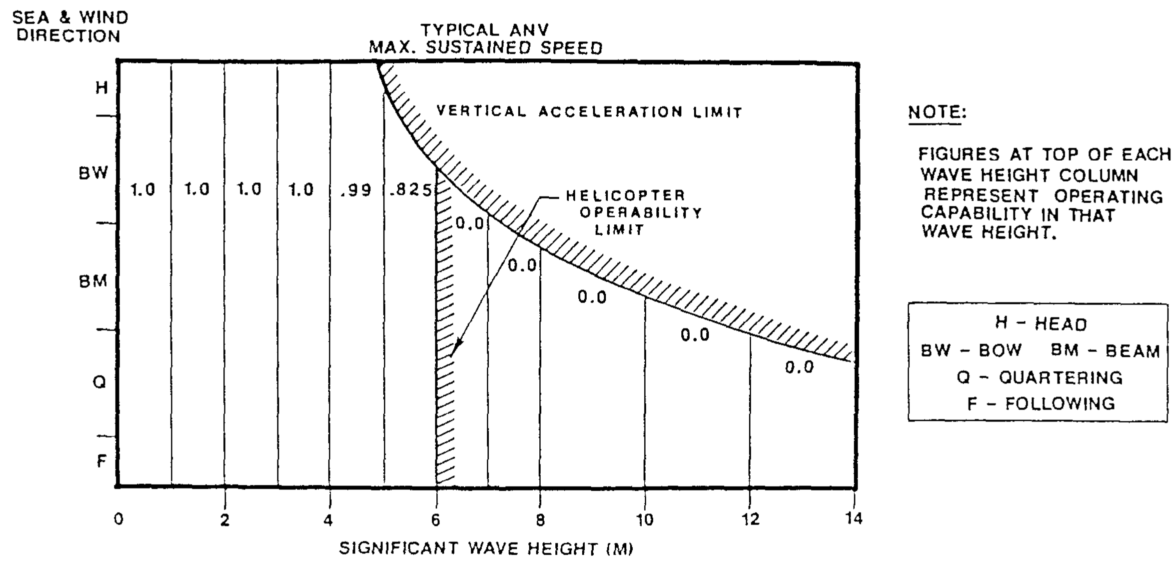
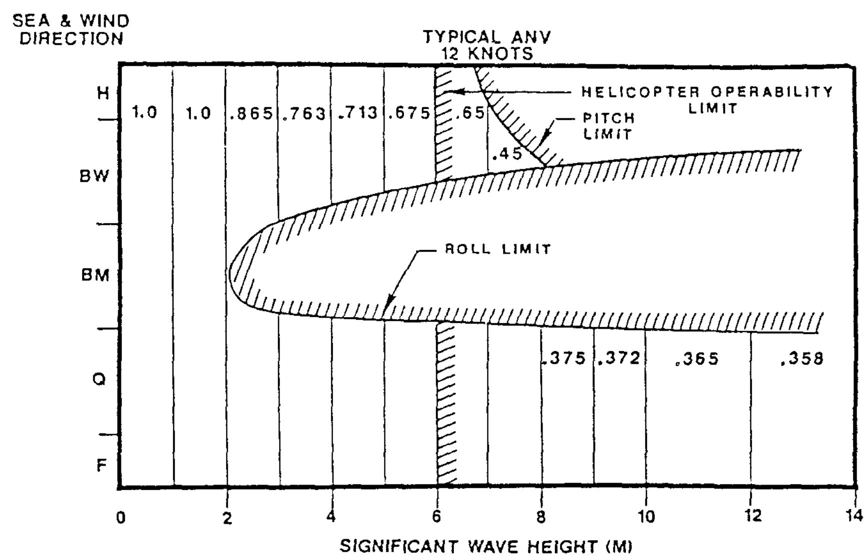


Figure 3.2.3-31. Estimated NFR 90 Seakeeping Limits - Effect of Sea State and Heading



(a) Maximum Sustained Speed



.225	.259	.181	.125	.080	.052	.032	.018	.011	.006	.004	.001	0.0

PROBABILITY OF OCCURRENCE OF WAVE HEIGHT (AVERAGE ANNUAL N. ATLANTIC)

(b) Low-Speed Mode, 12 Knots

Figure 3.2.3-32. Zones of Unrestricted Operational Capabilities for Typical ANV

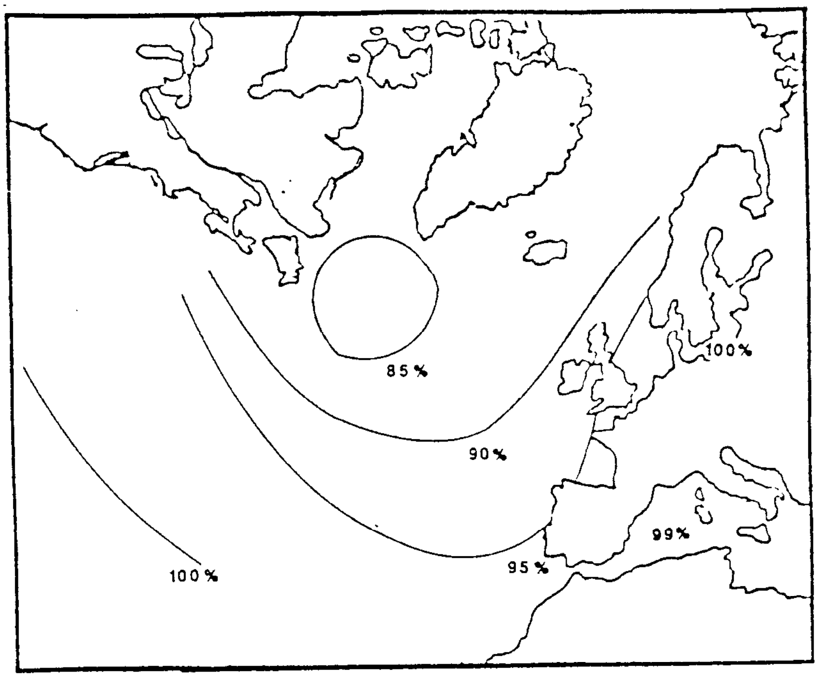


Figure 3.2.3-33. Operability Contour, UK SES, 27-40.5 Knot Range, Ride-Control, On-Cushion, Winter (Ship Operability)

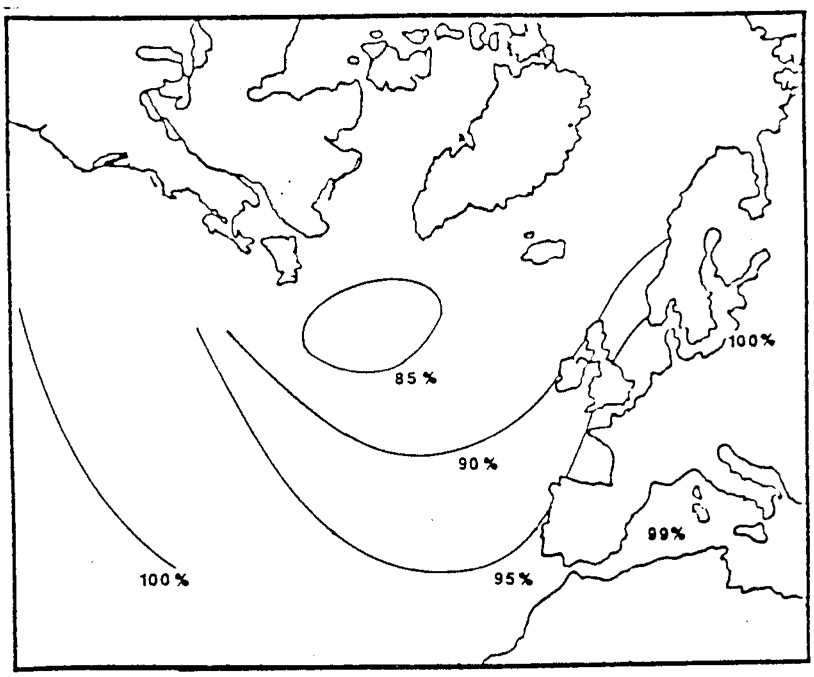


Figure 3.2.3-34. Operability Contour, UK SES 11-17 Knot Range, Off-Cushion, Winter (Ship Operability)

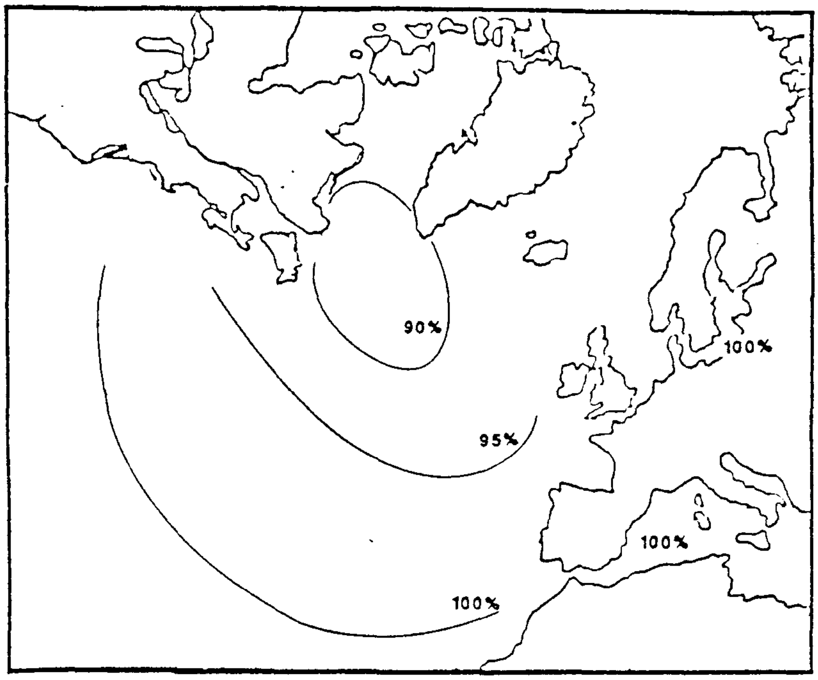


Figure 3.2.3-35. Operability Contour, FR SES, 35-52 Knot Range, On-Cushion, Winter (Ship Operability)

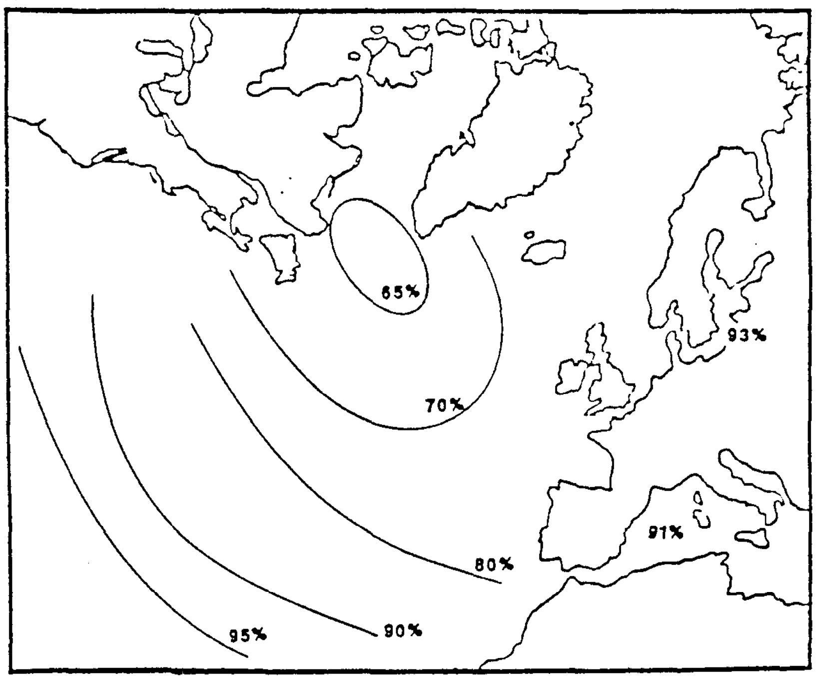


Figure 3.2.3-36. Operability Contour, FR SES, 12-18 Knot Range, Off-Cushion, Winter, (Ship Operability)

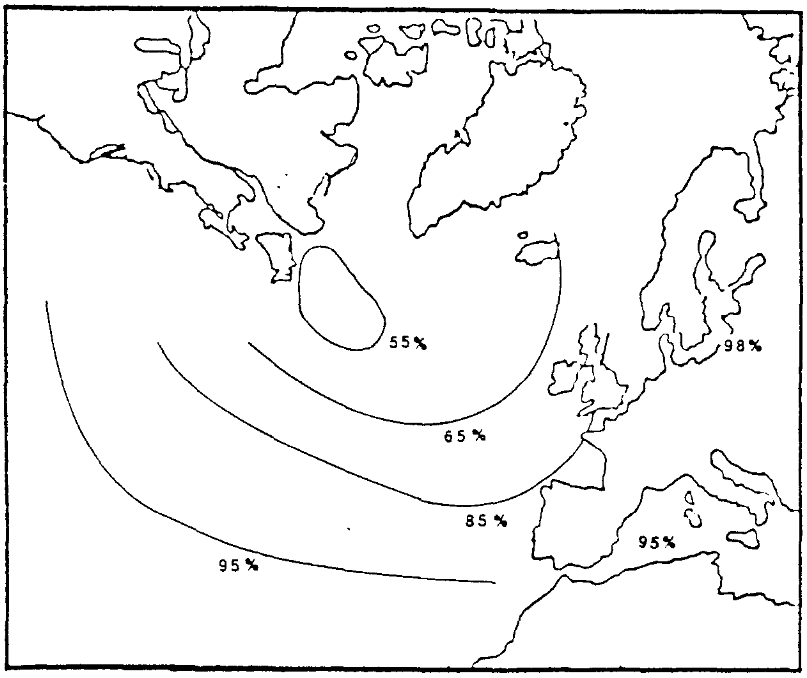


Figure 3.2.3-37. Operability Contour, US/G SES, 30 Knots, Ride-Control, On-Cushion, Winter (Ship Operability)

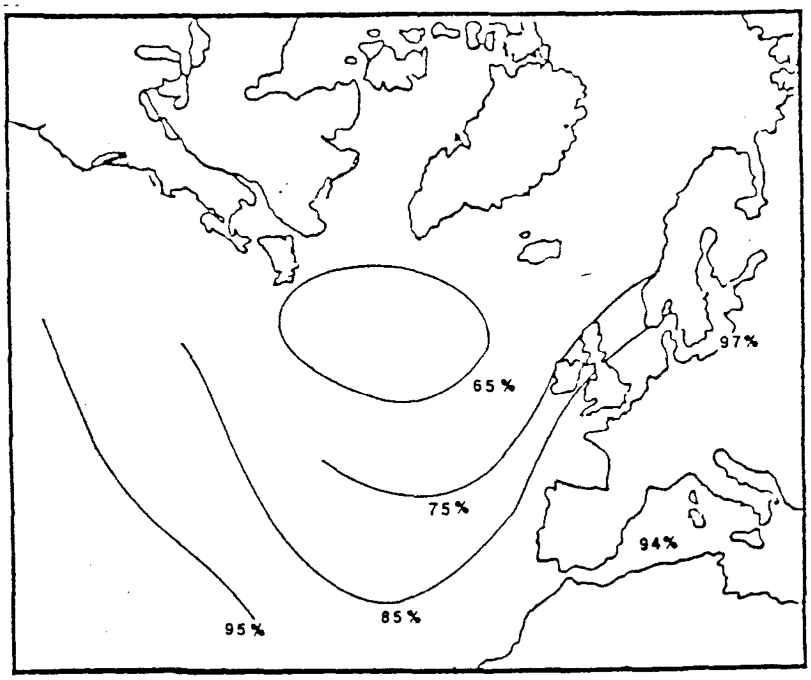


Figure 3.2.3-38. Operability Contour, US/G SES, 20 Knots, Ride-Control, Off-Cushion, Winter (Ship Operability)

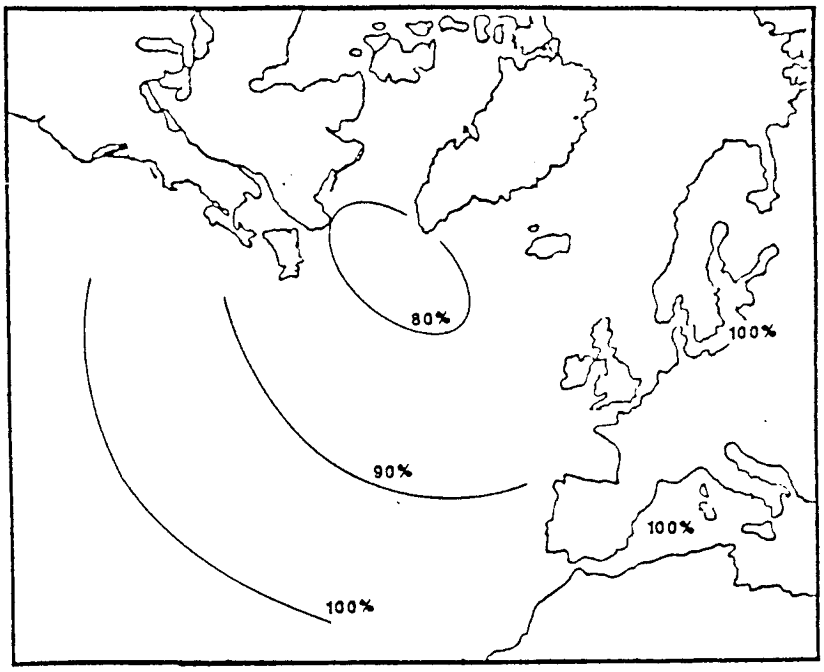


Figure 3.2.3-39. Operability Contour, U.S. Hydrofoil, 44-46 Knot Range, Ride-Control, Foilborne, Winter (Ship Operability)

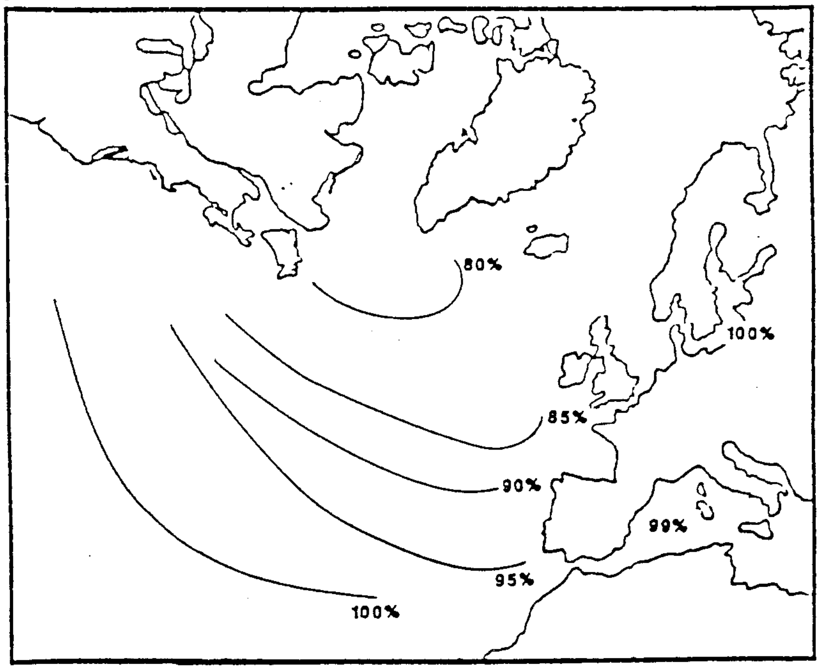


Figure 3.2.3-40. Operability Contour, U.S. Hydrofoil, 8-16 Knot Range, Hullborne, Winter (Ship Operability)

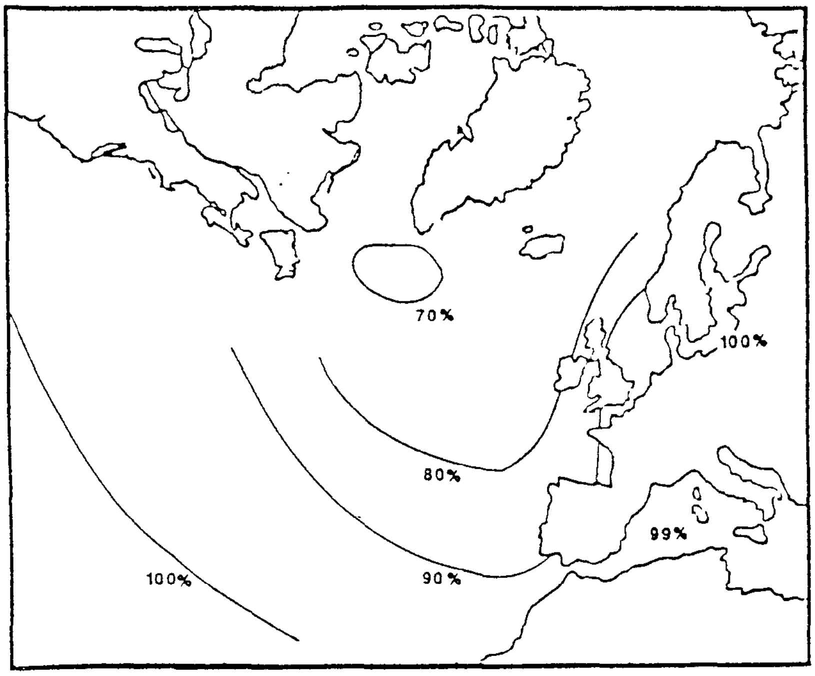


Figure 3.2.3-41. Operability Contour, Canadian Hydrofoil, 45 Knots, Ride-Control, Foilborne, Winter (Ship Operability)

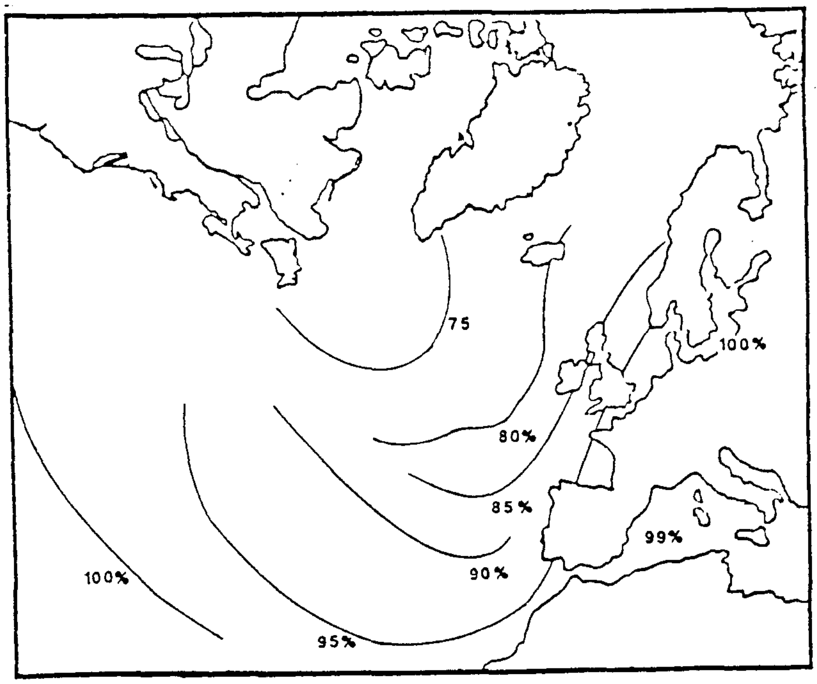


Figure 3.2.3-42. Operability Contour, Canadian Hydrofoil, 15 Knots, Ride-Control, Hullborne, Winter (Ship Operability)

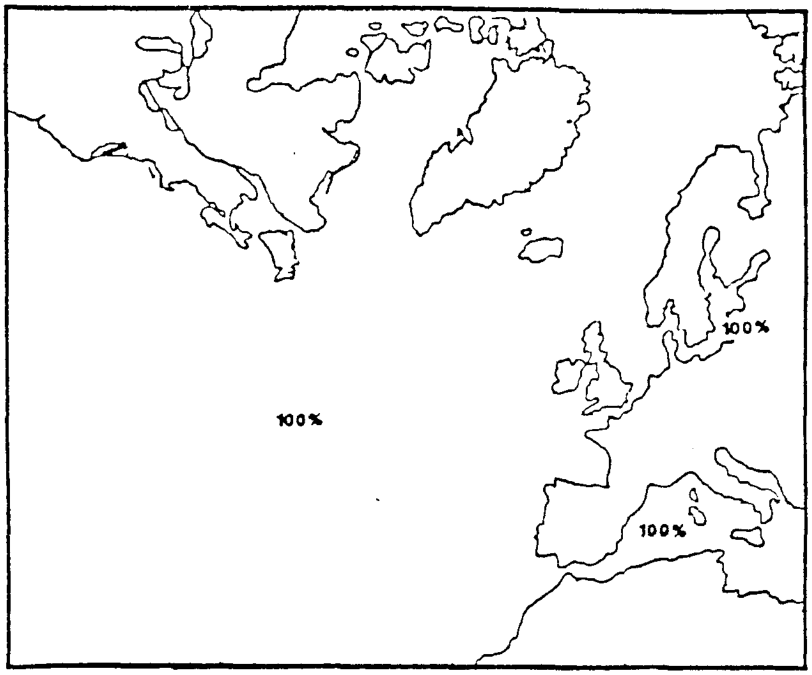


Figure 3.2.3-43. Operability Contour, Canadian SWATH, 25 Knots and 10 Knots, Winter (Ship Operability)

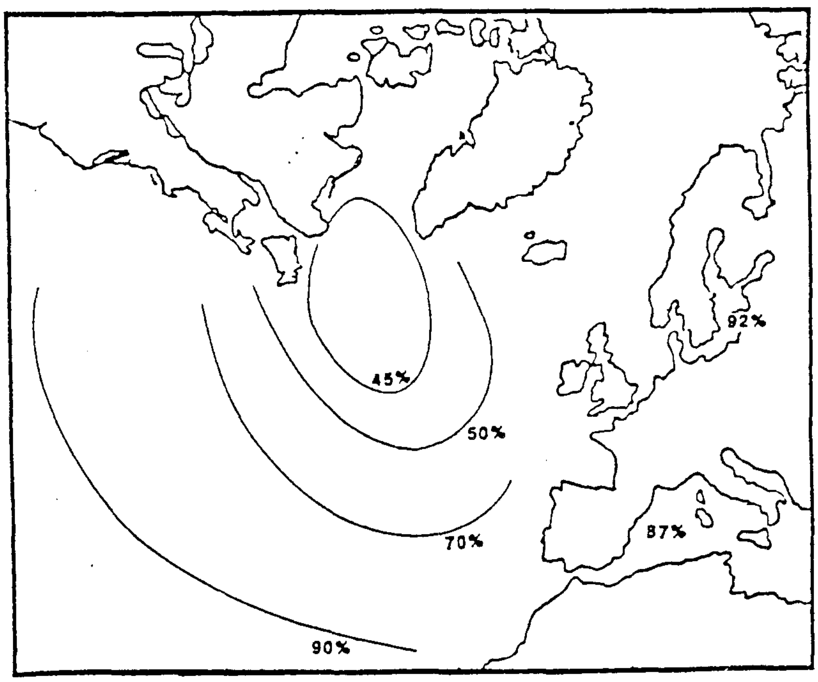


Figure 3.2.3-44. Operability Contour, FFG-7, 25 Knots, Active Fin Stabilizers, Winter (Ship Operability)

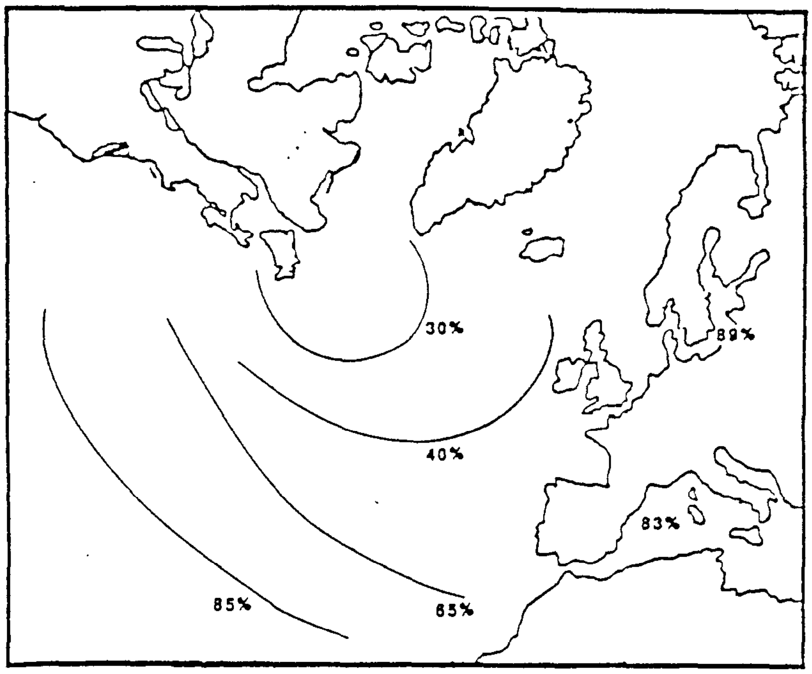


Figure 3.2.3-45. Operability Contour, FFG-7, 10 Knots, Winter (Ship Operability)

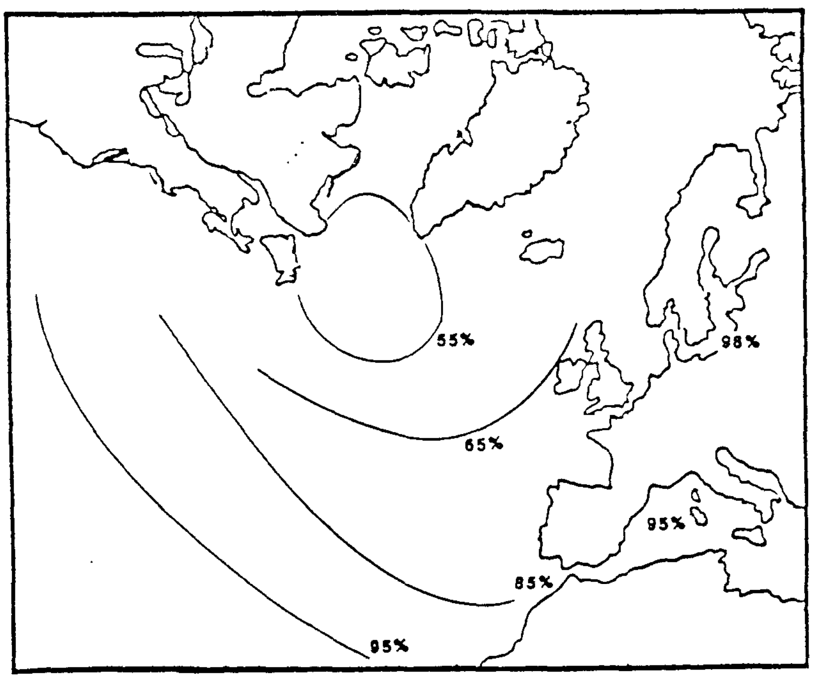


Figure 3.2.3-46. Operability Contour, NFR 90, 24-30 Knot Range, Active Fin Stabilizers, Winter (Ship Operability)

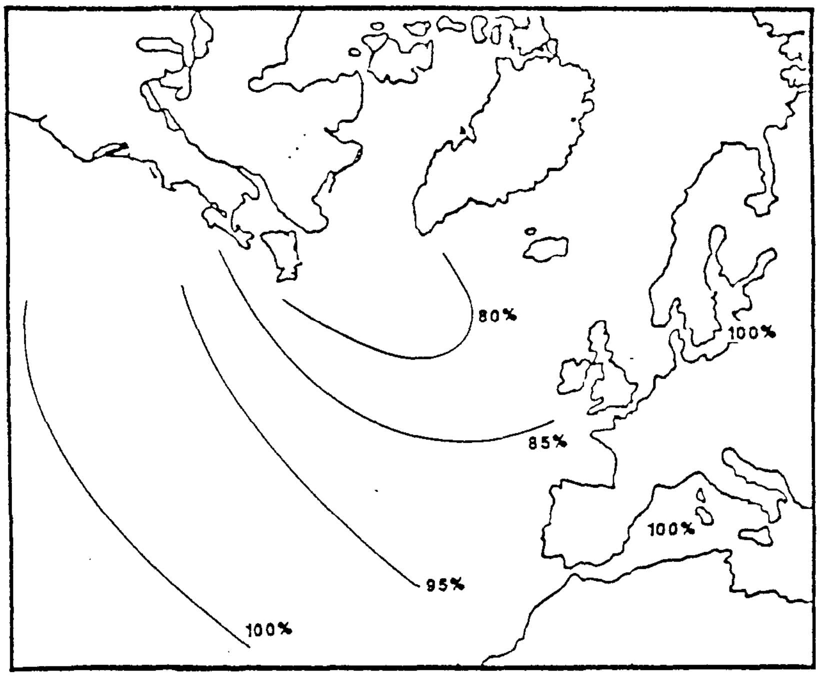


Figure 3.2.3-47. Operability Contour, NFR 90, 12 Knots, Foilborne, Winter, (Ship Operability)

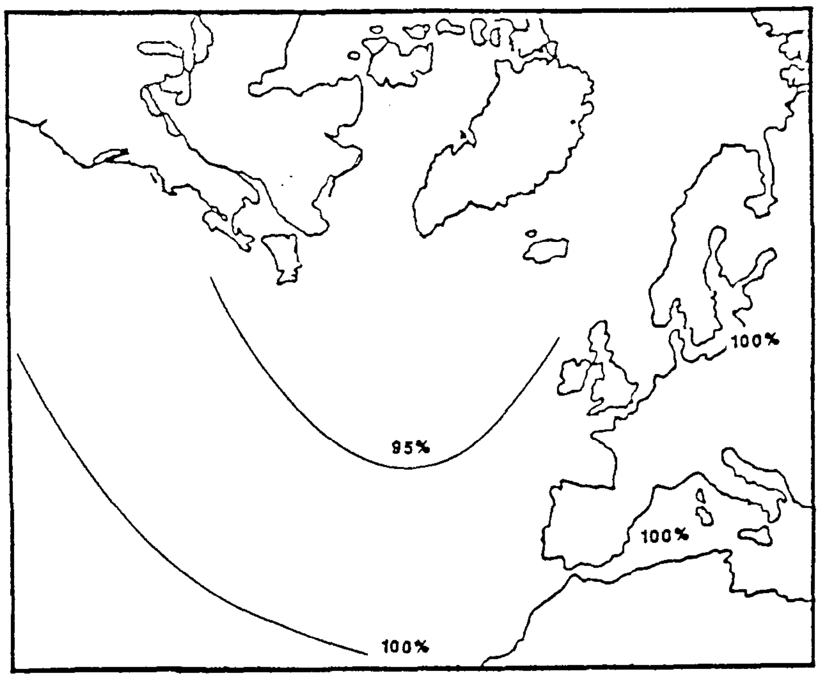


Figure 3.2.3-48. Operability Contour, UK SES, 27-40.6 Knot Range, Ride-Control, On-Cushion, Annual North Atlantic Average (Ship Operability)

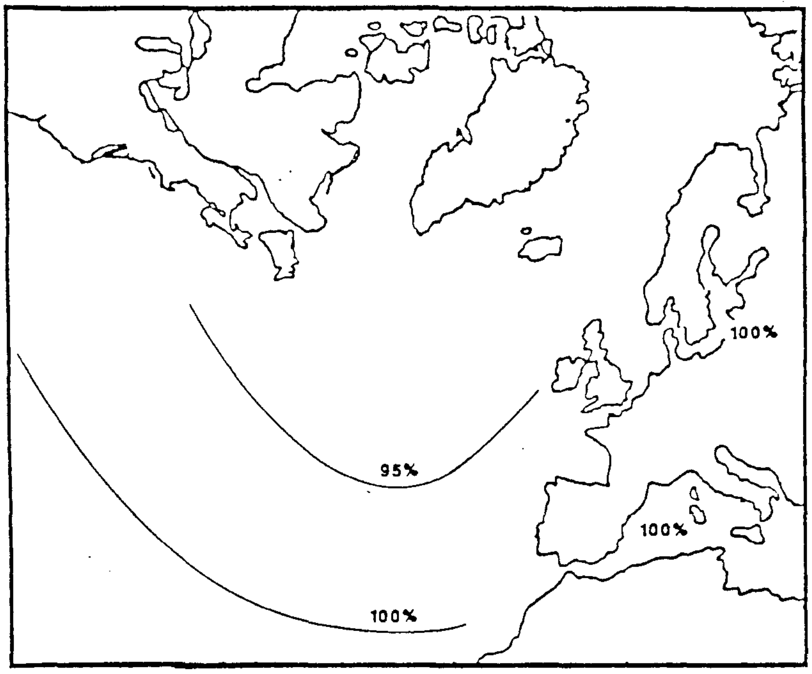


Figure 3.2.3-49. Operability Contour, UK SES, 11-17 Knot Range, Off-Cushion, Annual Average, (Ship Operability)

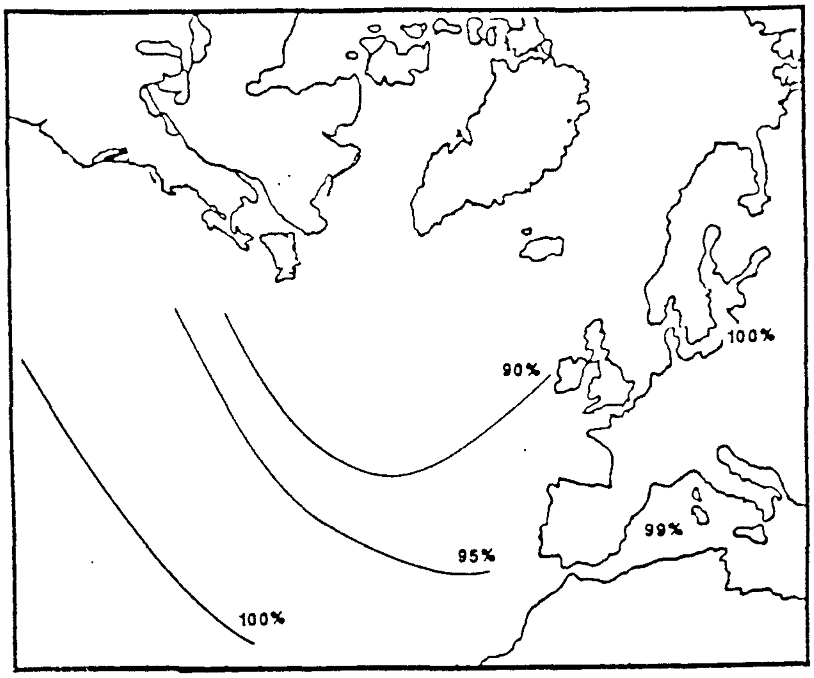


Figure 3.2.3-50. Operability Contour, UK SES, 27-40.5 Knot Range, On-Cushion, Annual Average (Helicopter Operability)

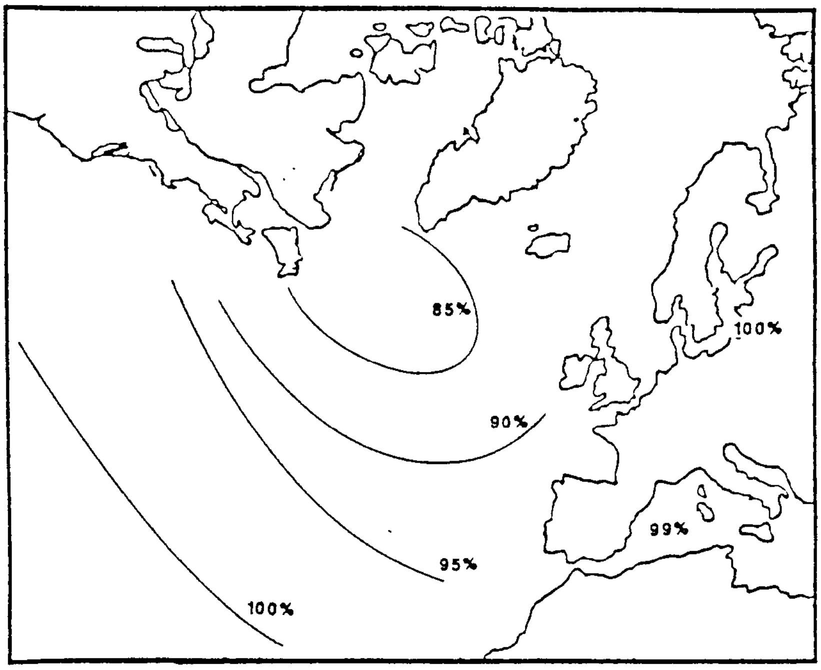


Figure 3.2.3-51. Operability Contour, UK SES, 11-17 Knot Range, Off-Cushion, Annual Average (Helicopter Operability)

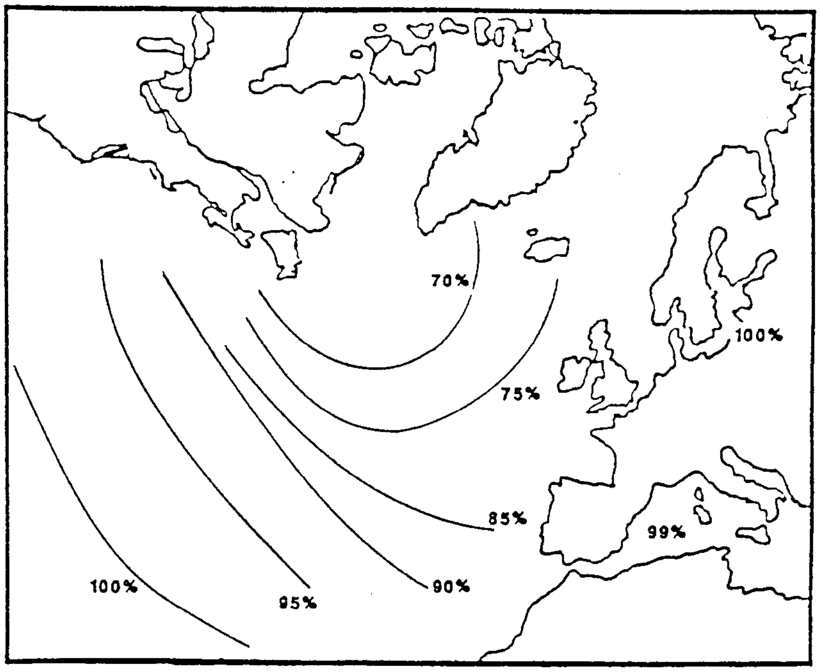


Figure 3.2.3-52. Operability Contour, UK SES, 27-40.5 Knot Range, On-Cushion Winter (Helicopter Operability)

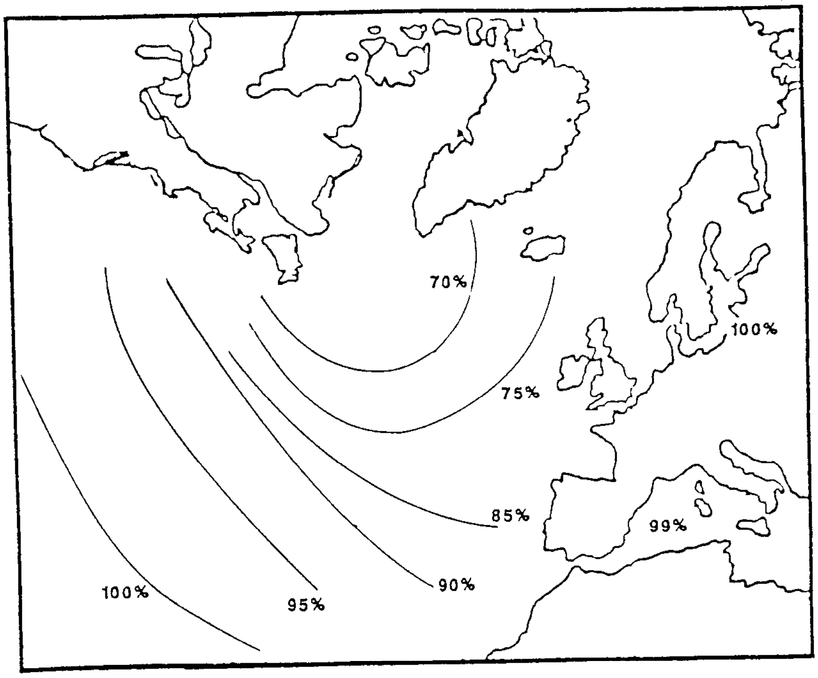


Figure 3.2.3-53. Operability Contour, UK SES, 11-17 Knot Range, Off-Cushion, Winter (Helicopter Operability)

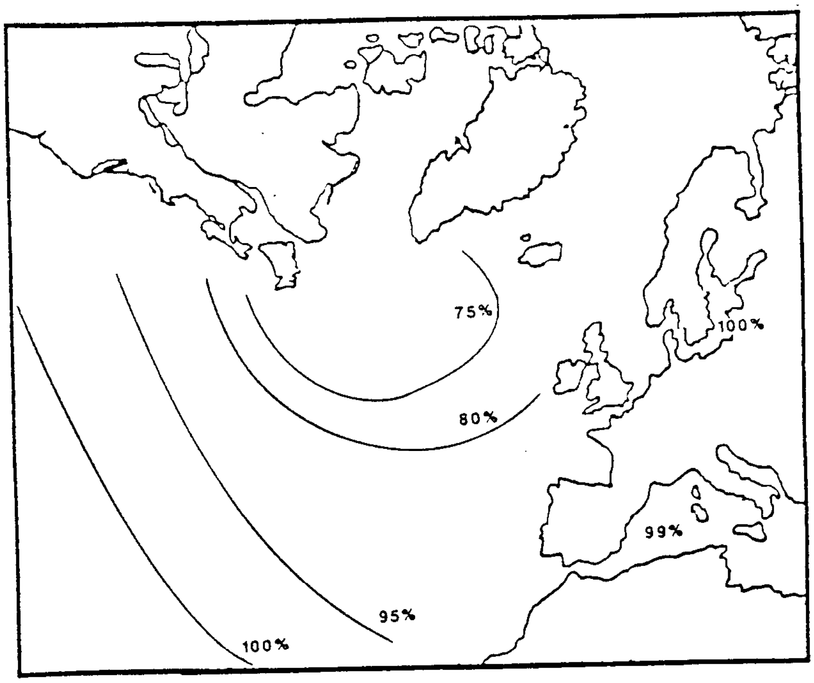


Figure 3.2.3-54. Operability Contour, SWATH, 25 Knots and 10 Knots, Northern North Atlantic (Helicopter Operability)

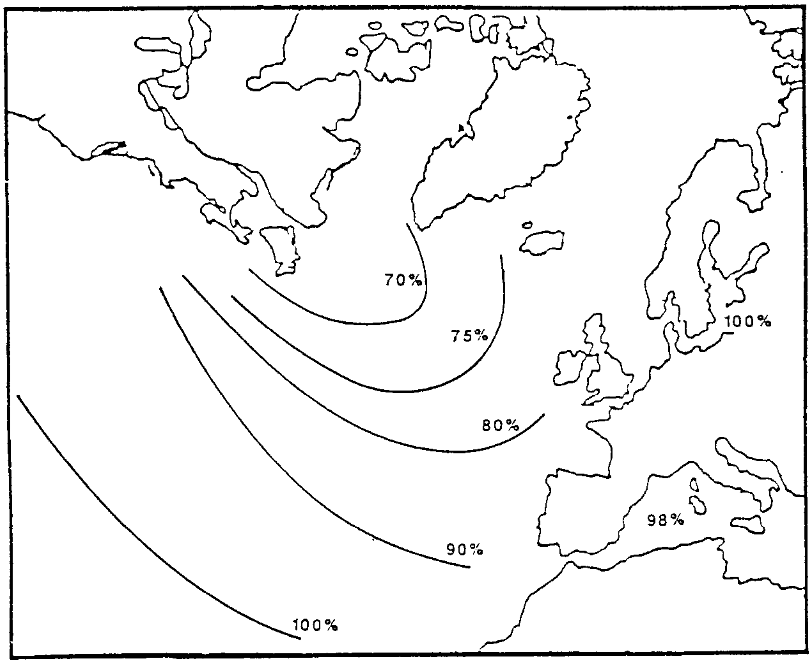


Figure 3.2.3-55. Operability Contour, Italian LUPO, 20 Knots, Active Fin Stabilizers, Winter (Ship and Helicopter Operability)

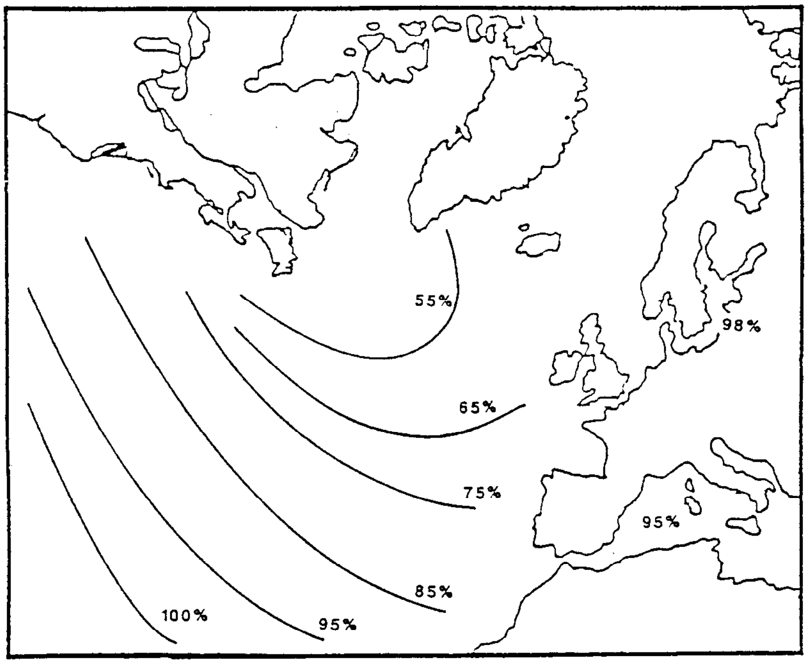


Figure 3.2.3-56. Operability Contour, Italian LUPO, 28 Knots, Active Fin Stabilizers, Winter (Ship and Helicopter Operability)

3.2.3.7 Operability Comparisons

The ship and helicopter operabilities are compared in Figures 3.2.3-57 through 3.2.3-62 for a number of conditions and sea operating areas and seasons. Note that the value which has been shown, in each case, for percent operability, is the percentage of time that each platform will not exceed its acceptable motion threshold or wind over the deck limitation. This value is not the operational availability of the platform since it does not include those periods of time when operations are restricted due to:

- System Failures
- At-Sea Maintenance
- Inport Time
- Underway Replenishment and Refueling
- Poor Visibility and Icing
- Combat Attrition

The figures are listed below.

Figure No.	Operating Mode	Ocean Area	Season
3.2.3-57	High Speed	Northern North Atlantic (Area 1)	Winter
3.2.3-58	High Speed	North Sea (Area 4)	Winter
3.2.3-59	High Speed	Mediterranean	Winter
3.2.3-60	Low Speed	Northern North Atlantic (Area 1)	Winter
3.2.3-61	Low Speed	North Sea (Area 4)	Winter
3.2.3-62	Low Speed	Mediterranean	Winter

Figures 3.2.3-57 and 3.2.3-62 show that there is considerable difference between the capabilities of the different ships in the worst of North Atlantic weather. The SWATH's superior seakeeping gives it a big advantage in this respect. However, as far as helicopter operations are concerned, the SWATH has very little advantage over the SESs or the NFR 90. All of the NATO ANVs have operability levels well above that of the FFG 7.

In the North Sea all of the ships, except, again, the FFG 7, have very high operability percentages and these increase even more in the Mediterranean.

For many areas of the world and seasons of the year, therefore, the excellent seakeeping characteristics of the SWATH are not really required. Its ability to operate for a few more days of the year in particularly rough areas such as the Northern North Atlantic must be carefully weighed against the speed advantages of all the other ships.

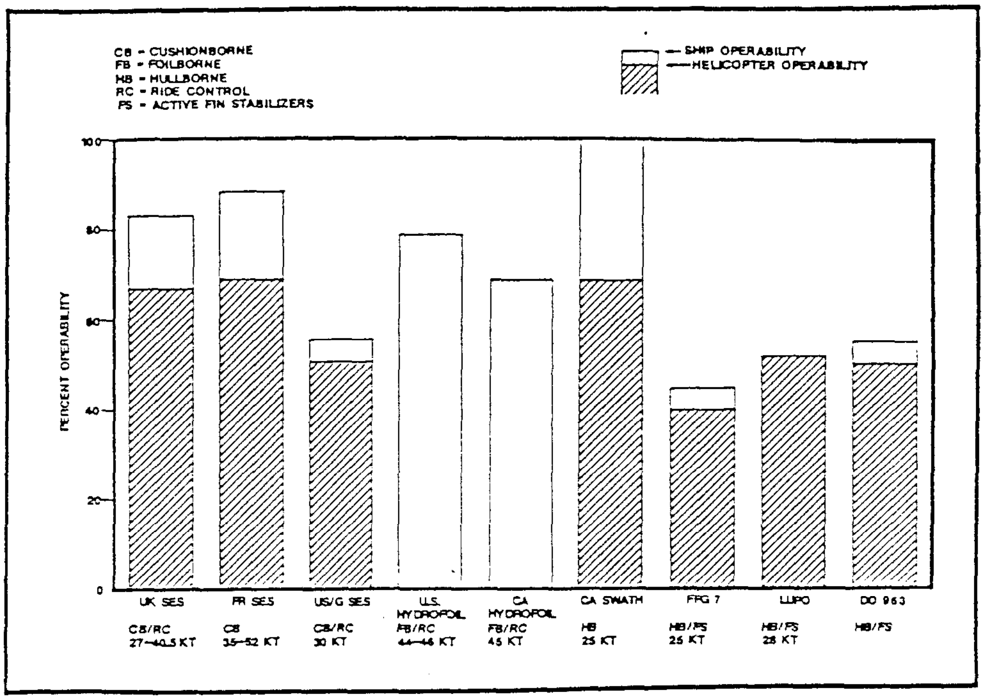


Figure 3.2.3-57. Comparison of Percentage Operabilities of ASW Ships at High Speed in the Northern North Atlantic in Winter

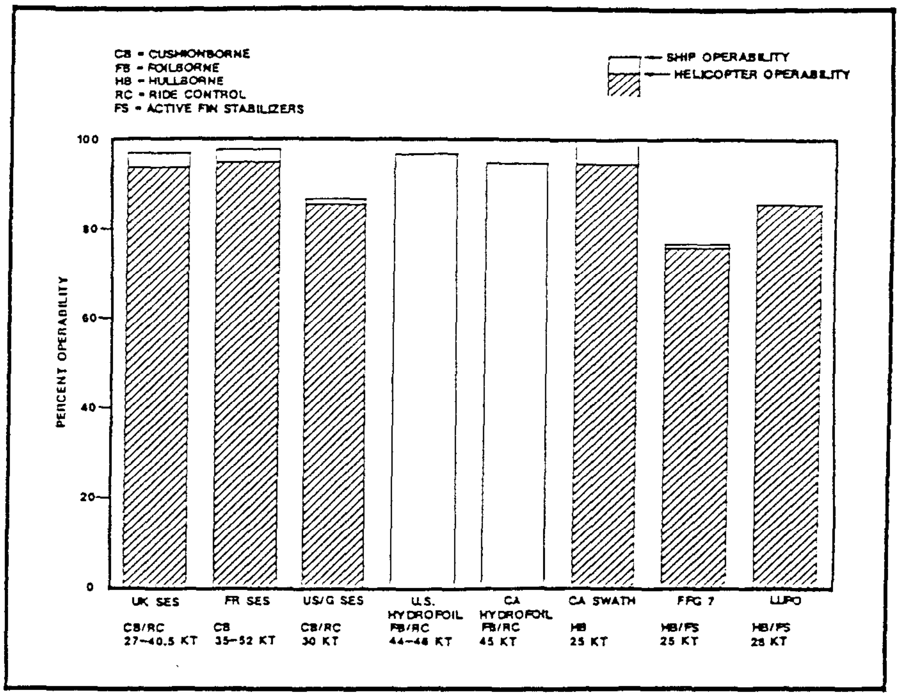


Figure 3.2.3-58. Comparison of Percentage Operabilities of ASW Ships at High Speed in the North Sea in Winter

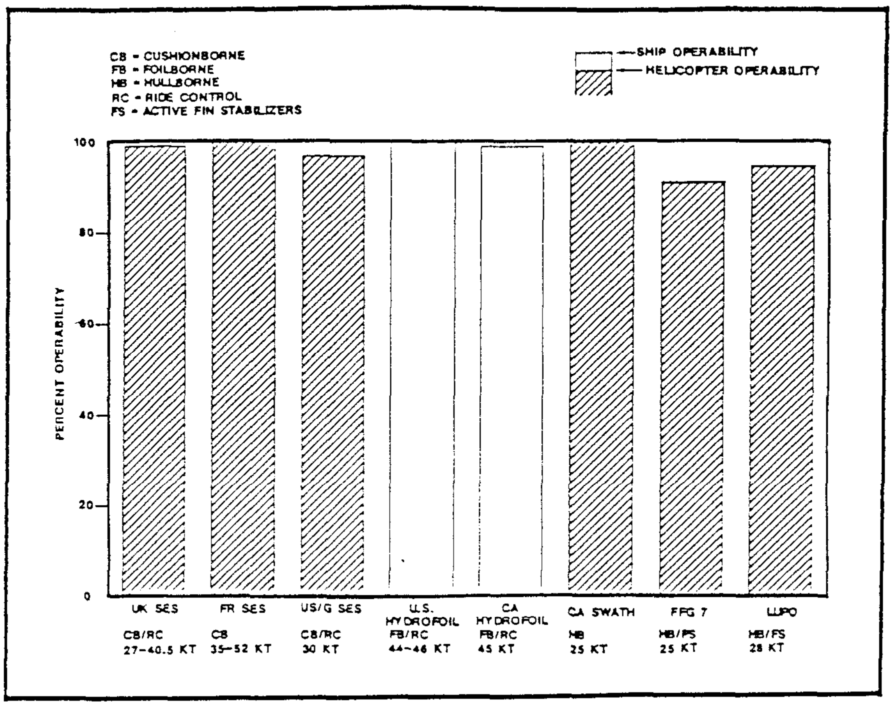


Figure 3.2.3-59. Comparison of Percentage Operabilities of ASW Ships at High Speed in the Mediterranean in Winter

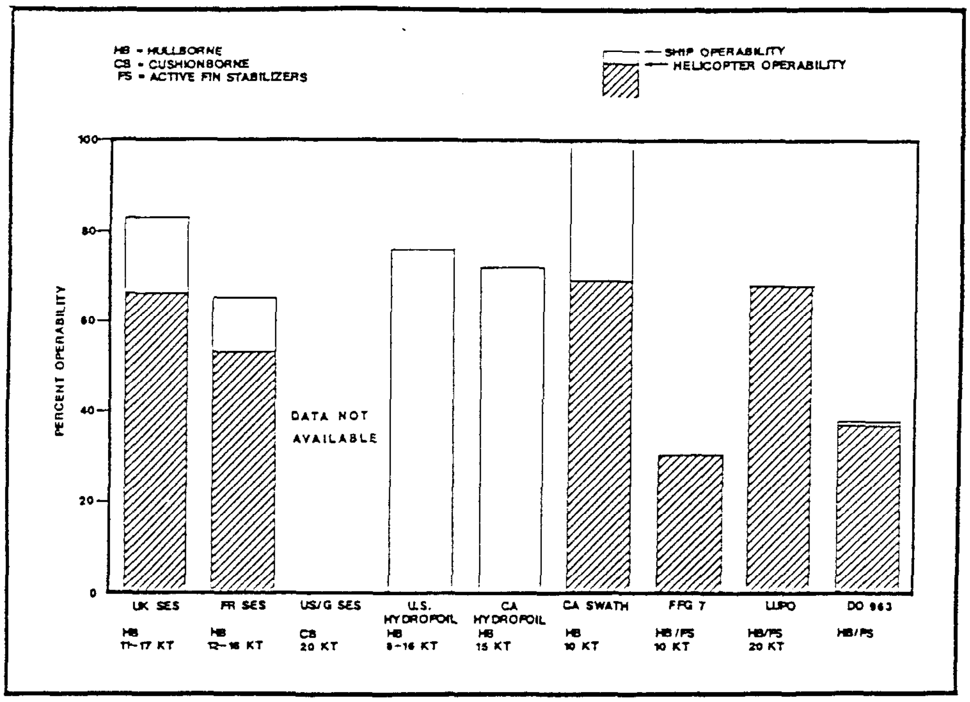


Figure 3.2.3-60. Comparison of Percentage Operabilities of ASW Ships at Low Speed in the Northern North Atlantic in Winter

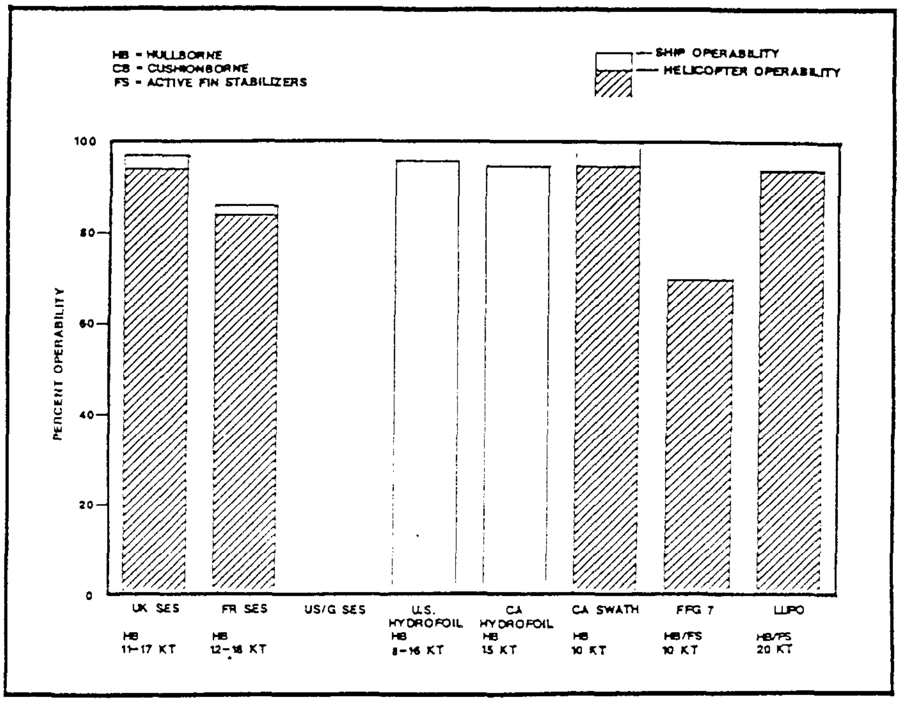


Figure 3.2.3-61. Comparison of Percentage Operabilities of ASW Ships at Low Speed in the North Sea in Winter

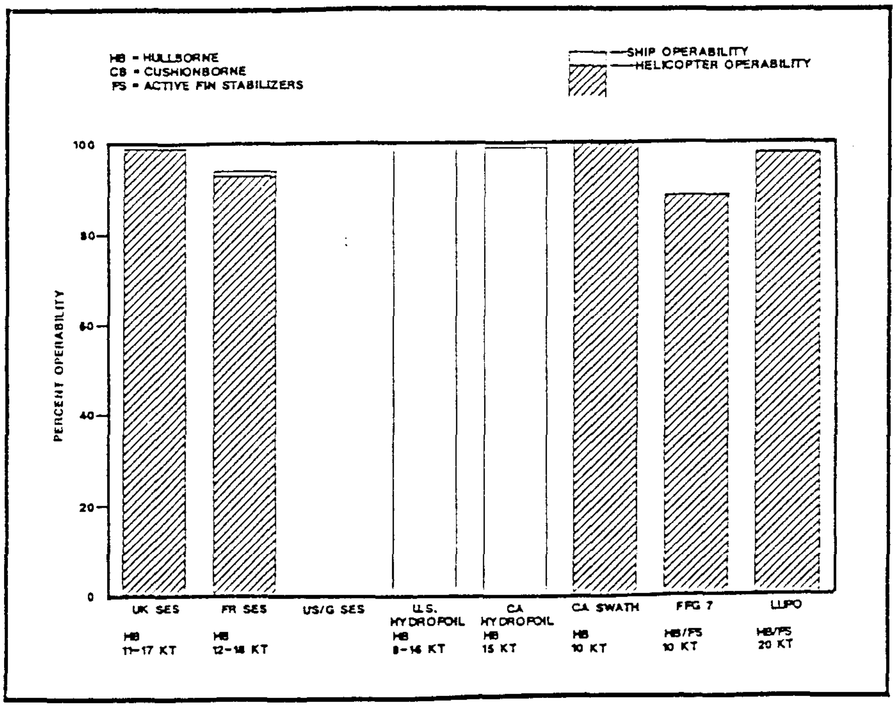


Figure 3.2.3-62. Comparison of Percentage Operabilities of ASW Ships at Low Speed in the Mediterranean in Winter

3.2.4 Maneuverability

3.2.4.1 Maneuvering Requirements

Turning requirements for the ANV point-designs are stated in the respective Outline NATO Staff Targets (ONSTs) and are summarized in Table 3.2.4-1. A requirement for the NFR 90 is included for comparison. No requirements for acceleration or deceleration performance were quoted.

Table 3.2.4-1. Point-Design Maneuvering Requirements.

		SES	HYDROFOIL (1)	SWATH (2)	NFR 90
Tactical Diameter			Tactical Diameter at Max. Speed		
Calm Water	m	*	500	*	650
Rough Water	m	*	*	800	*
Rate of Turn			Rate of Turn at Max. Speed		
Calm Water	deg/s	*	6	*	*
Rough Water	deg/s	*	4	*	*
Advance			Advance at Max. Speed		
Calm Water	m	*	500	*	*
Rough Water	m	*	*	800	*
Transfer			Transfer at Max. Speed		
Calm Water	m	*	500	*	*
Rough Water	m	*	*	*	*

(1) Rough-water requirement in 4.6m significant waves
(2) Rough-water requirement in 3.0m significant waves.

* Indicates that requirement is not stated

3.2.4.2 Turning Performance

The calm-water maximum high-speed turning performance of each ANV point design, in deep water and still air, is compared with the performance of the NFR 90, the FFG-7, the LUPO, the UK comparative monohulls and the SPARVIERO hydrofoil in the non-dimensional chart of Figure 3.2.4-1.

This figure shows the approximate ratio of tactical diameter (D) to overall ship length (L) plotted against the square of the operating Froude Number. The two sets of diagonal lines on the chart are lines of constant rate of turn (r), in nondimensional form $\left(r\sqrt{L/g}\right)$, and the corresponding steady-state lateral acceleration (in units of g) during the turn, respectively. In each case, the ship's forward speed (V) is the average speed achieved during the maneuver.

From this comparison it is apparent that the tightest high-speed turns are achieved with the hydrofoil followed by the monohull, the SES and the SWATH. This may be considered to be a general conclusion when comparing similar sized monohulls and ANVs of the various types shown. It is to be noted, that when a hydrofoil banks into a coordinated turn, lateral accelerations are resolved normal to the deck.

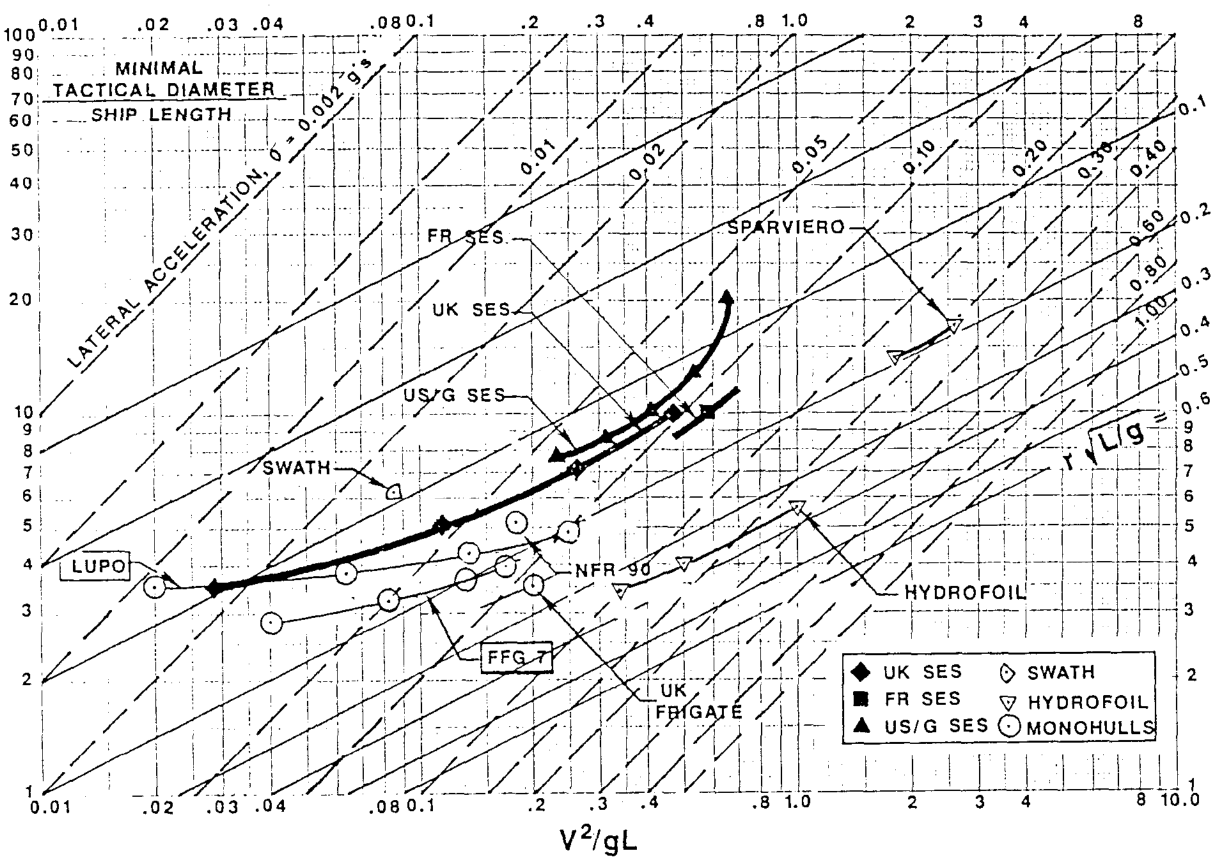


Figure 3.2.4-1. Comparisons of Maximum Non-Dimensional Maneuvering Performance in Calm Water

Tactical diameters in dimensional terms, for each design, are compared in Figure 3.2.4-2 with the stated requirements. This shows the hydrofoil to be capable of achieving, by far, the tightest turns, with the DESCUBIERTA and UK frigate second in performance to the hydrofoil. The SWATH is the least capable of achieving tight turns at high speed. The least capable SES design, the US/G SES design, can at least meet, in calm water, the rough water requirement stated for the SWATH design while the UK and French designs can do better than that required of the NFR 90 and better than the FFG 7 and LUPO at speeds below about 17 and 23 knots, respectively.

At the very low speeds required for docking the maneuvering capability of the SES and SWATH have been shown to be exceptionally good relative to monohulls because of the ability to use differential thrust between the screws, on waterjets, mounted on widely separated hulls.

Both the UK and FR SES designs use waterjet propulsors for maneuvering which are fitted with steerable nozzles and deflector buckets to obtain reverse thrust for going astern. The UK design also utilizes the waterjets at an angle of 15^{o} to the vertical in order to create an inward heeling moment while in turns.

The US/G SES design is fitted with twin controllable pitch propellers and wedge section rudders. All three designs are capable of using differential thrust to improve the turn rate during maneuvering but use of this facility also reduces craft speed in the turn.

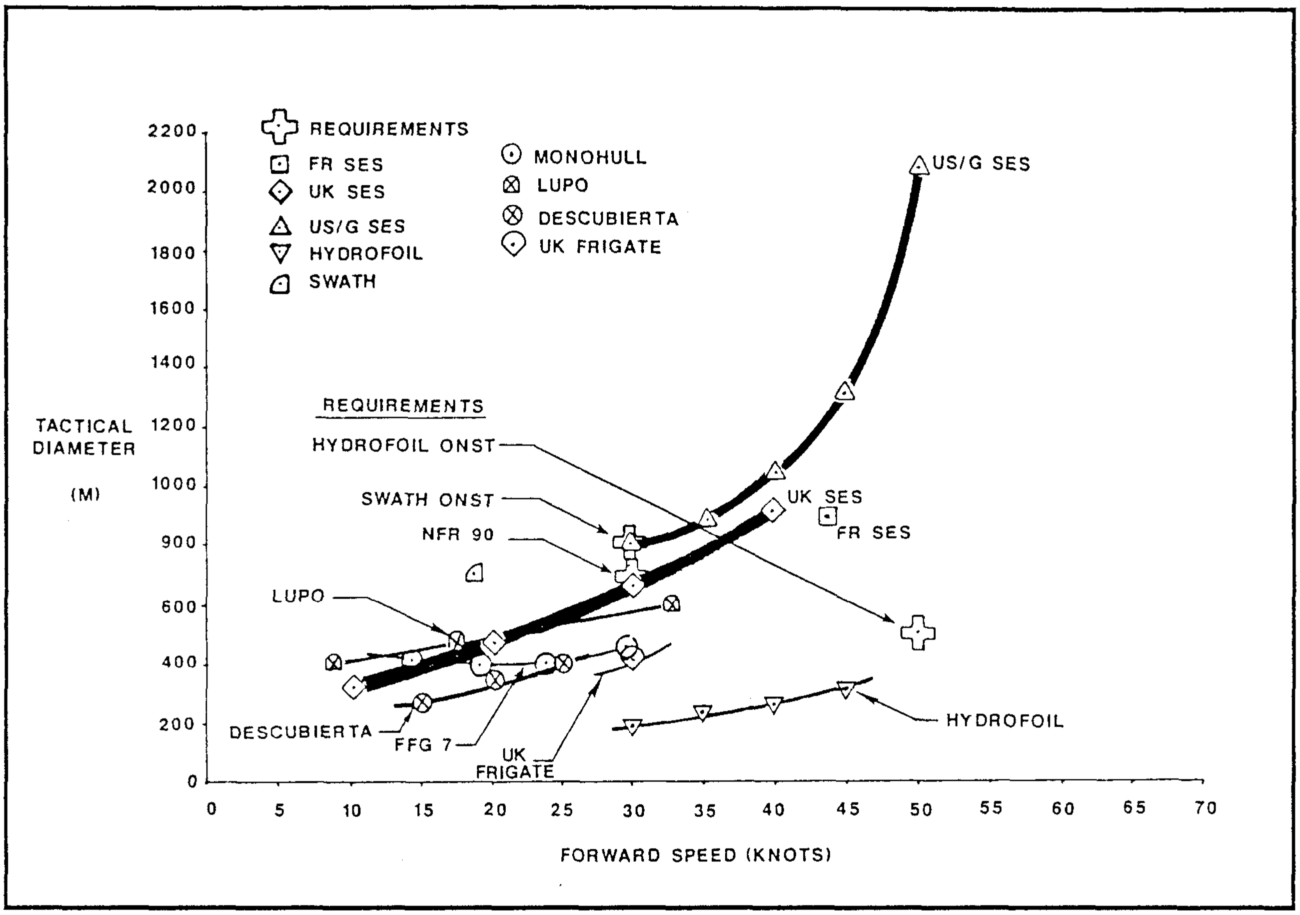


Figure 3.2.4-2. Tactical Diameter Versus Forward Speed in Calm Water

The hydrofoil uses its forward strut for steering in the foil-borne mode to produce fully coordinated banked turns, the radius of which is little effected by forward speed. Hullborne maneuvering is accomplished with the steerable strut and differential propeller thrust. With the foils retracted, the craft maneuvers with retractable stern drives and fixed-pitch propellers.

The SWATH maneuvers with a set of canted stabilizers placed forward of the trailing edge of the strut. This is a fairly new concept studied at DTNSRDC for the SWATH T-AGOS 19 design to eliminate the need for an additional rudder system. Low speed maneuvering is achieved with differential thrust.

In general, maneuverability is not of profound importance to the ASW mission. However, there are certain differences in the maneuvering performance of ANVs and monohulls which may affect their day to day operation. A good directional stability characteristic is desirable in ASW, especially when towing sonar arrays behind the ship. It is also an advantage in general terms for safe navigation and in the execution of operations such as RAS. On a comparative basis of equivalent displacement, the SWATH and SES in the hullborne mode have directional stability at least equivalent to, and probable in excess of, that of a monohull or hydrofoil in the hullborne mode.

High-speed turns are of no greater importance for ASW than for other forms of naval ships although it is obvious that good turn rate at high speed is always an advantage for tactical maneuvering. A foilborne hydrofoil and an equivalent sized monohull would have better high speed turning capabilities than an SES or SWATH, but as stated earlier, the UK and FR designs meet the NFR 90 SOW requirement for tactical diameter. This does not apply to lower speed turns where the SES and SWATH have far better turning circle diameters than a monohull. This is due to the very wide separation of the propulsors, which is an inherent feature of SES, SWATH and catamaran platform types. Large commercial craft, such as the 33 m, Marintechnik catamaran ferries, have proved to be exceptionally maneuverable with results showing that they can turn in approximately 1.5 craft lengths. This level of maneuverability was also demonstrated in the UK by a 1/10th scale manned model of a proposed SES. The use of differential thrust also enables SES and SWATH to berth or come alongside with greater ease than equivalent monohulls.

The technical risk associated with the maneuverability predictions is low since all point designs used model test data.

3.2.4.3 Acceleration Time and Stopping Distance

Figure 3.2.4-3 compares, as a function of ship forward speed achieved, the time required to accelerate from zero speed. The predictions presented for the UK SES and FR SES appear to agree well with each other for speeds up to approximately 40 knots. The time required for the FFG 7 monohull to accelerate at "ahead flank" to 28 knots from dead-in-the-water is approximately four times greater than for the SES. The full-scale LUPO results indicate that the SES is capable of accelerating in less than twice the time required for the comparable class monohull.

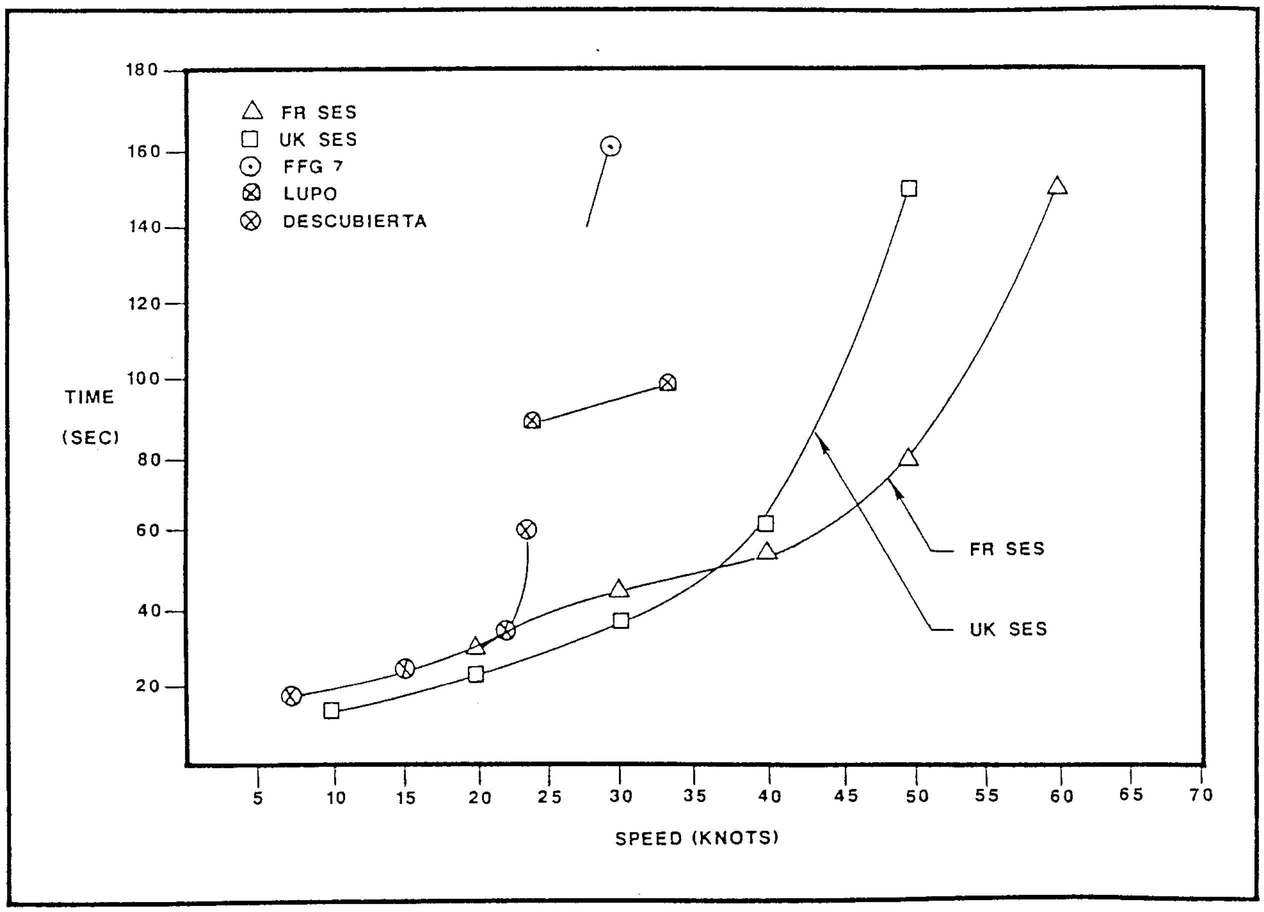


Figure 3.2.4-3. Comparison of Time of Acceleration to Speed

The predicted distances required to stop are compared in Figure 3.2.4-4. The French SES is predicted to have a much shorter stopping distance than the U.K. SES for speeds below 50 knots. The distance required to stop the FFG 7 from 28 knots is approximately twice the distance required for the UK SES and four times the distance required for the FR SES. The LUPO monohull is out-performed by the SES by a factor of approximately 2.0, while the DESCUBIERTA class indicates distance required to stop greater then the SES by only a factor of about 1.3. When stopping from speeds of less than 22 knots, the deceleration performance of the DESCUBIERTA is as good as the SES. The performance of the US/G SES, Hydrofoil and SWATH point designs were not available for comparison.

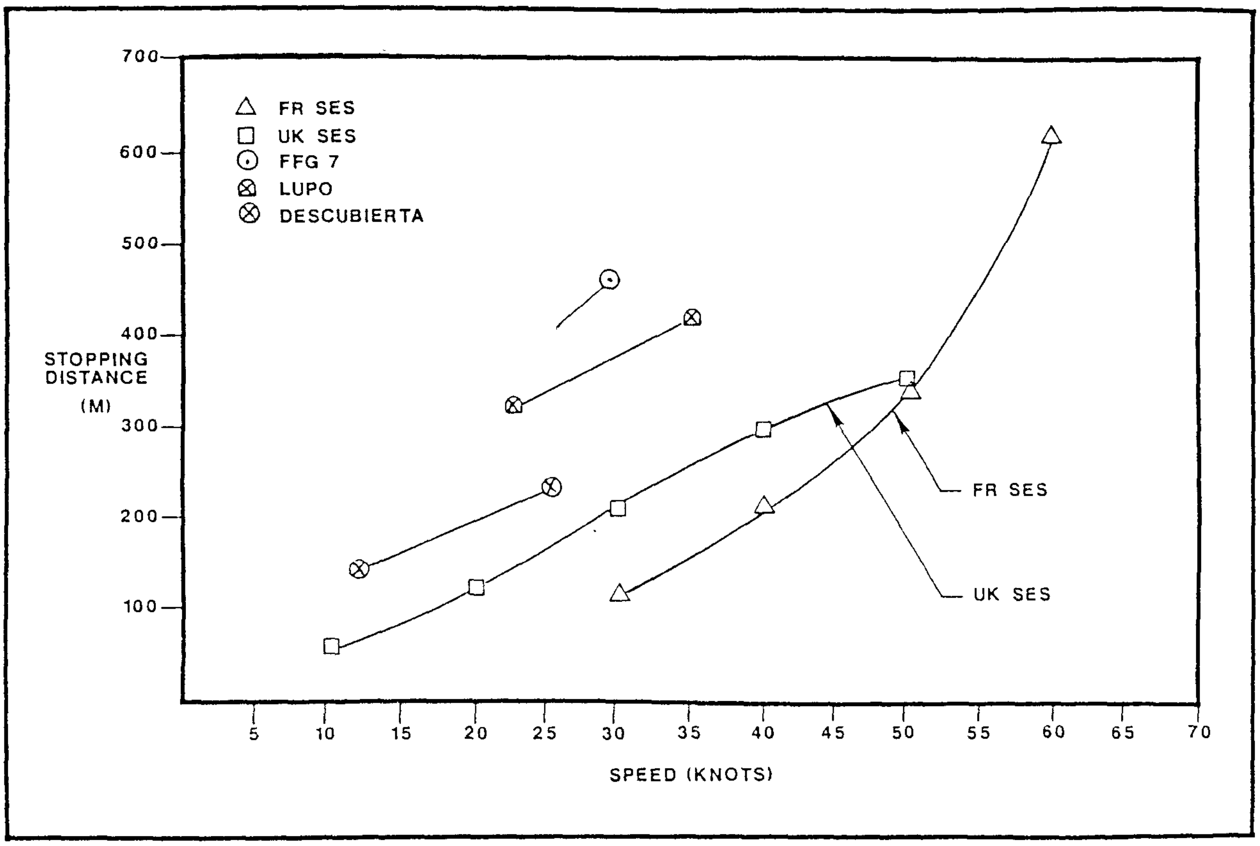


Figure 3.2.4-4. Comparison of Stopping Distance vs. Speed.

3.2.5 Seamanship and Navigation

3.2.5.1 Navigation

SES platforms as represented by the SES Point Designs have no significant navigational advantages or disadvantages over a conventional monohull. The navigational drafts, ranging from 3.9 m to 6.7 m off-cushion depending primarily on rudder configuration, do not restrict the mobility of a platform operating in normal mission areas and ports. The waterjet propulsion proposed in both the UK and FR designs provide increased propulsor survivability to grounding since neither the propulsor nor the steering equipment project below the keel, whereas, the US/G SES has a more vulnerable rudder configuration.

The U.S. Hydrofoil, hullborne with its foils down, draws 8.6 m which is more than any of the SES's and which may restrict its mobility in this condition. However, for low speeds, the foils can be raised giving a draft of 2.8 m which is less than that of any of the SES's, the FFG-7 or the SWATH. The CA Hydrofoil on the other hand has a more severe draft restriction because of its non-retractable foils. Its navigational draft is approximately 4.1 m when foilborne, but increases to 8.6 m when hullborne. This limitation could be a problem if the vessel were deployed from small coastal facilities. The scenario as an ASW frigate or corvette would, however, likely envolve operations from major naval bases.

The US/G SES and the U.S. Hydrofoil both use HYCATS, the Hydrofoil Collision Avoidance and Tracking System, developed for high-speed Hydrofoils and currently in use on the PHM's. It is assumed that the Collision Avoidance Systems specified in each of the Point Designs are similar to traditional practice and sufficient for the increased speed capabilities.

The SWATH design has an initial design draft of 9.2 m; greater than all other ANV configurations. The end of life draft of 9.6 m includes an increase due to weight growth over the life of the ship. The final draft of 9.6 m is more restrictive than the draft of a similar mission monohull (FFG-7 operational draft is 8.6 m); however, it can easily be accommodated in most deep-water ports.

The navigation system proposed for the SWATH includes SATNAV, OMEGA and TACAN Systems similar to the other ANV's. The SWATH uses a fiber-optic distributed data base system and is capable of integrating data from all the standard ship's navigation sensors with its own redundant inertial navigation system. It also includes an automatic collision avoidance system, a harbor maneuvering capability for automatic berthing and a capability to store all charts and chart data on optical storage media.

3.2.5.2 Anchoring

The operational requirements for anchoring systems on SES, Hydrofoil and SWATH designs do not deviate significantly from standard monohull practice. The anchoring systems used in the SES and Hydrofoil Point Designs vary somewhat but generally appear adequate based on systems sized for existing designs with similar platform characteristics. The UK SES uses two (2) high holding power anchors (920 kg bower and 325 kg stream) with anchor chain. The FR SES specifies two (2) Danforth type anchors with steel cable and chain. The US/G SES, presumably to reduce weight, specifies only one (1) lightweight STATO-anchor with nylon rope and chain. The use of a nylon rope for anchoring purposes is not standard practice since the weight of chain is relied upon to facilitate anchor setting; however, a combined steel chain and synthetic line could satisfy this function as well as reduce weight. This approach requires further evaluation. The U.S. Hydrofoil has one lightweight anchor with chain similar to that of the PHM hydrofoil.

The SWATH design has a single anchor deployed from the bottom of the port lower hull due to lower hull interference that would be encountered with conventional anchoring techniques. The system is similar to that found on submarines; however, the twin hull nature of this vessel could yield unsymmetric (weathervaning) about this point, yielding higher drag forces on the vessel and hence on the anchor and anchor line. This approach is also used on some surface combatants with large bow sonars; however, concerns have been expressed with respect to reliability.

3.2.5.3 Visibility

The primary obstacle to adequate visibility on monohulls, hydrofoils, and SES designs are obstructions to the line of clear sight from the bridge. Forward, the major obstruction is the bow of the ship; outboard, it is the side of the ship, and aft, it is typically the stacks, hangar or aft superstructure. Each of these obstructions create a blind spot, a limit to visibility, that becomes critical when maneuvering in close quarters alongside a pier or buoy, or performing rescue operations. The narrow pilot house and lack of bridge wings on the US/G SES limits direct visual access alongside and contributes to the blind spot aft. The stacks and hangar obstruct a clear view of the transom and aft quarters both port and starboard. On the FR SES, a 360 degree range of visibility is obstructed only by the stacks; however, the transom and flight deck are not visible from the bridge due to the step in the box structure aft. The range of visibility on the UK SES is obstructed only by the port and starboard stack arrangement and by the hangar which obstructs the transom. However, there is a clear view of the aft quarters both port and starboard, and the visibility alongsides is significantly improved by the extended bridge wings.

The hydrofoils generally have lower angles of declination and hence poorer near-limiting visibility ranges than the SES's or SWATH. The angle of visibility at 360 degrees is good; however, visibility of the transom area is restricted by the deckhouse and stacks. The height of the pilot house above the waterline is greater than that of the FFG-7, indicating a greater overall visual distance.

On the SWATH bridge wings provide generally good visibility fore, aft, and athwartships. The height of the hangar is such that personnel on the bridge wings have a limited line of sight aft, and visual access to the transom is blocked. The extension of the bridge wings outboard provides a high angle of declination athwartships (80 degrees). The total range of visibility is restricted only by the integrated stack and mast. The angle of declination forward, and the visibility restricted distance forward, are comparable to the other ANVs and the monohull.

The SES, SWATH and Hydrofoil Point Designs are compared to the FFG-7 in Figure 3.2.5-1 for range of visibility, and angle of declination forward and athwartships. The ranges of visibilities show that visibility is generally more restricted on the SES Point Designs, although the ranges of visibility tend to be limited by the geometric relationship of the stack and hangar to the pilot house and bridge wings. The effect of these obstructions can be reduced through extended bridge wings and alternate main machinery uptake configurations. The necessary ranges of visibility are the results of various design options, none of which are inherently better or worse on SES or on hydrofoil platforms.

3.2.5.4 Mooring

The large separation between thrust lines provides effective differential thrust, giving SES platforms a distinct advantage in low speed maneuvering and mooring operations relative to a monohull. The use of waterjets with directional thrust gives the UK and FR SES designs still greater low speed maneuverability. The Hydrofoil uses twin auxiliary propulsion units for low-speed maneuverability with the foils up. Compared to the SES for its size the Hydrofoil has less power and less thrust separation.

The projection of waterjet propulsors aft of the transom may require collision guards to be installed on the UK and FR SES designs. Likewise, protection from collision damage, both athwartships and aft, for the propellers used in the US/G SES design, will also be required. All propulsor guards could be mounted above the hullborne waterline to eliminate detrimental appendage drag at endurance speed. No guards are installed on the Hydrofoil to protect the foils or propellers while docking, instead camels are used when mooring alongside piers.

The primary restrictive element of the SWATH design with respect to mooring is the extension of the lower hulls forward of the struts. This represents a potential for damage below the WL in the event of a collision during mooring. Additionally, the large surface area of the SWATH could complicate mooring during conditions of high wind. The transverse separation of propellers should improve differential thrust characteristics for maneuvering; however, the use of canted rudder-stabilizers will provide low rudder effectiveness at very low speeds. The propellers will require guards to ensure no damage is incurred in docking and mooring evolutions.

3.2.5.5 Icing

The primary source of moisture for icing is sea spray generated as the vessel passes through waves. For SES's this spray may be increased when on-cushion; however, the increased freeboard may somewhat reduce the effect. The SWATH's much higher freeboard and hullform may also tend to mitigate spray and limit ice buildup. Generally, topside icing may be reduced on SES and SWATH platforms and exacerbated on Hydrofoils compared to monohulls. It should be noted that the sensitivity of icing parameters to ship characteristics has not been quantified to a degree that will permit an assessment for these designs.

3.2.6 Combat System Compatibility

Combat system compatibility is the ability of a given platform to accommodate various combat system elements. Platform characteristics and attributes, such as speed, principal dimensions, hull configuration and topside deck area, influence the arrangement and operation of combat system components. The integration of ASW mission combat systems, exemplified by the ANV Point Designs, provides a wide spectrum of design approaches.

3.2.6.1 Combat System Arrangements

Catamaran hull configurations impose certain physical limitations on the arrangement of larger, conventional combat systems. The box structure on the SES and SWATH hulls, which is traditionally only one or two decks high, limits the use of deep combat system modules. Three deck high VLS launchers, for example, cannot be located in the box or cross structure. This requires the VLS modules to be located either within the deckhouse or outboard of the inner sidewall longitudinal bulkheads, extending down into sidehulls or strut haunches where narrow widths may limit their fore and aft placement or require the use of non-standard modules.

	CA Hydrofoil	UK SES	FR SES	US/G SES	SP SES	FFG-7	U.S. Hydrofoil	SWATH
Range (δ_1)	334^o	336^o	353^o	334^o	360^o	360^o	360^o	360^o
Angle of Declination Athwartships (β)	39^o	54^o	41^o	41^o	73^o	90^o	45^o	80^o
Fwd (α_1)	5^o	5^o	7^o	5^o	7^o	5^o	9^o	9^o
X_1 (m) (hullborne)	57.3	49.4	73.8	66.4	54.7	133	32.3	77.4^o
X_2 (m) (hullborne)	6.4	4.2	4.2	10.1	1.5	0	4.3	3.8
Mn Dk Ht Above Hbwl (m)	2.6	6.9	5.6	5.5	4.9	4.3	4	9.6
Hb Wl (m)	1.8	4.6	4.0	3.6	4.4	4.8	2.8	9.2
02 Lvl Bridge Above Hbwl (m)	7.9	12.8	12.5	8.3	10.1	8.0	9.1	14

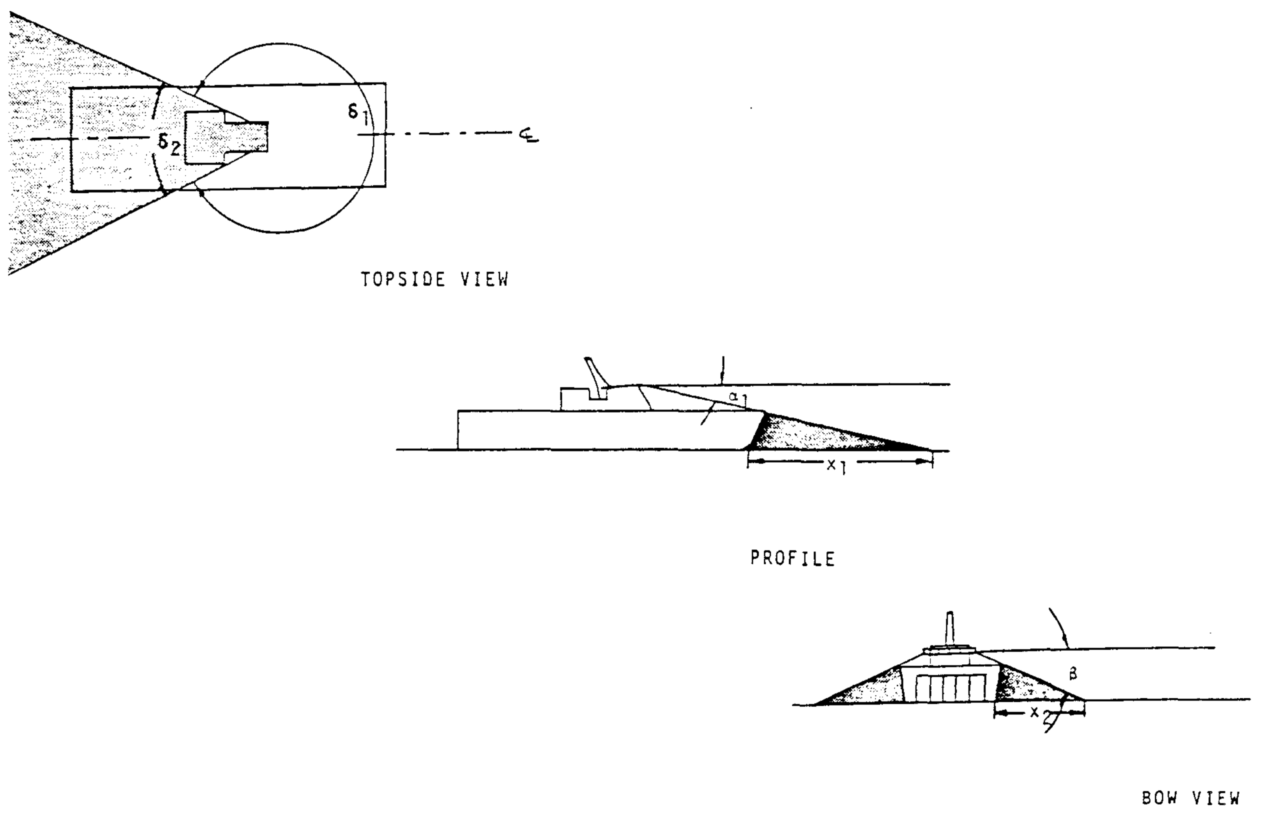


Figure 3.2.5-1. Range of Visibility

This is illustrated in the combat-system arrangement for the US/G SES, which includes VLS launchers extending down into the sidehulls as shown in Figures 3.2.6-1 and 3.2.6-2. This arrangement required the use of non-standard VLS modules with location limited to the middle third of the sidehull due to the narrow forward and aft sections of the lenticular hullform. This limitation is characteristic of catamaran platforms in the size range of the three SES point designs; obviously, larger SES's would not exhibit such restrictive arrangements. The larger CA SWATH was still forced to locate its VLS launchers in the outboard areas above the struts but was able to position them relatively far forward, because of its launch configuration.

The clear deck area available on SES and SWATH platforms is primarily a function of the superstructure configuration. The point designs illustrate the wide variation in available deck area, as shown in Figures 3.2.6-1 and 3.2.6-2. US practice has traditionally been to attempt to achieve minimum deckhouse size, thus reducing interference between superstructure and combat systems, which results in reduced weight topsides and reduced radar signature. The UK SES and FR SES integrate their combat systems within a larger deckhouse structure. This arrangement does not provide as much protection for combat system spaces as the US/G SES design, which has arranged all major combat system spaces within the central portion of the cross structure. The CA SWATH also has most of its combat spaces within the central box structure. Its large deckhouse, for example, consists primarily of a hangar large enough to garage 4 helicopters.

The wide beam of SES and SWATH platforms provides a wider flight deck for safer flight operations as compared to a monohull. The typical deck length, however, sometimes is limited by the required locations of the stack and weapon systems. The desirability of locating main machinery as far aft as possible to minimize shaft lengths can result in the gas-turbine exhaust stacks being placed relatively far aft. The CA SWATH, with electric drive, does not have this limitation.

Flight operations may also be restricted at the high speeds (50 + kts) achievable by the relatively small ASW escort SES platforms since the maximum wind over deck limitation is approximately 40 kts for helo operations. This characteristic can also be used to advantage by permitting proper relative wind conditions over a wider range of courses and true wind characteristics giving SES's greater operational flexibility in conducting flight operations.

Table 3.2.6-1 lists the combat suites envisioned for the three SES's, SWATH, and Hydrofoil Point Designs. The arrangements shown in Figures 3.2.6-1 and -2 show the wide variation in topside arrangement possible with the SES configuration.

The VLS used on the U.S. Hydrofoil requires a large amount of hull depth, which was only available just forward of the machinery in the deckhouse. This, unfortunately, results in its placement amidships where a weapon is most likely to strike and where the exhaust plume may impact other weapons and sensors.

The Hydrofoils have large deckhouses, which limit the usable deck area to just forward and aft of the superstructure. Although the flexibility of the more spacious deck of the SES designs is not available on the Hydrofoils, the combat systems were not greatly affected as many of the systems could be mounted on top of the deckhouse where they benefited from improved arcs of fire and reduced deck wetness, in addition to being located on the main deck. This is particularly true of the U.S. Hydrofoil. On the CA Hydrofoil most fo the weapons have been retained on the main deck, with the exception of the CIWS which is on the 01-level.

The arrangement of radar and communications equipment on SES's and SWATH's may vary slightly from conventional monohull practice. The lower L/B decreases length available for antenna and radar equipment separation needed to reduce electromagnetic interference (EMI); however, potential EMI problems resulting from tight longitudinal arrangements may be mitigated by the transverse separation achievable on SES and SWATH platforms. The CA SWATH, for example, has (4) whip antennas arranged transversely on top of the hangars.

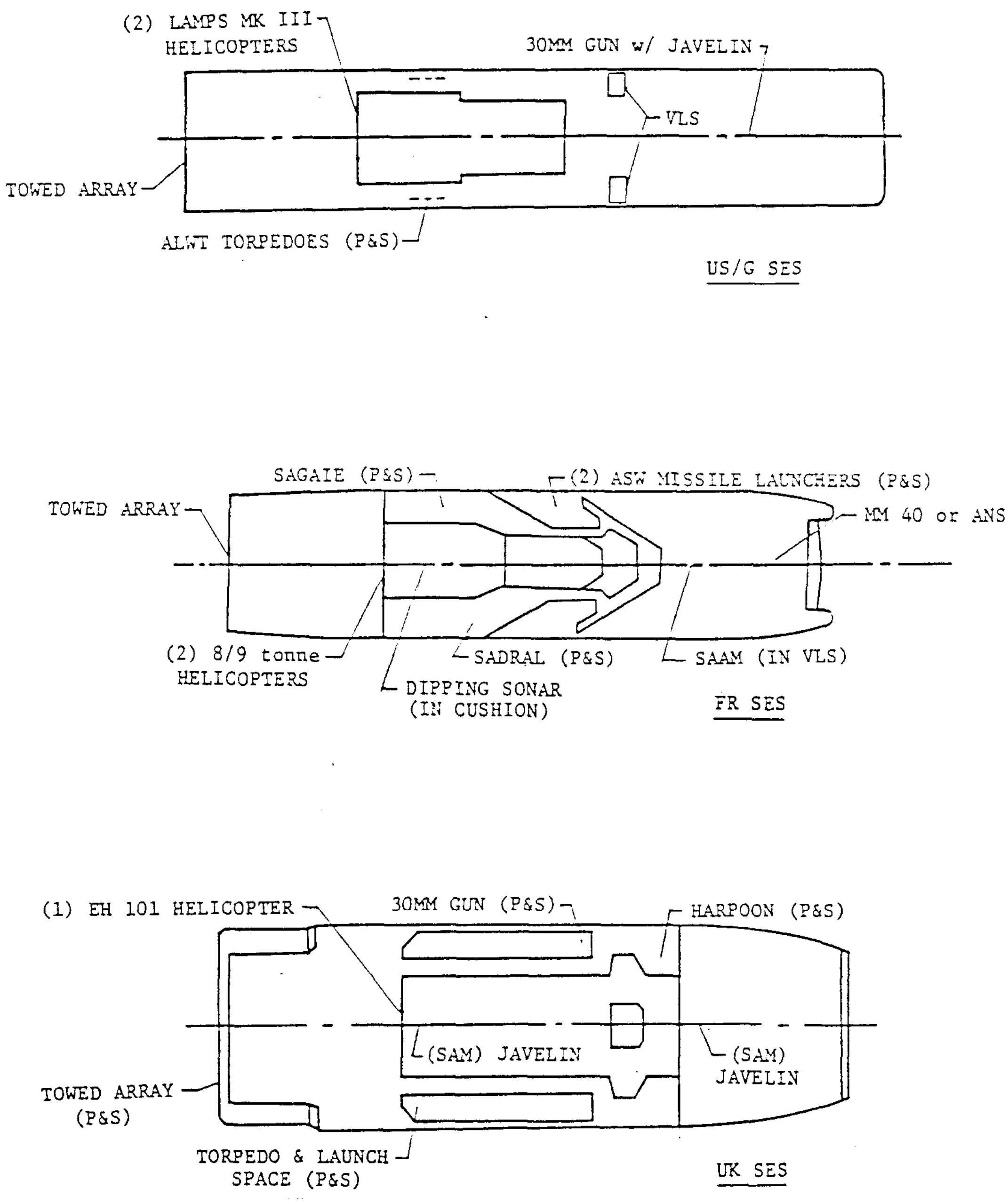


Figure 3.2.6-1. Combat Systems Arrangements Plan View (Sheet 1 of 2)

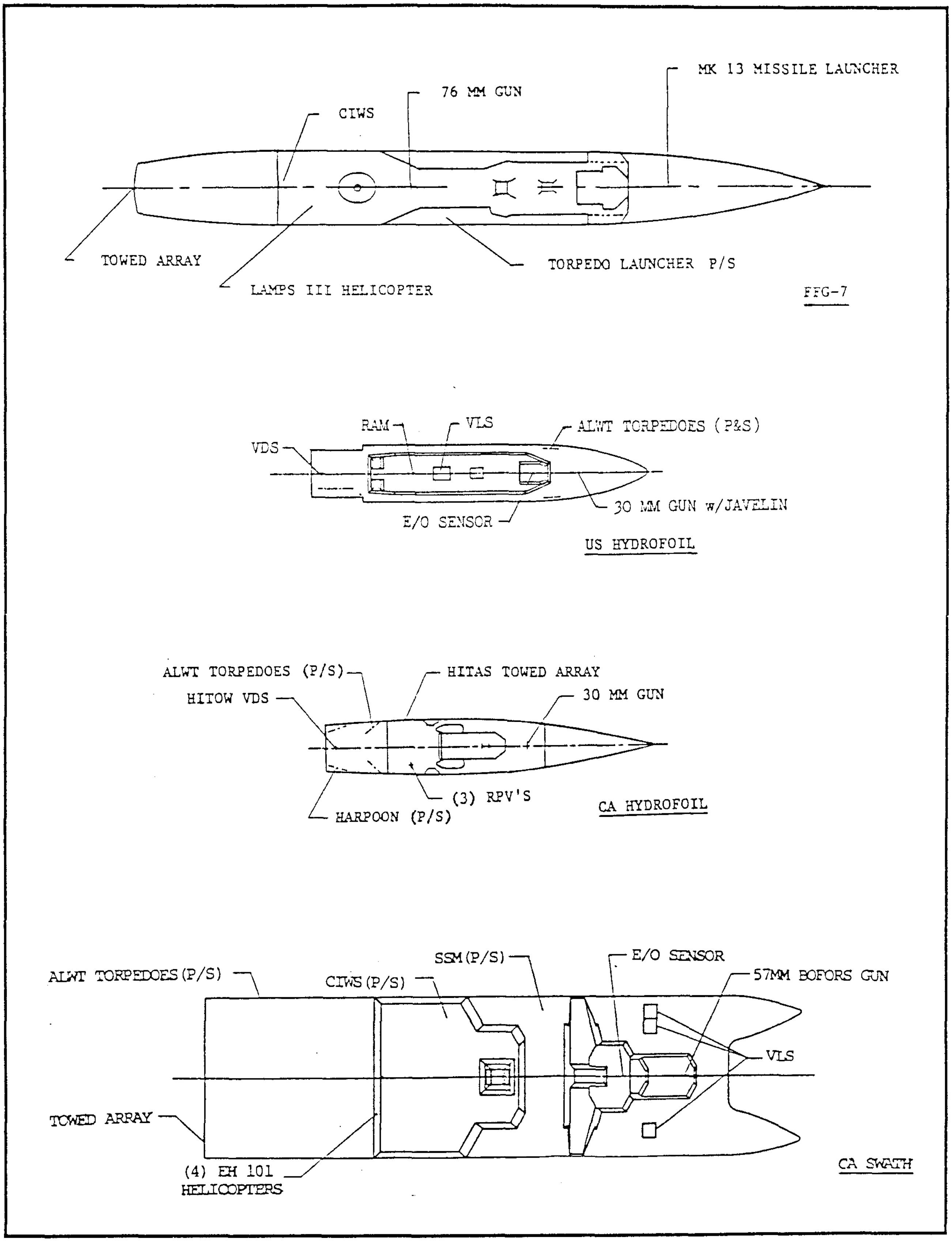


Figure 3.2.6-1. Combat Systems Arrangments Plan View (Sheet 2 of 2)

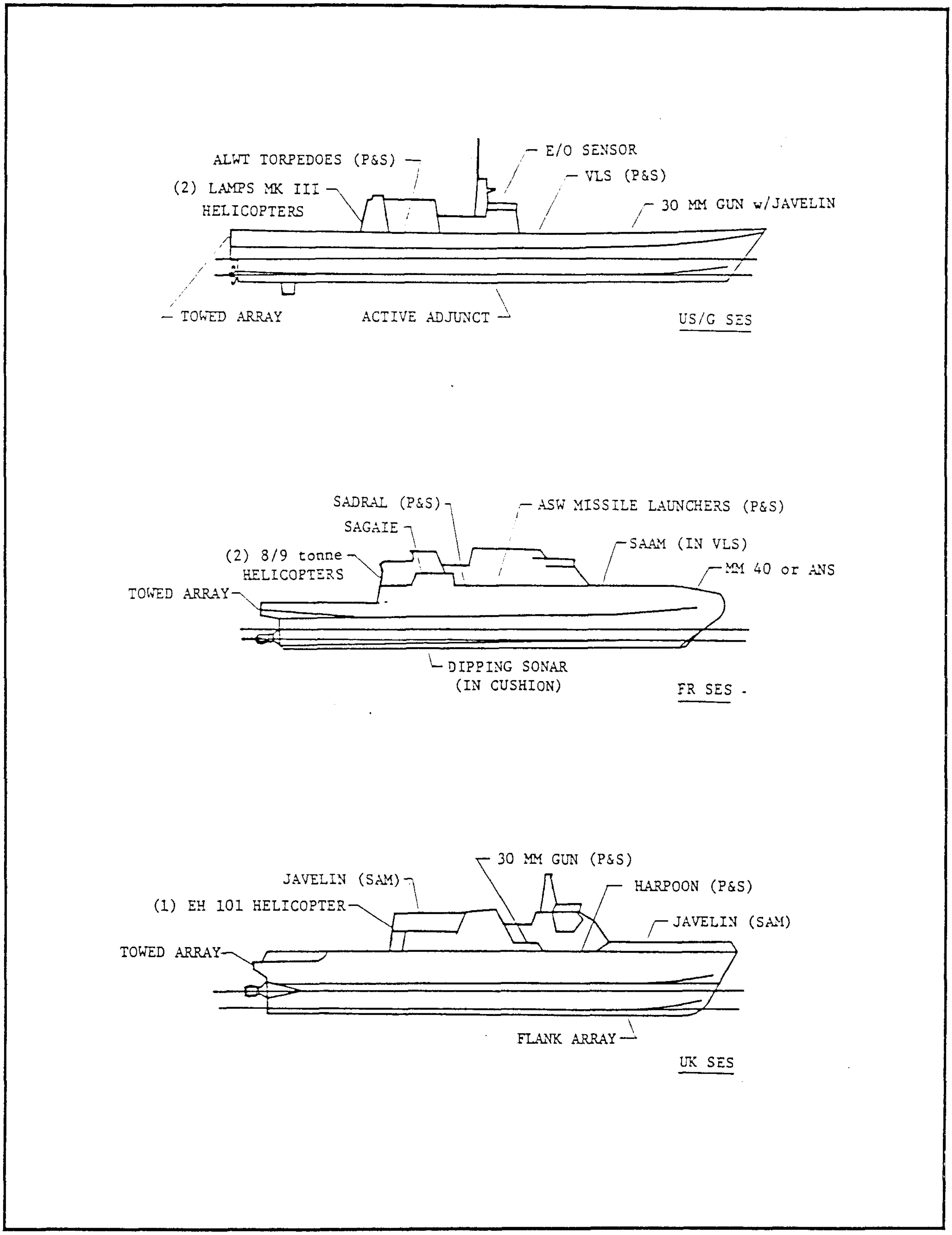


Figure 3.2.6-2. Combat Systems Arrangements Profile View (Sheet 1 of 2)

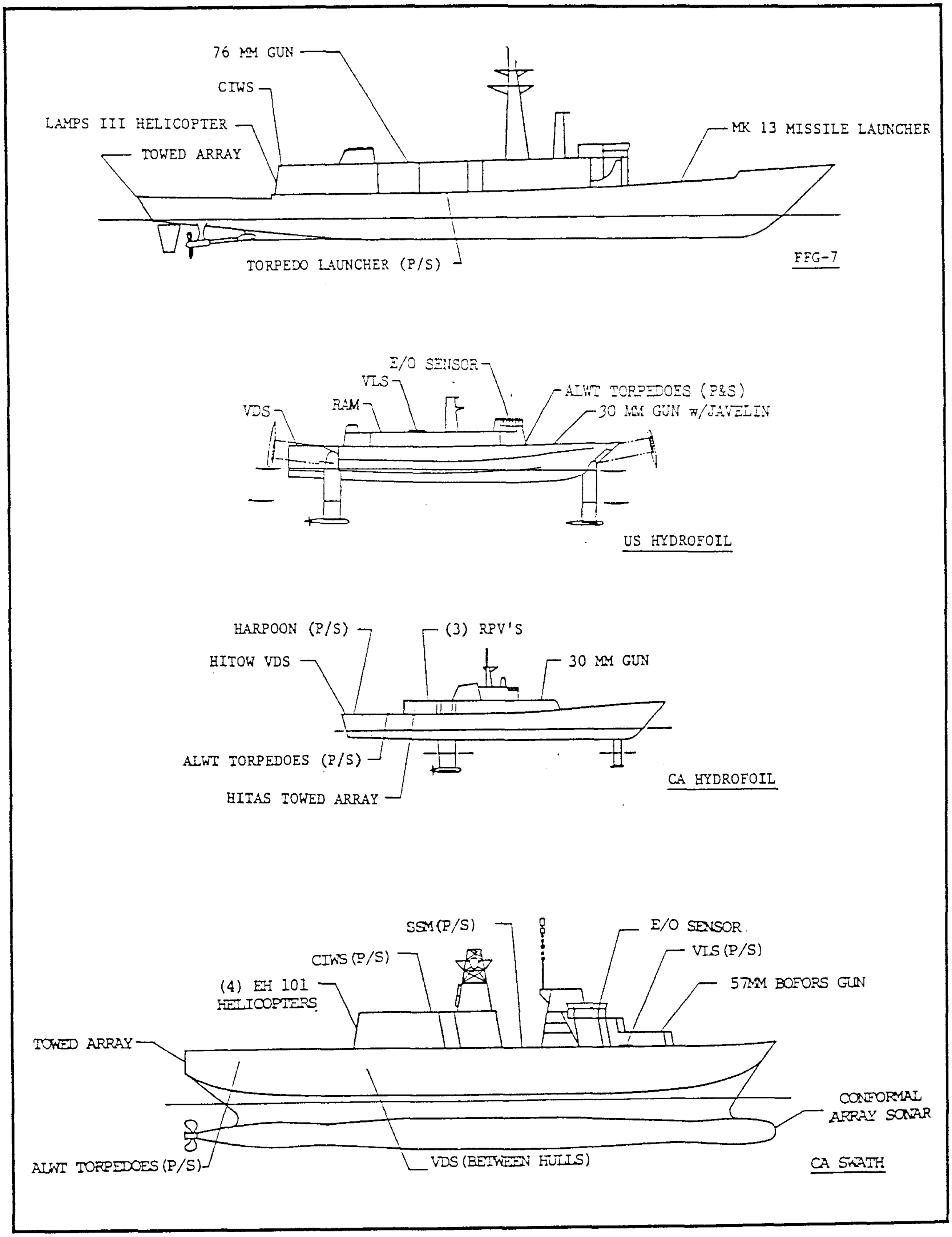


Figure 3.2.6-2. Combat Systems Arrangments Profile View (Sheet 2 of 2)

Table 3.2.6-1. Combat System Summary

	CA Hydrofoil	UK SES	FR SES	US/G SES	SP SES	Hydrofoil	SWATH
Guns	(1) 30 mm CIWS (Goal-keeper)	(4) General Purpose Machine Guns (2) 30 mm Guns (LS 30 B)	(2) 30 mm CIWS (Goalkeeper) (Optional)	(1) 30 mm CIWS (Goal-keeper)	(1) 76/62 76 mm (Oto Melara) (1) 20 mm CIWS (Meroka)	(1) 30 mm CIWS (Goal-keeper)	(1) 57 mm DP (BOFORS) (2) 30 mm CIWS (Phalanx)
Missiles	(8) Antiship Missiles (Harpoon)	(50) AAW Close In (JAVELIN) W/2 5 Round Launchers or High Velocity Missiles (HVM) (4) Antiship (Harpoon) Canister Launched (16) Antiship Medium Range (Sea Skua) Helo Launched (?) ASW Missile Carried Torpedoes (MCT) Canister Launched (Optional)	(12) AAW Close In (SADRAL) W/2 Launchers (Not on CIWS Equipped Options) (16) AASW (SAAM) VLS Launched (4) Antiship (MM40 or ANS) W/Canister Launchers In Bow (4) ASW Missile Launched Torpedoes (NTL 90) W/ Canister Launcher	(50) AAW Close In (JAVELIN) W/2 Triple Launchers (4) AAW Medium Range (SM1) VLS Launched (6) Antiship (Harpoon) VLS Launched (6) ASW Standoff (ASROC) VLS Launched	(65) AAW Close In (JAVELIN) W/3 5 Round Launchers (6) Antiship Missiles (Harpoon) VLS Launched (4) AAW Medium Range (SM-2) VLS Launched (6) ASW Missiles VLS Launched	(18) AAW Close In (JAVELIN) W/2 3-Round Launchers (21) AAW Medium Range Box Launcher (4) ASW (ASROC) VLS Launched (4) Antiship (Harpoon) VLS Launched	(56) AAW Close In (Sea Amraam) VLS Launched (8) Antiship (Harpoon) Canister Launched (4) ASW Standoff (ASROC) VLS Launched *VLS Has a Strike-down Capability
Torpedoes	(12) Lightweight (A LWT) W/2 (MK 32 Mod 9) Triple Tubes	(24) Lightweight (Stingray) Helo and Tube Launched W/4 Tubes In Magazine	(16) Lightweight (NTL 90) Helo Launched	(24) Lightweight (MK 50) Helo and Tube Launched W/2 (MK 32) Triple Tubes	(18) Lightweight (MK 50) Helo and Tube Launched W/2 SLTT Tubes	(6) Lightweight (MK 50) W/2 (MK 32) Triple Tubes	(48) Lightweight (ALWT) W/2 (MK 32) Double Tubes
Sonar	(1) Towed Array (HITAS) (1) VDS (HITOW)	(1) Twin Passive Towed Array (1) Or Single Passive Towed Array (Optional) (1) Or VDS Active/Passive (Optional) (Shorter Range) (1) Flank Array Active/Passive (1) Or Circular Active/Passive Array (Optional) *Sonar on Helo *Sonobuoys on Ship and Helo	(1) High/Low Freq Active/Passive Depressor Towed Array (ETBF) (1) Dipping Active Sonar *Sonobuoys on Helos	(2) High/Low Freq Active/Passive Depressor Towed Array (LASS) W/Hull Mounted Active Adjunct (1) Lamps Processor (SQQ 28) *Sonar and Sonobuoys on Helos	(1) VDS (1) Towed Array	(1) VDS (HYTOW) W/ (MK 116) ASW FCS	(1) Conformal Mounted Hull Array (1) VDS (AN/SQS-510) (1) Towed Array (AN/SQR-19 TACTAS) *Sonar and Sonobuoys on Helos

Table 3.2.6-1. Combat System Summary (Continued)

	CA Hydrofoil	UK SES	FR SES	US/G SES	SP SES	Hydrofoil	SWATH
Radar	(1) Surveillance Air Search (AN/SPS-58) (1) Surface Search (AN/SPS-67) (1) Fire Control (RCA R-76)	(1) Surveillance (ASWS 6) W/IFF (1) Navigation (1007) (2) Optronic Trackers (Sea Archer) (1) Phased Array (Optional)	(1) Surveillance (V15) (1) Navigation (DECCA) (1) FCS (SAAM) (1) FCS (Rodeo)	(1) Surveillance (Sea Giraffe (1) Navigation (SPS-64(V)9) (1) IFF (1) E/O Sensor	(1) Surveillance, Air-Surface Search (1) Fire Control Radar	(1) Surveillance (Sea Giraffe) (1) Navigation (DECCA) 'SS' (1) IFF (1) E/O Sensor	(1) Surveillance 2-D (AN/SPS-49) W/IFF (1) 3D Air Defense (GE Fast) W/IFF (1) Guns FCS Radar & Optical (HSA LIROD) (1) E/O Surveillance Sensor (AN/SAR 8)
Counter-Measures	UNKNOWN	(1) ESM System (Cutlass) (100) Radar/IR Decoys (Shield) W/2 Launchers (4) Inflatable Decoys (Rubber Duck)	(1) ESM System (ARBB 17) (1) Torpedo Decoy (Nixie) (2) Decoy Launcher (Sagate) (1) Anti Torpedo Defense (Slat) (Optional) (2) Jammers (ARBB 33)	(1) EW System (SLQ-32) (2) Decoy Launchers (Modified MK 34 W/4 Tubes Each) (1) Torpedo Decoy (SSTD) (1) Degaussing System	(2) Decoy Launchers (1) Integrated ESM/ECM System	(1) Integrated ECM/ESM System (2) Lightweight Decoy Launch System (1) Torpedo Decoy (SSTD)	(1) Integrated EDM/ESM System (Canews Ranses) W/Passive Chaff & IR Decoys & Decoys & Active Jamming (1) Torpedo Decoy (AN/SLQ 25 Nixie) (1) Degaussing System
Embarked Aircraft	(3) RPH Vehicles	(1) EM 101	(2) 8 to 9 Tonne Helos	(2) Lamps MK III	(1) Lamps MK III	(?) RPV's (Optional)	(4) Med Helos (Sea King or Equiv) (10) VTOL RPV's (Canadiar CL 227)

Although electromagnetic interference was not addressed in either design report it is expected that the Hydrofoils will have more difficulties due to their reduced arrangeable deck areas and smaller size. (The size factor of the Hydrofoils is partially mitigated by the higher length-to-beam ratio when compared to the SES and SWATH Point Designs, and the generally less complex C^3I systems found on these smaller platforms.)

Arc of fire limitations for guns on all of the ANV point designs appear similar to conventional monohulls. The UK SES has two 30 mm guns outboard to eliminate deckhouse interference and to obtain an effective 360^{o} coverage. The US/G SES, the hydrofoils and the SWATH have a centerline gun (or CIWS) forward; however, due to the small deckhouses and the location of the gun, the arcs of fire are not severely degraded.

The sonar systems employed by each of the Point Designs are listed in Table 3.2.6-1. Active/passive towed arrays are the primary sonar-system element on all three SES designs. The reliance on towed arrays is both a result of the incompatibility of traditional hull-mounted sonars as well as the improved performance obtainable with those systems. The excessive drag penalties of standard keel mounted bulb or skeg type sonars at high speeds precludes the use of conventional sonar. The US/G SES and UK SES Point Designs do, however, list hull mounted sonar equipment elements. The US/G SES uses a hull mounted active adjunct, an active emitter, in conjunction with the towed array receiving device. The UK SES employs an active/passive flank array.

The reliability of conventional towed-array systems is well tested and they appear to be very compatible with SES platform configurations. The operation of towed array sonars will require sprint-and-search operations due to the degradation of sonar performance with increased speed; however, SES platforms compensate for the sprint and drift requirement with very high sprint speeds. This allows a higher speed of advance than conventional monohull ASW configurations. The technology risks associated with high-speed deployment and retrieval, as well as high speed inactive towing are as yet unknown. A study conducted by the French indicates that deployment and retrieval of towed arrays can be successfully accomplished by SES platforms in the hullborne mode at a maximum speed of 20 knots. The state of development of these systems may represent a risk area and the actual operational characteristics are unknown at this time; however, it is projected that the system will be developed sufficiently to satisfy tactical needs.

Sonar system compatibility is much the same for Hydrofoils as for SES's. Any hull mounted sonar which requires an appendage will greatly increase the take-off power requirement and would not be usable while foilborne. A VDS or towed array overcomes these difficulties and will not reduce a Hydrofoils' effectiveness provided it can be towed at high speeds. The drag impact of the variable depth sonar is not addressed in the Hydrofoil design reports; however, it has been successfully implemented on existing hydrofoils. As with monohulls, proper integration of the conformal arrays, with the hullform, requires additional development.

The SWATH carries a towed array, a VDS, and a hull-mounted conformal array. Its greater draft will make cavitation and bubble sweepdown less of a limitation for the hull mounted array and may allow the use of higher powers. Its relatively low speed will enable a more continuous sonar operation as in a monohull as opposed to the sprint-and-search mode of the SES's and Hydrofoil. As with monohulls, proper integration of the conformal arrays with the hullform requires additional development.

A summary of the combat-system restrictions imposed on ANV platforms is provided in Table 3.6.2-2. These restrictions are in addition to the constraints imposed on traditional monohulls.

Table 3.2.6-2. Typical ANV Configuration Imposed Limitations on Combat Systems

System Element	Restriction		
	SES	Hydrofoil	SWATH
Guns	• Large Module Location • Arc of Fire	• Large Module Location	• Arc of Fire
Missiles	• Large Module Location	• Large Module Location	• Large Module Location
Torpedoes	• None	• None	• None
Sonar	• Hull Mounted Drag Penalties • Technology Risks of Hull Conformal Arrays • High Speed Array Towing • High Speed Array Deployment/Retrieval • Stationary Dipping Sonar	• Hull Mounted Drag Penalties • High Speed Array Towing • High Speed Array Deployment/ Retrieval	• Technology Risk of Hull Enclosed Conformal Arrays • Location of VDS Deployment Compartment
C^3I	• Separation for Low EMI	• Separation for Low EMI	• None
Aircraft	• None	• No Capability	• None

3.2.7 Detectibility

3.2.7.1 Radar Cross Section

The goal of Radar Cross Section (RCS) design is to reduce the radar reflectivity of the ship and, thus, the magnitude of its radar signature. There are two approaches to minimizing RCS. The first is to concentrate the radar signal to the primary and secondary axis of the ship resulting in signal spikes from the reflection of the bow, stern and sides. The second approach is to reduce the overall magnitude of the signals in all directions. By spreading the signature or reflectivity out over the entire range of detectibility the magnitude is minimized in any one direction. Regardless of which of the two approaches is used, certain geometric configurations and equipment contribute to an increased radar signature and should generally be avoided. Table 3.2.7-1 summarizes the primary contributors to RCS and the design guidelines leading to their reduction.

The UK SES has 6^{o} sloped hull and superstructure surfaces and has avoided 90^{o} corners and curved surfaces. The UK SES design contains metalized FRP composite skins in the hull and superstructure. This type of structure is intended to produce radar reflecting properties similar to those of a metal hull. Internal equipment should therefore not reflect radar transmissions.

Table 3.2.7-1. RCS Design Guidelines

CONTRIBUTOR	GUIDELINE
1. Hull	• 90° angles between the hull sides and water surface should be avoided. • Minimize size.
2. Superstructure	• $5\text{-}10^{\circ}$ slope on exterior non-horizontal surfaces. • Right angled recessed corners should be avoided due to direct reflection back to source. • Curved surfaces should be avoided due to direct reflection back to any source. • Unobstructed openings should be avoided due to resonance chamber reflection.
3. Masts and Stacks	• Enclosed and sloped as in superstructure.
4. Life Rails and Stanchions	• Radar transparent material.
5. Vents, Hatches and Bridge Windows	• Opening and windows screened with grounded conductive grid.
6. External Foundations on Combat Systems	• Same as superstructure.
7. Combat Systems and Deck Gear	• Clean uncluttered [illegible] sides • Equipment designed for minimum reflectivity. • Enclosed or recessed to degree possible to minimize reflectivity.

The US/G SES used a 9° slope in the deckhouse sides and mast. Although the box sides are vertical, they concentrate the RCS reflection directly athwartships. Curved surfaces have been avoided, with the exception of the lenticular curvature of the lower sidehulls. There is a minimum of deck c[illegible] from combat systems and deck gear.

The FR SES incorporates 5° slopes in the deckhouse sides. The primary contributors to RCS are the hull curvature, deck mounted combat systems and combat-system foundations.

In general, the point designs illustrate the RCS characteristics of typical S[illegible]atforms. Aside from the traditional box shape, which inherently concentrates the major radar reflection to th[illegible]mary and secondary ship axes, SES platforms appear to have no significant RCS advantages over conventional monohulls. On-cushion RCS for SES is a question at this time because of the increased projected area above the [illegible] and the presence of end-seal spray.

The U.S. Hydrofoil has 10° of slope in the deckhouse. All plating is or[illegible] on one of the primary axes except for the curved plating in the bow. No right angled recesses are formed[illegible] the top side arrangement is relatively uncluttered. The foils are an exception having curved surfaces and righ[illegible]s. They will have the greatest impact in the hullborne mode with the foils raised. Lowering the foils will re[illegible] the RCS signature considerably. The foilborne mode will expose more strut length and the hull bottom. The [illegible]hip will be raised 5 m so that the ship will be visible from a further distance. The small size of the ship comb[illegible] with these RCS reduction features will contribute to a relatively low RCS signature. The CA Hydrofoil's lack [illegible]tractable foil system reduces its RCS signature in the hullborne mode as compared to the U.S. Hydrofoil with[illegible] retracted (however, the U.S. Hydrofoil would not normally operate at sea with foils retracted). The apparent b[illegible] superstructure will probably be more radar reflective than the other ANVs.

The SWATH employs a topside flare of 9° and a superstructure slope of 11° for RCS reduction. Most of the plating is oriented fore and aft or transversely except at the bow. Additionally, right angle recessed corners have been eliminated. The use of non-metalic hull fittings and radar absorbing material is considered; however there will likely be some penalty in weight for the latter. The SWATH's large size and especially large freeboard will make it more visible than the other point designs, other factors being equal.

3.2.7.2 Infrared Signature

The infrared signature is a measure of the radiated heat of a given object relative to its background. The primary shipboard sources of IR signature are: (1) hot spots such as exposed exhausts from diesels or gas turbines, (2) extended warm areas, typically exterior surfaces heated by machinery and warm compartments, (3) solar re-emitted radiation. Tests performed on the SES100A and SES100B have shown that at speeds of 40 knots and above, the wind over the deck was sufficient to eliminate solar re-emitted radiation. Those tests also concluded that spray from the seals and cushion quickly cools warm areas in the outer hull structures. The point designs have not attempted specific IR signature reduction, however; inherent SES attributes should provide some IR signature reduction. No steps were taken to reduce the IR signature of the U.S. Hydrofoil but a study showed that the weight impacts of water spray cooled exhaust and special paint would be 4.1 and 3.6 MT, respectively. No assessment of IR signature or IR signature reduction methods was made in the CA Hydrofoil design report. The regenerative gas turbines of the SWATH result in exhaust temperatures equivalent to that of a diesel engine at about 300°C. It was felt that any specific IR-reduction measures for the SWATH would not be cost-effective and that IR decoys would likely be needed in any case.

3.2.7.3 Acoustic Signature

The acoustic signature for all ship types is primarily dependent on the number and configuration of underwater appendages, machinery induced vibration, and propulsor generated noise. Vendor tests of waterjet propulsors and fully submerged controllable pitch propellers for an equivalent sized monohull (on the order of 400 tonnes), indicate that the waterjets produce lower radiated noise. Further, it is believed that a semi-submerged propeller will yield equivalent if not more radiated noise levels than a fully submerged propeller, particularly in a cushionborne mode. Thus, the UK and FR SES designs that employ waterjets should have a lower acoustic signature than a comparable monohull using fully submerged propellers. The absence of rudders or other underwater appendages should further reduce acoustic noise on the UK and FR SES designs. The UK SES design report details additional efforts involving double resilient mounts for diesels and noise attenuation mounts for diesel generators. The larger volume allocated to machinery on the UK SES design is also understood to be a part of the silencing initiatives. The FR and US/G SES design reports specified only the use of "normal ship silencing techniques" presumably similar to traditional surface ship practices. Some increased radiated airborne noise may exist in SES designs relative to the other ANV's or a monohull, because of the operation of lift fans.

No special measures were taken to reduce the acoustic signature on the Hydrofoil. Compared to past Hydrofoils with waterjets the U.S. Hydrofoil will have an increased acoustic signature. No information is provided in the CA Hydrofoil design report on acoustic signature characteristics.

The SWATH uses several features to lower waterborne noise. Primary machinery is placed in a machinery box above the waterline and mounted on resilient rafts. Very quiet low RPM motors are substituted for transmission gearing, and low cavitation propellers are used. Fin noise and flow separation are considered to be potential noise generators.

3.2.7.4 Pressure Signature

Each of the SES designs will have a pressure signature roughly equivalent to a monohull of equal tonnage. No design or platform dependent advantages are known to exist for an SES at low speeds. However, the location of the negative pressure peak and the short signal duration may make SES's at speeds above 40 kts less vulnerable to currently used mines. The Hydrofoils' pressure signature was not addressed in the reports; however, it is expected that the hullborne signature will be much the same as for a monohull of equivalent size while the foilborne signature will be much smaller due to the lower wave making resistance of the foils. The SWATH will likely have a pressure signature somewhat lower than an equivalently sized monohull because of its lower wavemaking characteristics.

3.2.7.5 Magnetic Signature

The principal influence on ship's magnetic signature is the structure, contributing roughly 90% of the total magnetic signature. The remaining 10% is due to major ship systems and their foundations. The UK and FR SES designs have the distinct advantage of non-magnetic material for the hull structure, reducing the ship's magnetic signature in comparison to the steel structure of the US/G SES and the CA SWATH. These latter designs use degaussing to lower their signatures.

The aluminum structure of the Hydrofoil vessels will also greatly reduce their magnetic signature in comparison to standard steel monohulls and the US/G SES. However, the impact of steel struts and foils, while not quantified in the reports, may have a significant impact but the overall signature should still be less.

The magnetic signature of an SES or Hydrofoil is not expected to be distinguishable from a monohull having an equivalent magnetic moment. The SWATH is generally larger with a deeper draft than a monohull with the same payload capability; hence, it is likely to have somewhat higher magnetic signature. The magnetic-signature reduction procedures, i.e., degaussing, should not vary significantly from monohull technology with the exception of relocation of degaussing coils to account for different hull configurations.

3.2.8 Vulnerability

3.2.8.1 Survivability Issues

Using conventional design practice, ANV's can be designed to traditional levels of survivability. There are certain aspects inherent in the SES and SWATH platforms that may provide improved survivability over conventional monohulls. Table 3.2.8-1 lists the design items associated with each category of survivability. The Hydrofoils do not have any features, other than avoidance characteristics of higher speed and smaller sizes, that will result in better survivability than an equivalently sized monohull. All the ANV's are weight sensitive and the addition of special systems to enhance survivability will result in a reduction in performance.

3.2.8.2 Air Blast

Although the study guidance document recommended a structural resistance to an incident blast overpressure of 3 psi, the FR SES design report contains no mention of specific design efforts in this area. The UK SES, US/G SES's and the U.S. Hydrofoil have all been structurally designed to withstand 3 psi blast overpressures. The synthesis model used to develop the CA Hydrofoil does not provide a means of incorporating air-blast pressure. ANV's platforms, in general, have no inherent attributes which would improve survivability with respect to air blast. Provided that the structure is adequately designed to withstand the required levels of blast overpressures, ANV's platforms should perform similarly to monohulls. However, the ANV's increased sensitivity to weight makes the potential design for higher blast overpressure costly in terms of displacement and power requirements. The SWATH was assessed for external blast vulnerability and FAE (fuel-air explosives). Although not specifically stated, it is assumed the 3psi blast guideline of the ONST was used.

Table 3.2.8-1. Survivability Features

	UK SES	FR SES	US/G SES	U.S. Hydrofoil	SWATH	CA Hydrofoil
Fire Protection	• Fire Retardant Material/ Low Flame Spread Fabrics used in BHDS, Panels & Decks • Smoke Curtains • Auto Sensors/Controls • Flame Retardant Paint in Machinery Spaces • Fire Zones • Emergency Diesel-Driven Fire Pumps in Each Zone • Chemical/Gas for Machinery	• Smoke and Heat Sensors • Thermal Insulation • Sprinklers in Super-structure • Foam for Machinery and Aviation Facilities • CO^2 for Magazines, Machinery, and Computer Spaces • Halon for Machinery	• Fire Sensors • Automatic Halon Systems in Machinery Spaces • AFFF for Helo Facility • Fire Zones • Magazine and Hangar Sprinklers • Steel Structure	• Portable CO^2 & PK Throughout • AFFF in Fuel Spaces • Halon in Machy Spaces • Fire Zones • VLS Deluge • Magazine Sprinkler • Smoke, Thermal, and Optical Sensors • Thermal Insulation (Optional 13.3 MT Impact)	• Fixed AFFF in Machinery Spaces and Hangar/ Flight Deck • Fire Zones • Magazine Sprinkler • Halon in Electric MCS Spaces and Engine Enclosures • Steel Structure	• Not Addressed
Shock Hardness	• 0.3 Shock Factor	• Not Addressed	• 0.3 Shock Factor	• 0.3 Shock Factor	• Not Addressed	• Not Addressed
Ballistic Protection	• Light Splinter Protection of Critical Spaces Located Outboard	• Light Splinter Protection of Vital Spaces	• Ballistic Protection of Magazines, Vital Spaces	• Ballistic Protection of Vital Spaces (Optional 26.8 MT Impact)	• Ballistic Protection of Vital Spaces (25 MT)	• Not Addressed
Air Blast	• 3 Psi Overpressure	• Not Addressed	• 3 Psi Overpressure	• 3 Psi Overpressure	• 3 Psi Overpressure	• Not Addressed
NBC	• Pressurized Citadel • Decon Stations • Seawater Washdown	• Pressurized Citadel • Decon Stations • Seawater Washdown	• Pressurized Citadel • Decon Stations • Seawater Washdown	• Seawater Washdown • Pressurized Citadel and Decon Station (Optional 12.2 MT Impact)	• Pressurized Citadel • Decon Stations • Seawater Washdown	• Not Addressed
EMP and TREE	• Aluminized Conductive Coating Around Sensitive Areas • Fiber Optics in Control System to Avoid EMP Interference	• Aluminum Structure Provides Shielding	• Steel Structure Provides Some Shielding	• Aluminum Structure Provides Shielding	• Steel Structure Provides Some Shielding	• Aluminum Structure Provides Shielding

3.2.8.3 Surface Weapons Effects

The primary survivability characteristic of SES's and SWATH's relating to the effects of surface weapons is the hull configuration, which provides a degree of natural protection of internal spaces within the box structure for location of critical items, such as CIC and control spaces. The protection, primarily against fragmentation, is afforded by the wide beam and internal longitudinal bulkheads, except in certain circumstances as discussed in the SWATH Point-Design Report. This allows spaces to be enclosed within the hull envelope but not border the sideshells. By arranging the mission critical spaces within the center of the ship, the spaces located outboard, the main deck and superstructure above provide an inherent layer of protection.

The arrangement of distributive systems on SES's and SWATH's can also provide improved survivability. The wide decks, catamaran-hull configuration, and internal longitudinal bulkheads create a system that limits the extent of transverse damage. Major damage to one side amidships will not necessarily impair the ship in a particular capability. As an example, the athwartships separation and redundancy of propulsion, electrical power generation and other auxiliary systems provides two independent systems that run the length of these ships.

The Hydrofoils on the other hand with their narrow beam, large deckhouse, and lack of longitudinal subdivision will be no more survivable than a conventional monohull of similar size and less survivable than a conventional frigate.

A somewhat extensive analysis of internal blast and fragmentation susceptibility was undertaken for the SWATH. Deactivation diagrams were prepared indicating impact to various mission areas as a result of specified blast and fragmentation magnitudes. Based on the above analyses as well as the airblast analysis, several survivability enhancement features were recommended for incorporation in further phases of design:

- armour the operations room
- provide redundancy for sonobuoy processing
- relocate the Diesel/Generator Room No. 1 and Propulsion Engine and Generator compartment No. 2

The study also indicated that double bulkheads at damage control-zone borders could exacerbate a survivability problem if components or elements contributing to a mission area are not decoupled. The SWATH Point Design report notes that the use of double bulkheads and the wide beam and natural side protection tend to focus pressure and fragments inward toward interior compartments.

The combat systems on all the point designs have the ability to detect, decoy and destroy incoming missiles, although the limited combat systems on these designs could be easily saturated if desired. The SWATH, because of its large size, has, by far, the most extensive defensive weapon capabilities of any of the ANV designs.

3.2.8.4 Subsurface Weapons Effects

The vulnerability of SES and Hydrofoil platforms to subsurface weapons, such as non-contact underwater explosion (UNDEX), differs from that of conventional monohull surface combatants. The effect of UNDEX on SES platforms while on-cushion and Hydrofoils while foilborne is relatively less severe than on monohulls due to the reduced wetted surface area. For SES's there will also be some attenuation of the shock by the cushion based on extensive ACV shock-test experience in the U.S. and UK. Attenuation will also be a function of location within an SES or SWATH. While the sidehulls will experience relatively greater shock inputs, particularly in the hullborne mode, the cross-structure will receive a relatively lower input because of the load path. The degree of attenuation is as yet unknown. Tests of SES indicate that some attenuation of shock is experienced in both cushionborne and hullborne modes, because of the screening effect of one sidehull on the other. While hullborne, the Hydrofoils are likely to be just as susceptible to UNDEX as a monohull of equivalent displacement.

While extensive experience is available on the effects of subsurface weapons on steel ship hulls, the potential effects on aluminum or GRP hulls are less well known. Due to relatively lower elastic modulus somewhat larger excursions of typical GRP hull shell panels and stiffeners can be expected under shock loads unless those members are specifically designed to limit excursions. This should be considered in the arrangement of equipment, particularly in those areas of an SES with limited dimensions such as the sidehulls.

The transverse separation of the sidehulls on SES's and SWATH's does provide improved survivability against underwater contact explosives compared to conventional monohulls. The main machinery arrangement on SES's and SWATH's separates the propulsion plant and, more importantly, the propulsion shafting. On conventional monohulls, despite the 15% separation of main machinery spaces longitudinally, the shaft lines run in close proximity to one another aft of the aftmost machinery space. This increases the potential for full loss of propulsive power resulting from a single hit. This vulnerability is minimized on SES's and SWATHs by virtue of the separation of both the main machinery and shafting by the full width of the ship, although maneuverability will be reduced. Further, the use of electric propulsion in the SWATH design reduces the overall shaft length and hence vulnerability to damage. The U.S. Hydrofoil is configured to provide one compartment of separation between propulsion prime moves, while the CA Hydrofoil provides no intermediate compartments between propulsion components.

As currently configured, the SWATH does not have significant separation of propulsion electrical generators. The two propulsion prime movers have only one subdivision of separation between them and that subdivision is made up of two of the three diesel generators. The relocation of compartments, as noted above, should decrease vulnerability.

3.2.8.5 **Fire Protection**

Conventional design practices are used in the SES and U.S. Hydrofoil Point Designs to provide localized fire protection. The primary issue in fire protection for the SES and Hydrofoil Point Designs is the hull material. Fire resistance of GRP, in particular, warrants special attention. The UK SES design has specified the use of fire retardant materials throughout. Although the fire resistant properties of GRP composites are well understood, their viability for naval surface combatant applications demands further investigation. Fire protection systems for the aluminum FR SES also requires specific attention. Extensive protection of structural bulkheads and decks has resulted in increases in both weight and cost. No passive protection of the aluminum structure of either the Hydrofoils was specified. To meet the ONST requirement to prevent a bulkhead collapse after a 30-minute oil fire, it is estimated that 13.3 MT of insulation would be required to be added to the U.S. Hydrofoil design.

The wide beam inherent in SES and SWATH hull configurations provides a unique opportunity to divide a ship into longitudinal fire zones. The UK SES exploited this opportunity by using 'L' shaped fire zones on their No. 2 deck, thereby not allowing a single zone to extend full width, and thereby maintaining longitudinal access in the event of major damage. Each zone also has localized control of all major ship-system elements such as electrical power generation, HVAC, firemain, freshwater and control and access to one propulsion engine. The SWATH design employs a traditional pressurized ring main supplied by four pumps located in the four damage control zones. These zones function similar to those of the UK SES noted above. In addition to the firemain, fixed AFFF systems are specified for machinery spaces, and the hangar/flight-deck area. Halon is used for unmanned electrical/electronic spaces and engine enclosures.

3.2.8.6 Damaged Survivability

The damaged stability characteristics of an SES, Hydrofoil and SWATH, relative to a monohull, are compared in Section 3.3.21. This shows that the worst damage-case equilibrium list angle for SES and Hydrofoil platforms is significantly lower than for conventional monohulls.

The damaged stability analysis indicated that the SWATH had somewhat worse damaged stability characteristics as compared to a monohull. Although list was acceptable, according to the U.S. Navy stability criteria, damage forward or aft caused large trim angles because of the small moment-to-trim inherent in SWATH's, and, therefore, required the use of foam in forward and aft compartments to lower the permeabilities.

3.2.8.7 Arrangements

As discussed previously, SES's and SWATH's have certain advantages over conventional monohulls and Hydrofoils with respect to location of critical systems: the athwarthships separation of propulsion machinery, auxiliary machinery and transmission systems, the inherent protection afforded to the internal spaces by the wide beam, such as CIC and central control, and the lateral separation of deck mounted combat systems.

Figures 3.2.8.7-1, -2, -3, -4, -5 and -6 show the machinery and C^3I spaces for the point designs. Notice that the power distribution system on the SES's and SWATHS's affords full power to any area of the ship regardless of the location of damage, unlike conventional monohulls or hydrofoils, where the ends of the ship might be cut off from electrical power.

3.2.8.8 NBC Protection

All three SES Point Designs utilized a citadel concept for the collective protection system. The UK SES citadel encompasses all spaces inboard of the longitudinal passages on the No. 2 deck and the bridge superstructure. Neither the FR or US/G SES designs specify the extent of the CPS protection although both specify its use. The UK SES design also includes a seawater prewet/washdown system that is fed off the firemain. The Hydrofoil was not designed with a pressurized citadel; however, an impact of 12.2 MT was estimated to install one including a decontamination station. As noted previously, this added weight could significantly reduce the performance of the Hydrofoil. The Hydrofoil does have a water washdown system. The SWATH HVAC system has been organized into four citadels and five subcitadels (the main machinery spaces). Two NBC filtration plants are provided for the four main citadels and two smaller NBC filtration plants are specified for the subcitadels. Additionally, a prewetting system is used to protect the entire vessel from NBC fallout.

NOTE: With the exception of the SWATH internal blast and fragmentation studies, no specific vulnerability studies were conducted for any of the Point Designs. The observations of Sections 3.2.7 and 3.2.8 are generally supported by a previous ANV vulnerability study summarized in Volume III.

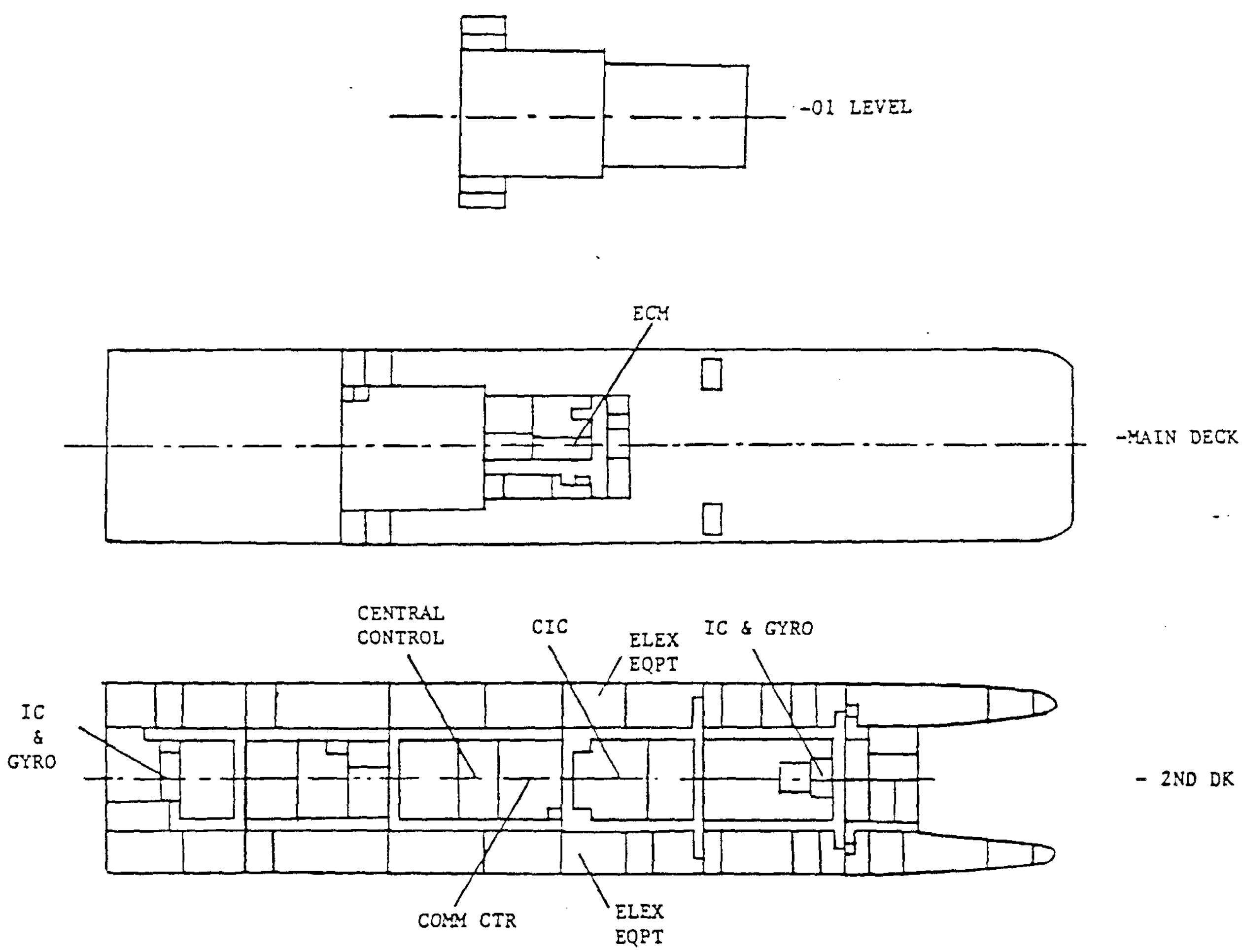


Figure 3.2.8.7-1. US/G SES C^3I Space Arrangement (Sheet 1 of 2)

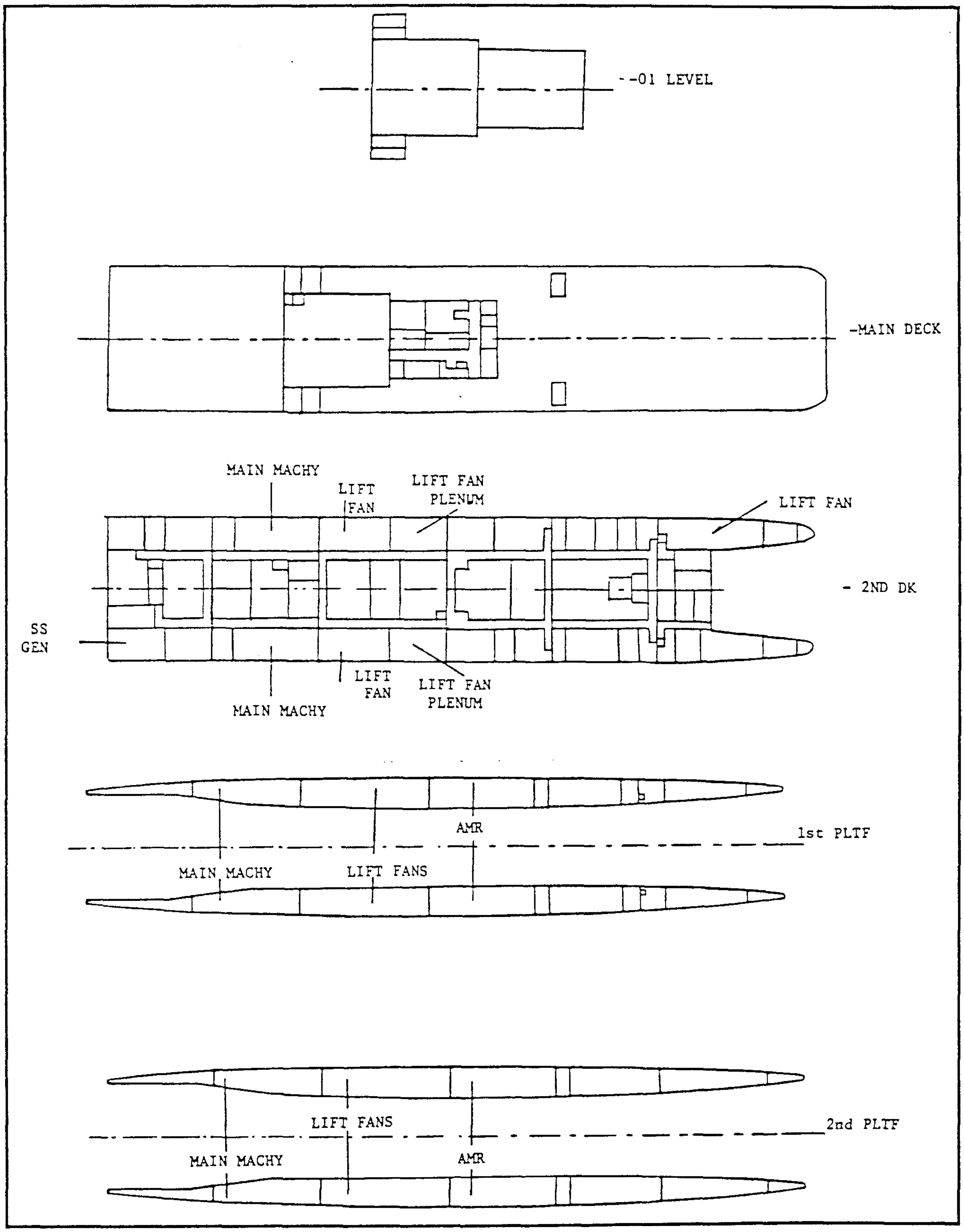


Figure 3.2.8.7-1. US/G SES Machinery Arrangement (Sheet 2 of 2)

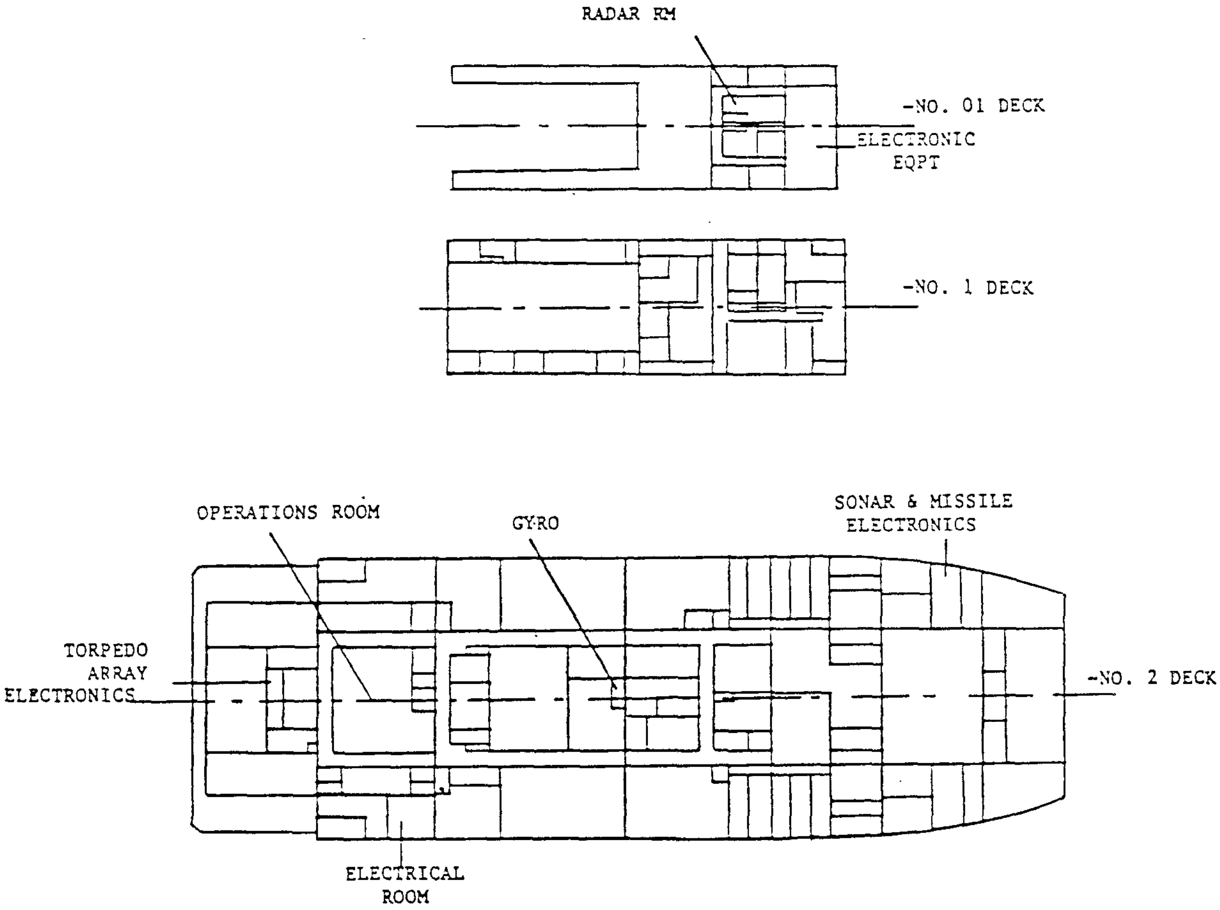


Figure 3.2.8.7-2. UK SES C^3I Space Arrangement (Sheet 1 of 2)

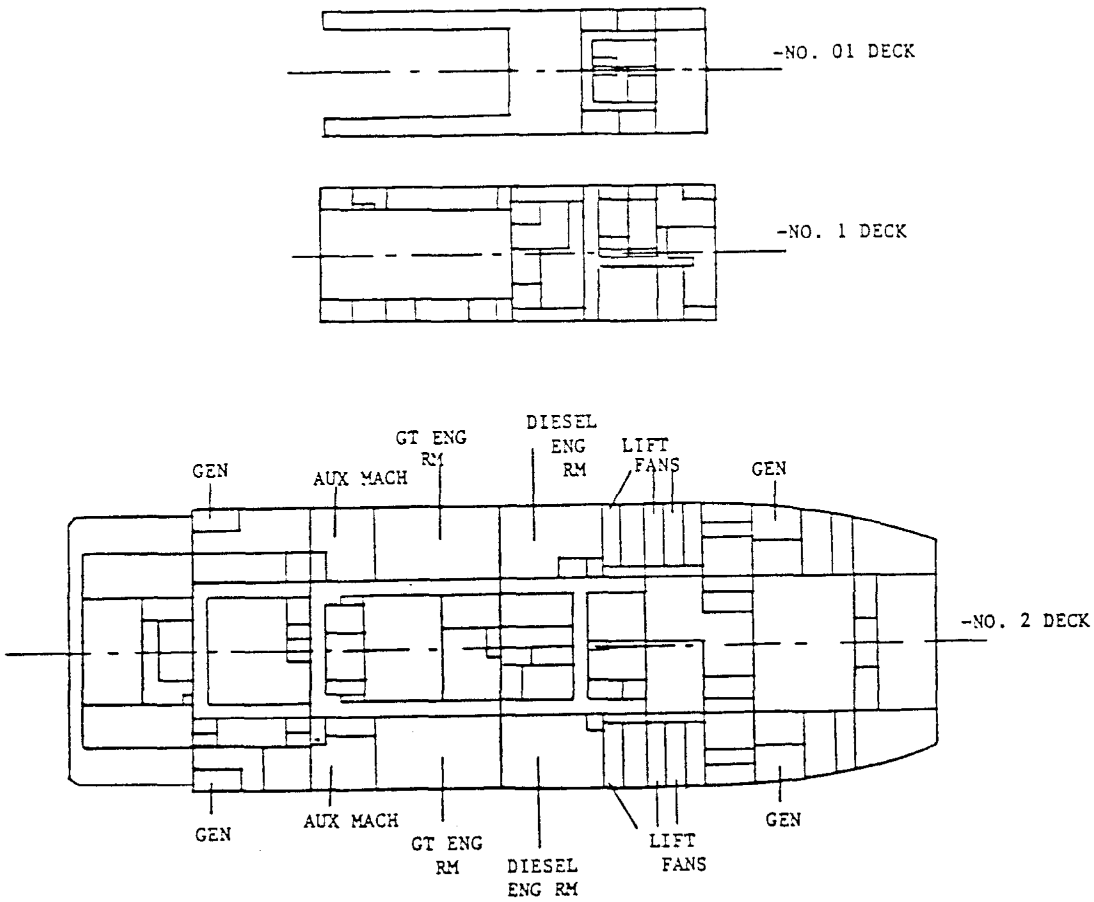


Figure 3.2.8.7-2. UK SES Machinery Arrangement (Sheet 2 of 2)

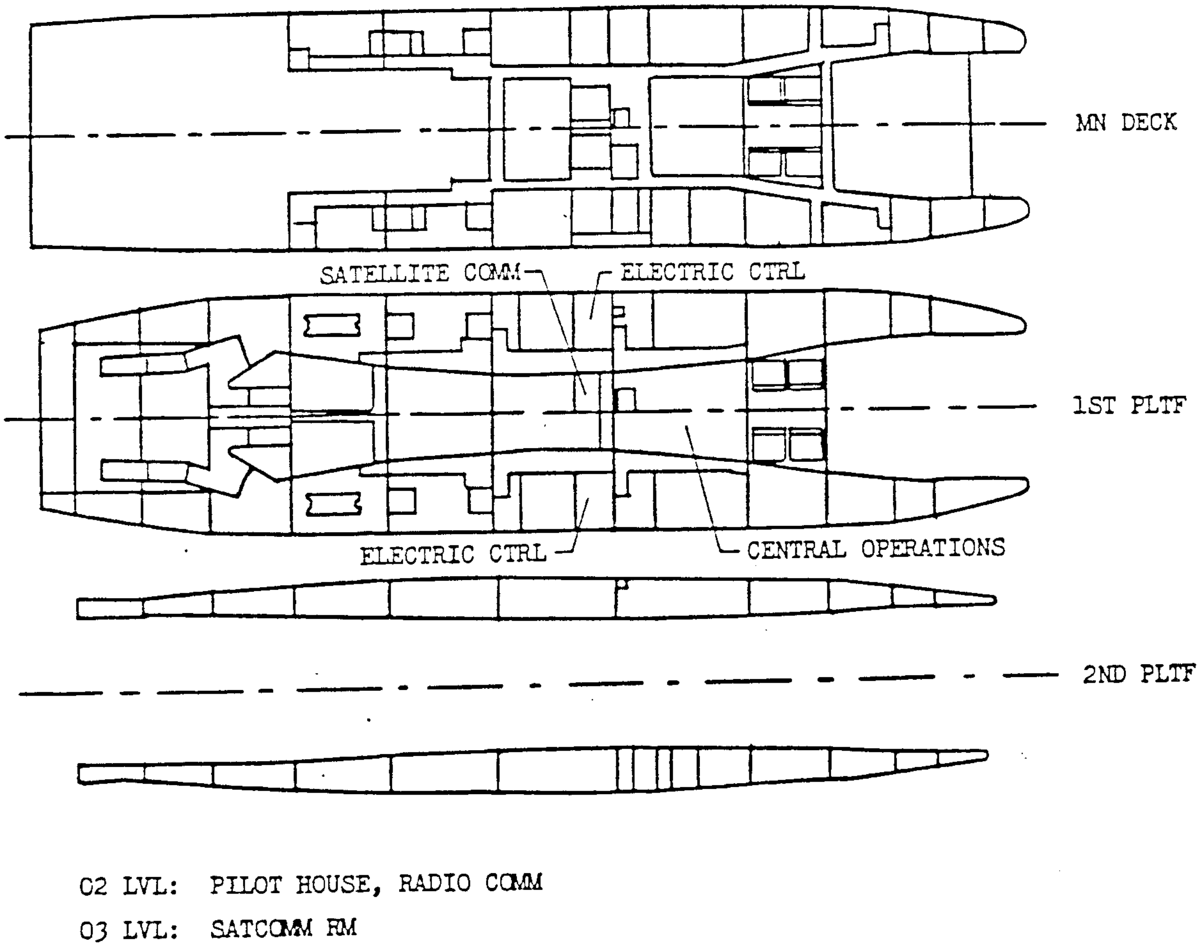


Figure 3.2.8.7-3. FR SES C^3I Space Arrangement (Sheet 1 of 2)

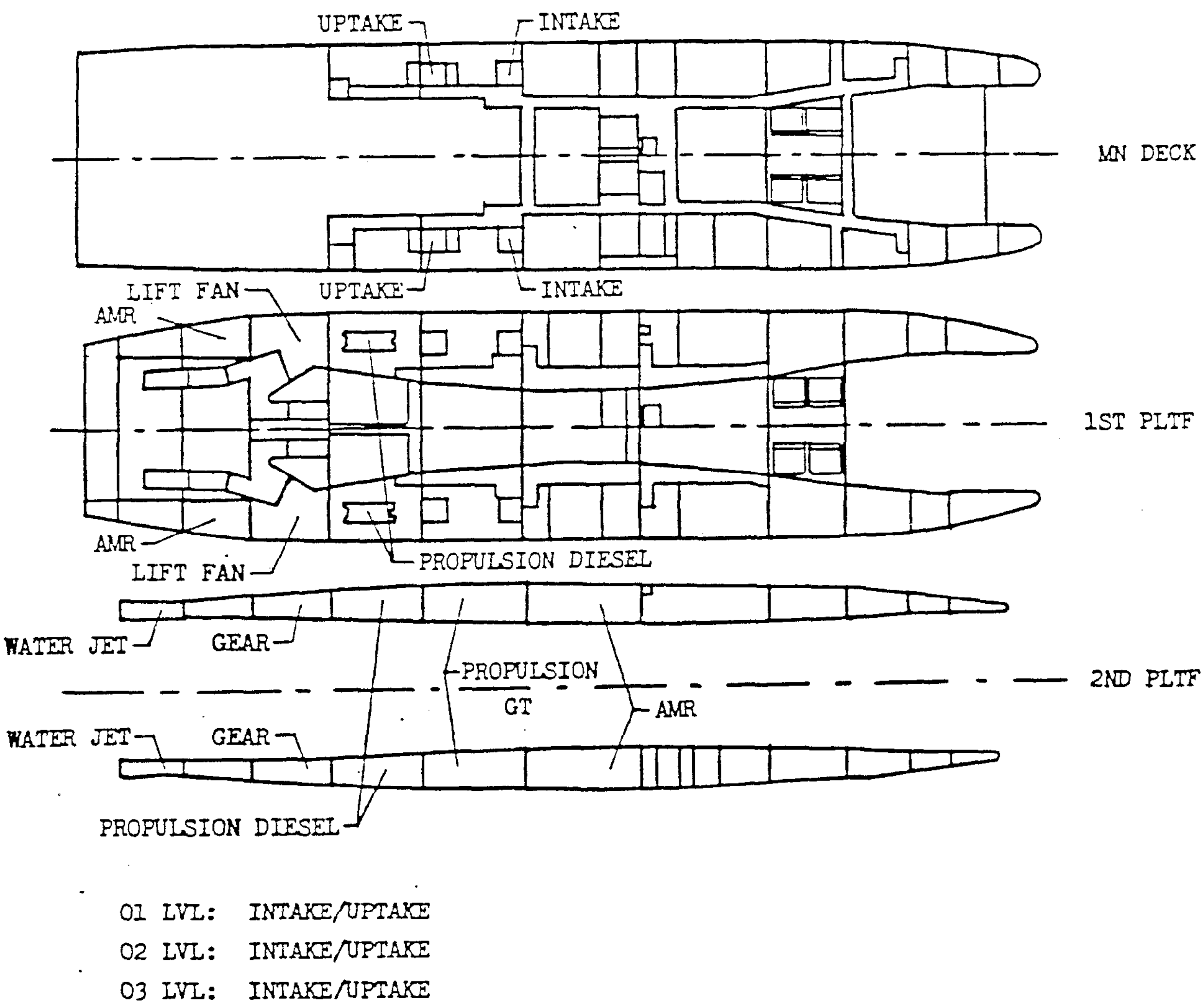


Figure 3.2.8.7-3. FR SES Machinery Arrangement (Sheet 2 of 2)

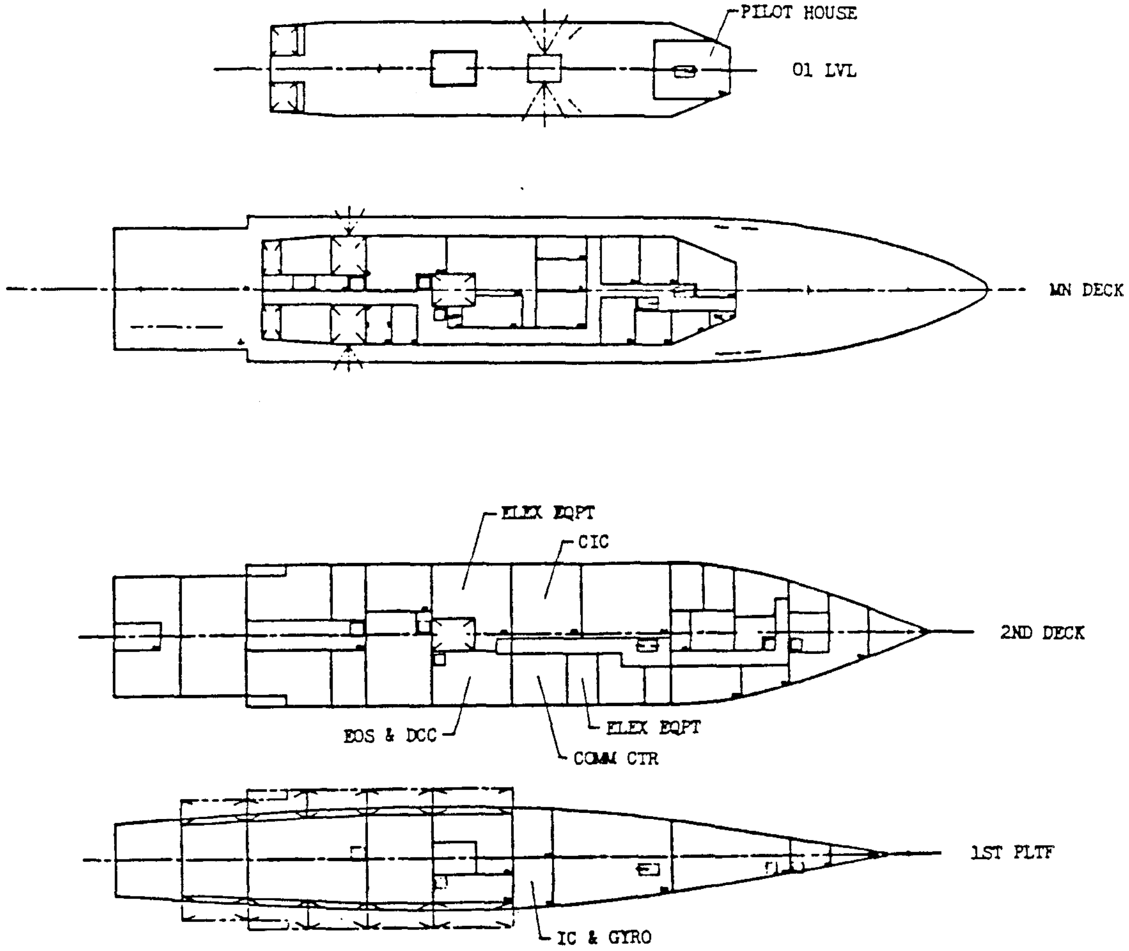


Figure 3.2.8.7-4. US Hydrofoil C^3I Space Arrangement (Sheet 1 of 2)

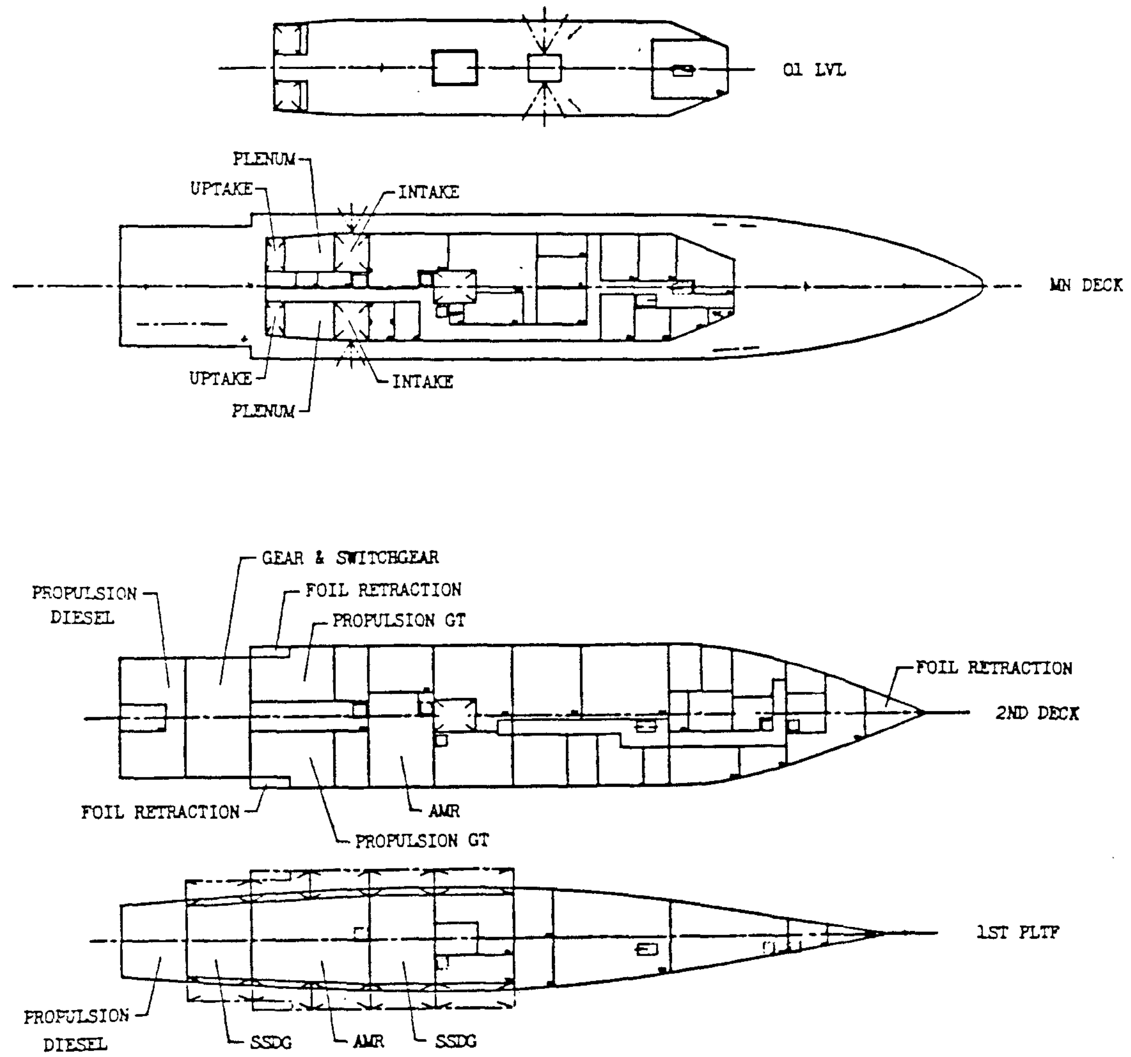


Figure 3.2.8.7-4. US Hydrofoil Machinery Arrangement (Sheet 2 of 2)

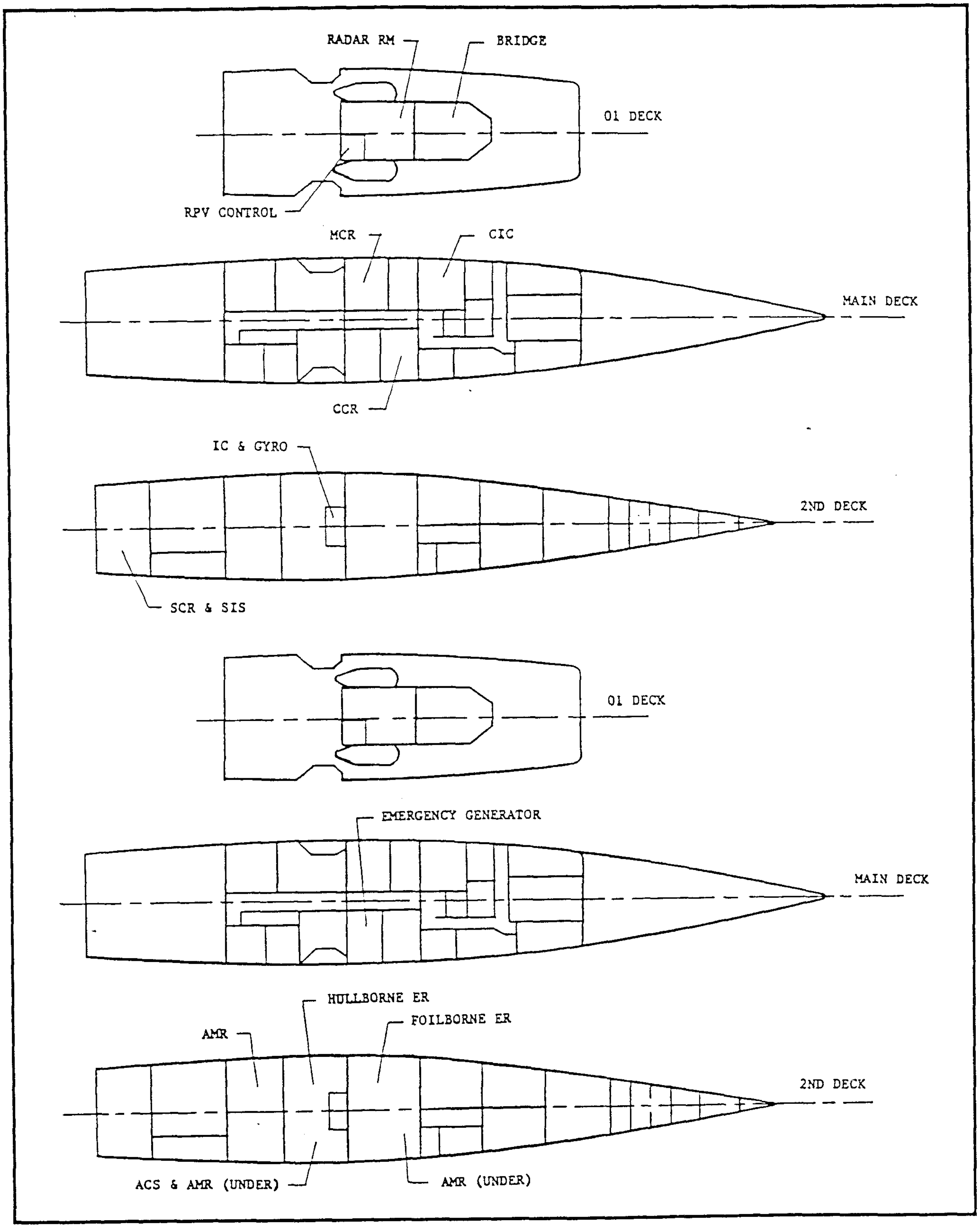


Figure 3.2.8.7-5. CA Hydrofoil C^3I Space Arrangements

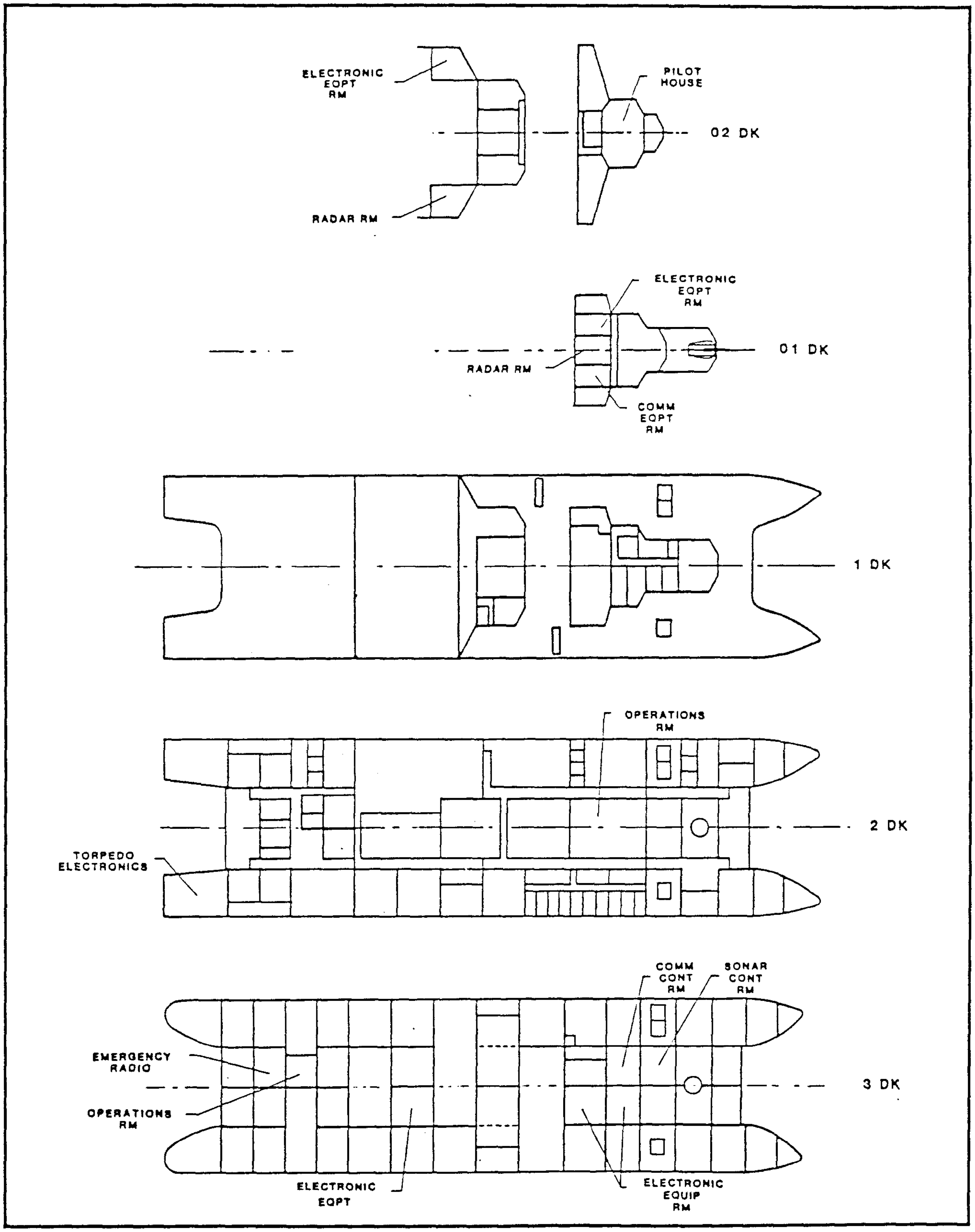


Figure 3.2.8.7-6. SWATH C^3I Space Arrangement (Sheet 1 of 4)

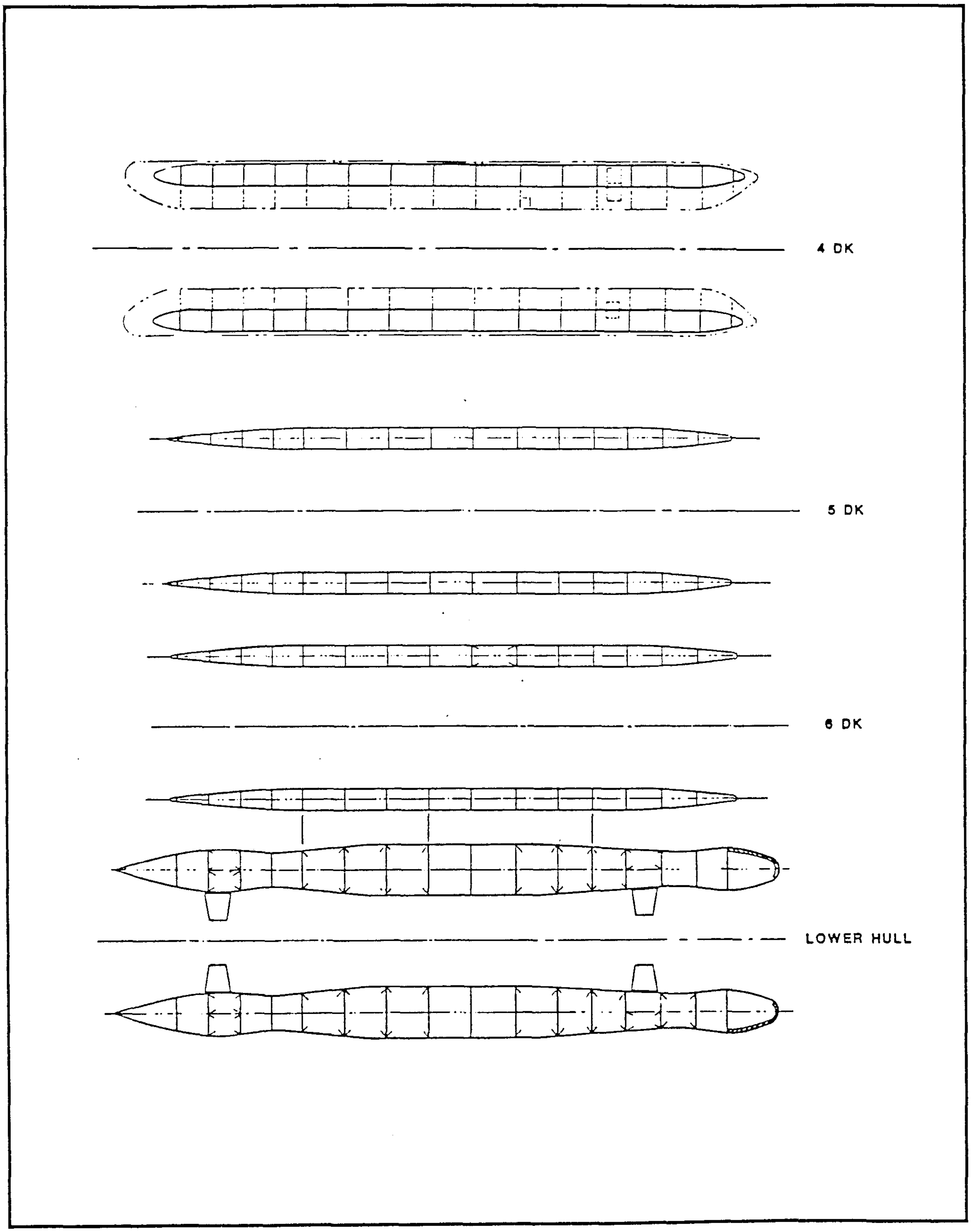


Figure 3.2.8.7-6. SWATH C^3I Space Arrangement (Sheet 2 of 4)

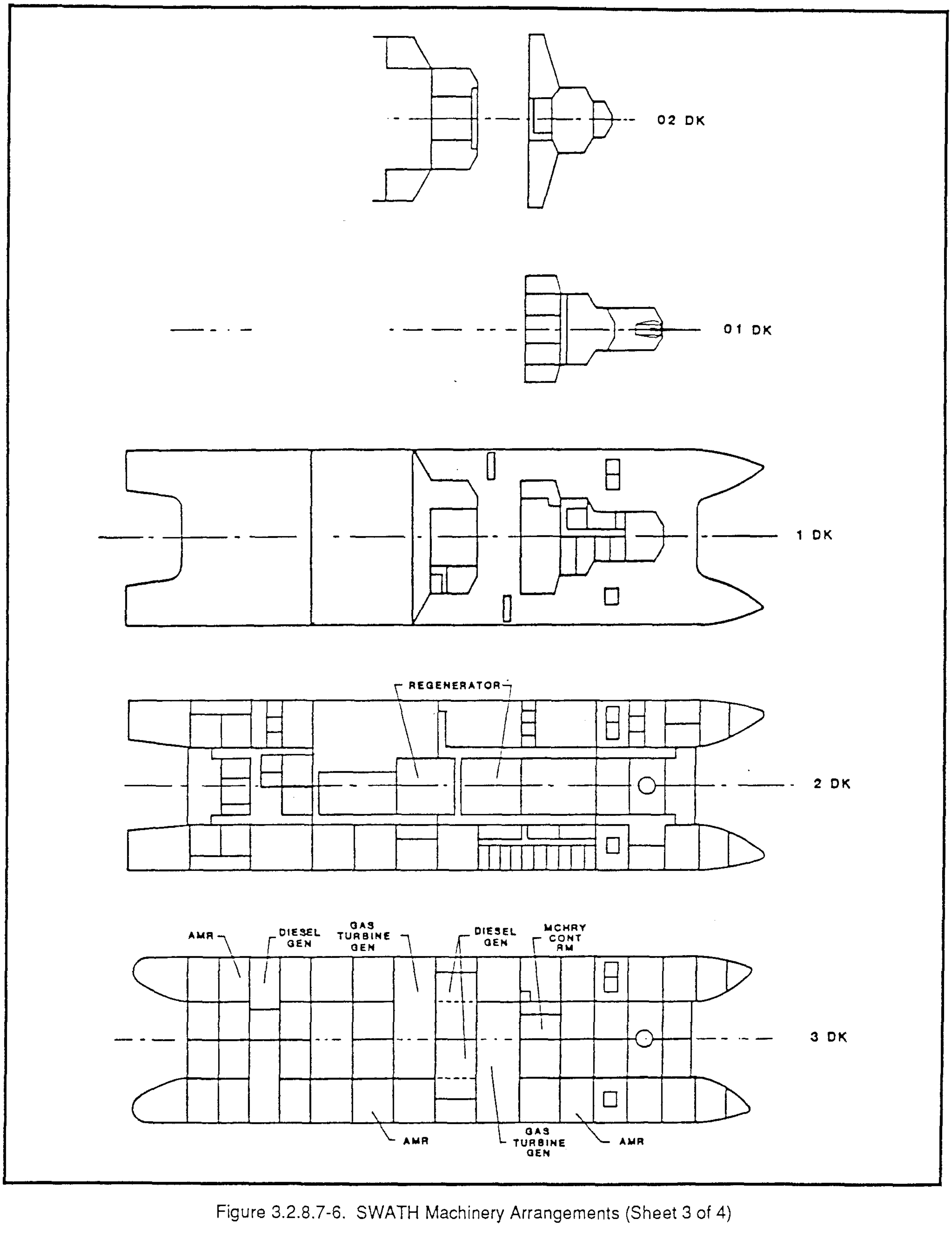


Figure 3.2.8.7-6. SWATH Machinery Arrangements (Sheet 3 of 4)

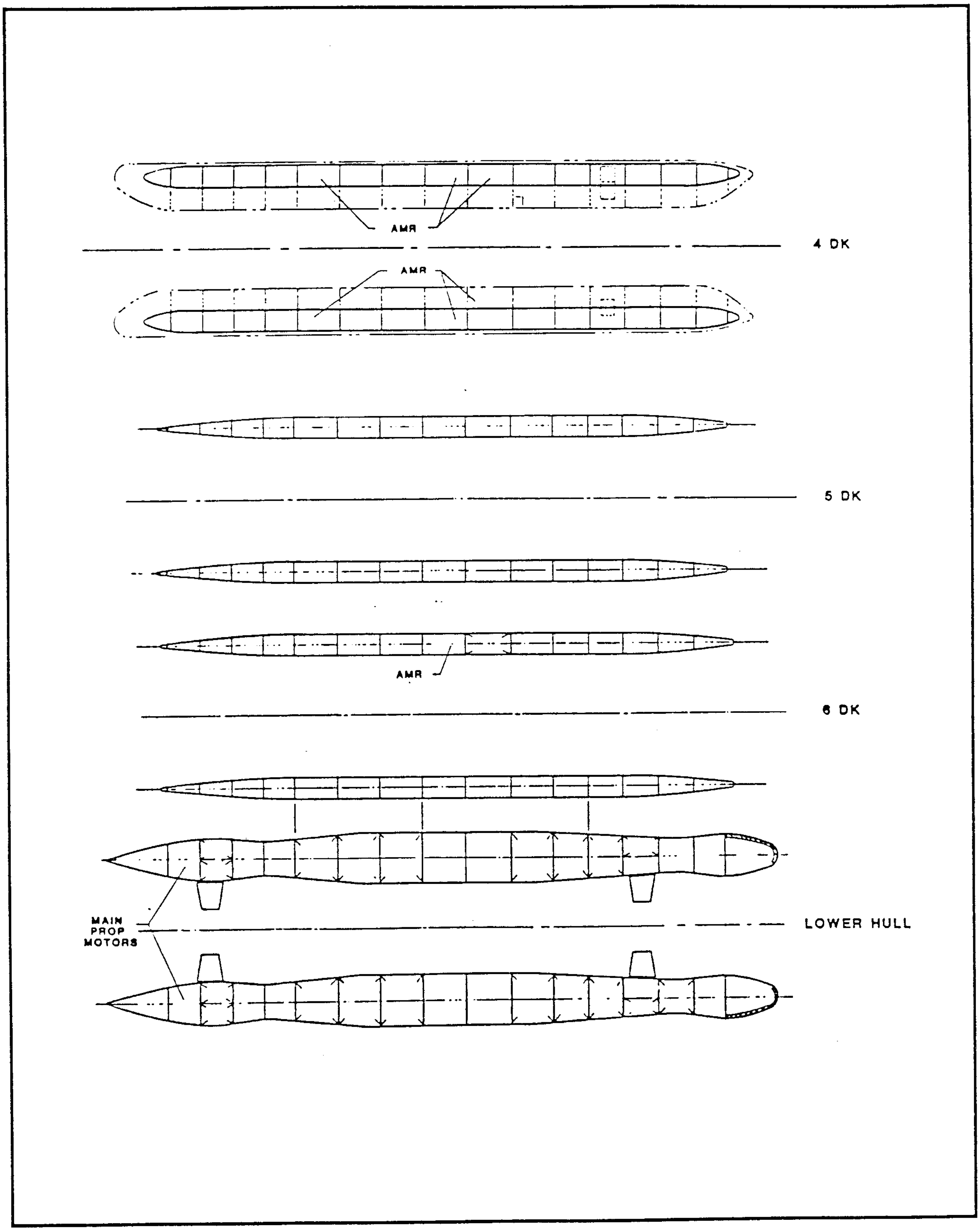


Figure 3.2.8.7-6. SWATH Machinery Arrangements (Sheet 4 of 4)

3.3 ASSESSMENT OF SUBSYSTEM-RELATED CHARACTERISTICS

This section contains an assessment of the technical feasibility of the subsystems proposed for each ANV Point Design. The primary purpose is to serve as a basis for the overall ship performance assessment of Section 3.2 and to serve as input to the identification of R&D needs in the (PTE) process contained in Section 4.0. Although point designs, particularly at such an early stage in the design process, do not necessarily represent an optimum ship design solution, it is assumed that the technologies and approaches used in these cases are representative of those that could be considered appropriate for ANVs such as those proposed.

In performing these subsystem assessments, the emphasis has been on providing a general comparison with established conventional monohull and ANV practice as opposed to providing a detailed component by component analysis. This was considered to be more appropriate to the state of development of the designs, the level of detail presented in the design reports and the overall goals of the program.

Several existing ASW monohull ships are used as points of reference with respect to modern conventional NATO ship design practice. These monohulls are not used to imply the "correct" approach since mission differences and the unique design drivers associated with ANVs make such a direct comparison inappropriate.

Some of the assessments in this section make use of various parametric plots. These are used to highlight any gross deviations from "current" ANV or monohull practice which may indicate the use of unique technologies or design approaches. These plots are not used to imply correctness, or lack thereof, in the point designs; instead, they are used as an aid in characterizing the point designs and level of new technologies used.

3.3.1 Design Practices and Margins

Point Designs Margins. Margin values used in the development of the point designs are contained in the Study Guidance Document and are summarized in Table 3.3.1-1. Also included for comparison purposes in Table 3.3.1-2 are recommended values currently used by the U.S. Navy for conventional ships and the margins used in the U.S. CONFORM Program, which addresses a wide range of advanced ship concepts using the entire spectrum of hull forms. Based on the information contained in the design reports, it appears that the three SES designs and the Hydrofoil meet the Study Guidance Document margin goals, although no specifics were provided by the French on margins for speed/power, accommodations, or arrangeable area. The SWATH also meets the Study Guidance Document requirements with the exception of the acquisition margin on KG which has been limited to 5% of the lightship KG.

Margin Selection - General. The overall question of margins including what values are appropriate and and how they are applied is a controversial subject even for conventional ships, and is more so for advanced naval vehicles (ANV's) because of significantly more limited data on growth and their developmental nature. The values contained in the Study Guidance Document are derived from U.S. practice. Table 3.3.1-3 further elaborates on the weight and KG margins showing recommended values for advanced hullforms over a range of displacements.

Recent studies conducted to establish a revised margin policy in the United States have resulted in the proposed values shown in the last column of Table 3.3.1-2. These differ from the CONFORM values by suggesting an increased margin for electric generating capacity and a decrease in service-life weight and KG growth. The future growth margin for electric generating capacity is not intended to be applied to SWBS group 200 and 500 loads which are expected to remain stable, e.g., steering gear, anchor windlass, etc. It should be noted that the weight and KG values presented as conventional U.S. practice are nominal, and are a function of the characteristics of the design being considered.

Table 3.3.1-4 presents selected monohull margin philosophies provided by some of the nations participating in SWG/6.

Table 3.3.1-1. SWG/6 Design Margins (Study Guidance Document)

Item	Description
Space	5%
Accommodations	10%
Electrical Load	40% growth margin on generating capacity with one unit out of commission
Weight - Acquisition or Design and Build	12.5% of light-ship load displacement for Preliminary, Contract, Detailed Design and Construction Margin
- Service Life	10% of full load displacement (not included in performance predictions or FLD)
KG - Acquisition or Design and Build	12% of lightship KG for Preliminary Contract Detailed Design and Construction Margin
- Service Life	+0.30 m on worst case KG FLD
Speed/Power	8% on power required (not on engine rating)

Table 3.3.1-2. Comparison of Margin Values

Type	Acquisition/ Service Life	U.S. Conventional Practice	U.S. CONFORM	U.S. ANV (Proposed)
Space	Acquisition	5%	5%	--
Accommodations	Acquisition	10% OFCR/CPO	10%	--
Electric Load	Acquisition Service Life	20% 20%	20% 20%	34% 15%
Weight	Acquisition Service Life	3.1% - 12.3% (LS) 10% (FL)	15% (LS) 10% (FL)	15% (LS)* 5% (FL)**
KG	Acquisition Service Life	12.5% (LS) 0.3 m (FL)	10% (LS) 0.3 m (FL)	10% (LS) 0.15 m (FL)**
Power	Acquisition	9%	8%	--

* At the end of preliminary design for high performance ships
** Assumes a 20-year life

Table 3.3.1-3. CONFORM Weight/KG Acquisition Margins for Use in Advanced Hullform Studies

Ship Type	Small (500 Tons) Wgt/KG	Medium (4000 Tons) Wgt/KG	Large (20,000 Tons) Wgt/KG
SWATH	17%/12%	15%/10%	15%/10%
Hydrofoil	17%/12%	15%/10%	15%/10%
Surface Effect Ship	17%/12%	15%/10%	15%/10%

Table 3.3.1-4. Selected Non-U.S. Margin Values

	FRG	NOR	SP	UK
Acquisition				
WT	0-4% Design 3% Constr.	10%	5% Des & Build 1.25% Contr. Mod. 0.13% GFM (1)	7-8% Design (2)
KG		0.1 m	2.5%	
Volume		8%		
Service Life				
WT	6% Normal 3% Min	5%	1.5 - 2.75%	5-8% Growth 1-2% Board (3)
KG			1%	
Volume		5% (4), (5)		

NOTES:
(1) 13.42% realized on Principle de Astories
(2) 10% on commercial SESs
(3) 2-3% proposed for SESs
(4) Not applied to all areas
(5) Plus a 10% margin on accommodations

Although France did not provide specific margin values, the French have said that their proposed margins for SESs do not differ appreciably in aggragate values from those contained in the Study Guidance Document. The major departure being their method of application. The French selectively apply margins to the different weight groups, i.e., hull structure, propulsion, etc., depending upon confidence in the initial weight estimate for each group. This is similar to the approach taken by the U.S. Navy in small boat design and is apparently also the procedure used in the UK.

Table 3.3.1-4, shows that, in general, the acquisition-weight margins used by other nations for conventional ships fall within the range used by the U.S. Navy (Table 3.3.1-2) and are less than those proposed by the Study Guidance Document for ANVs. Based on comments by France, Spain, and the UK, the use of larger weight margins on weight sensitive designs to ensure the predicted performance on delivery appears justified; however, the KG margins in the Study Guidance Document are generally considered excessive.

The UK has proposed the concept that the more complete definition of an ANV at each stage of design as compared to conventional monohulls can offset some of the unknowns inherent in some ANV system technologies. This form of weight control during design will reduce the need for larger design margins.

It has been suggested by France that although an SES normally requires lightweight technologies to ensure meeting performance goals, a given SES design may be able to accommodate appreciable weight growth during design and construction and still perform adequately. In fact, a "high technology" SES could be less weight sensitive than a "low technology" platform like a SWATH. Overload tests done by France using the MOLENES purportedly indicate degraded yet satisfactory performance at overload displacements of 10 to 20% of lightship over normal full-load displacement.

This implies that margins and weight control practices may not need be as restrictive as previously thought for particular ANV designs. Technical risk could be reduced since lower risk (and higher weight) systems introduced as necessary fallbacks during design and construction may not have devastating results on performance.

The service-life growth margins presented in Table 3.3.1-4 are generally less than those used by the U.S. Navy and those proposed in the Study Guidance Document. Comments from some of the SWG/6 nations indicate that future-growth margins, including such items as Board margins, should be limited to values less than those in the Study Guidance Document. This approach admits the need for significantly increased discipline by the national naval organizations that establish performance requirement upgrades and ships' operating crews.

Volume margin information from participating nations is limited. Both France and Norway however effectively place a 10% margin on accommodation space. The overall volume margins used by Norway on conventional ships and summarized in Table 3.3.1-4 are more generous than those given in the Study Guidance Document.

The main problem with volume margins and the SWG/6 ANVs is that the SESs are not volume limited; therefore, excess volume already exists on these ships. Given the tendency for ships' crews to make use of available space, this could lead to further service-life weight growth. This argues in favor of minimizing SES volume margins and, as discussed previously, a heightened discipline by operating crews with respect to weight control.

Advanced Naval Vehicle Margin Selection. The real issue at hand is the assignment of margin values appropriate to ANV's. There are two sides to the question, and a brief discussion of each follows.

First, the point has been made that design and construction margins can be minimized through the application of higher quality weight control and the use of design procedures analagous to those used by the aerospace industry and to some degree in the submarine community. This has been the normal procedure for all SES and Hydrofoils built to date. Such procedures require, however, more effort, attention to detail and money, particularly during construction. Significant discipline not commonly found in many nations's shipbuilding industries will have to be enforced, assuming that ANV's are not all constructed by aerospace concerns. This assumption is seen as reasonable, particularly for larger ANV's, and will result in reduced acquisition costs.

On the other hand a case can be made to use relatively conservative margins for these ANV's for the following reasons:

- The SWG/6 Point Designs are in the very early stages of design with many aspects being ill-defined.
- Many systems/subsystems are unconventional or developmental in nature or are new to the ANV's. Additionally, system configurations in some of the ANV's (SWATH and SES in particular) differ from those used in conventional ships and can affect the weight estimating relationships used.
- The combat systems, particularly in the sonar area, are, in most cases, developmental.
- Limited experience with design of ANV's of this size and no experience with their construction exist; therefore, the data base on weight and other parameter growth is extremely limited and in some cases nonexistent.

- The ability of shipyards to exercise the degree of weight control required, if minimal margins are used, is questionable at this time. Contractual methods of enforcing weight control in the shipyard and for vendors will play a large role in this regard.

The issue of service-life growth must also be addressed. Enforcing discipline with respect to weight, KG, and other parameter growth may be more difficult than in the acquisition process. This is particularly true with unauthorized, or anticipated, growth resulting from ship's force modifications/initiatives.

The other service-life growth issue is the perennial one regarding the amount of inherent growth in capability that is desired by the customer/user. This can be closely watched and enforced and can be kept to a minimum as long as there is realization that exceeding limits can adversely and noticeably affect platform performance, particularly with hydrofoils.

Selected ANV Experience. The following discussion presents some limited examples of U.S. experience in weight growth of ANV's, specifically with the AALC JEFF(A) prototype ACV landing craft and the PHM-3 Hydrofoil. This is not purported to be a comprehensive or a statistically valid analysis; it is provided as an example only.

JEFF(A). Table 3.3.1-5 contains lightship weight information for the JEFF(A). In addition, after the weights for some components not installed (when the "as built" weights were determined by weighting the platform) were finally defined, a true lightship weight of 178,864 lbs. resulted. This indicated a weight growth of only 9.3% from the end of preliminary design to delivery, which is well below the margin values used for the SWG/6 Point Designs.

Table 3.3.1-5. Evolution of AALC JEFF(A) Weights

	Prelim. Des.	Detail Design Accepted Wt. Est.	As Built
Lightship (lbs)	163,595	170,413	178,233
Margin	8,142 (4.7%)	8,387 (4.7%)	0
Total Lightship	171,737	178,800	178,233

Subsequent to delivery a number of modifications were made to the JEFF(A) including the following:

- Modification to propulsor shrouds
- Modification to lift-fan volutes
- Installation of a new spray suppression skirt
- Installation of mixed flow fans
- Installation of a sweep deck to conduct mine sweeping tasks (an R&D item not originally intended for the craft).

These modifications resulted in a further lightship weight growth of 31,782 lbs; however, because this craft was an R&D experimental prototype this growth cannot be considered typical of a production ship.

Similar information for the experimental prototype JEFF(B) indicates an approximate 14% weight growth from completion of preliminary design to delivery, which is greater than the 12.5% used for the SWG/6 Point Designs. The as built measured weight, however, was within 0.22% of the engineering prediction (without margin) made at the end of detail design, which indicates how very precisely ANV weights can be estimated after detail design. A further 6% growth in lightship weight was incurred, however, as a result of subsequent RDT&E activity.

PHM. The PHM-4 can be used to illustrate another example of post delivery weight growth. Upon completion of its fitting out availability (FOA) PHM-4 had a full-load displacement of 240.55 tonnes, which included items added by

Puget Sound Naval Shipyard subsequent to delivery of the ship from the contractor. Approximately three months later an inclining experiment was conducted with a resulting displacement of 249.73 tonnes. This represented the departure condition which included realistic operational loads for the ship. In addition, approximately 3.7 tonnes of the increase was attributed to unauthorized ship's force modifications and increased spare parts and documentation load-out. Finally, a planning yard weight report, issued about one year later, indicated a full-load displacement of 253.9 tonnes for a total weight growth over two years of 13.35 tonnes or 5.5%. This is almost one half that used for the SWG.6 Point Designs. KG growth over the period described was negative, i.e., a reduction of 0.02 meters.

Significant weight growth has also been exhibited by other ships of the class. Much of this growth is a result of items not accounted for, or not required to be accounted for, by the designers and indicates one of the difficulties in establishing margins.

Conclusions. Given the state of the technology and the early stage of design of the point designs, the SWG/6 design and build margins in Table 3.3.1-1 do not appear unreasonable. Reductions in KG margins such as the Canadian choice of a 5% design and build KG margin, although less than the required (12.5%), may be logical Actual margins selected, especially in the acquisition phase, will be a function of the characteristics of the systems/ subsystems being considered and the time and money invested to achieve a quality design and product. Sensitivity of a given design to weight changes and consideration of the overall weight-cost-risk performance trade-off will determine what optimum margin values should be. The 10% service-life growth margin, however, does appear to be somewhat excessive. *Finally, only when additional data is obtained from actual experience with ANV's of the configuration and size of those considered in these studies, will margin selection become a more rational process.*

3.3.2 Hullform and General Configuration

3.3.2.1 Hullform

The principal characteristics of the SWG/6 Point Designs and comparative monohulls are shown in Table 3.3.2-1.

Table 3.3.2-1. Principal Characteristics

		UK SES	FR SES	US/G SES	SP SES	FFG 7	US Hydrofoil	SWATH	CA Hydrofoil	DD 963	LUPO	DESCUPIERTA
LOA	m	92.9	89	104	95	135.6	75.5 Foils Up	115.8	64	171.0	113.2	88.8
LBP	m	84.5	82	103	88.5	124.4	60	96	57.9	160.0	106.0	85
B MAX	m	29.0	21.2	19.5	20.4	14.3	10.5	30.5	11.1	16.46	44.3	10.4
D (Amidships)	m	11.5	12.0	9.8	9.2	9.1	6.8	19.2	4.94	12.95	7.9	6.2
Tcb	m	1.5	1.6	1.2	1.3	–	3.6	–	3.64	--	Unknown	Unknown
Thb	m	4.6	4.0	4.3	4.4	4.8	2.8	9.2	8.63	5.49	3.7	Unknown
Tnav	m	4.6	4.0	6.7	4.4	7.9	8.6	9.2	4.08	8.68	Unknown	Unknown
Displacement LS	MT	1041	911	1513.5	1328	3130	582	7391	286.1	6023	2000	Unknown
Displacement FL	MT	1061	1399	1934.0	1747	4066	780	9548	457.7	8030	2462	1520
Volume	m^3	16302	14557	1060.0	10800	15150	3487	35925	2409	29473	8447	5674
Cushion Area	m^2	1380	948	1425	1180	–	–	–	–	--	--	–
L/B		3.2	4.2	5.2	4.7	9.1	5.7	3.3	5.77	9.72	9.37	8.17
Cushion L/B		3.43	5.6	6.3	5.8	–	–	–	–	--	--	–
Freeboard: HB	m	6.9	5.6	5.5	4.8	4.3	4.0	10.0	3.3	7.46	4.2	Unknown
Freeboard: CB	m	10.0	8.0	8.6	7.9	–	9.0	–	7.78	--	--	–
Depth: MN Deck	m	11.5	9.6	9.8	9.2	9.1	6.8	4.5	5.05	12.95	Unknown	Unknown
Depth: Wet Deck	m	7.6	4.7	6.7	6.1	–	–	–	–	--	--	–
Hull Vol	m^3	12892	12235	9105	8120	11170	2713	29435	1731	20631	Unknown	Unknown
SS Vol	m^3	3410	2322	1495	2680	3980	774	6490	678	8842	Unknown	Unknown

Table 3.3.2-2 and Figure 3.3.2-1 give the basic hullform characteristics for the Point Designs. The SWATH particulars are not included in Table 3.3.2-2 because its configuration does not lend itself to conventional description

Table 3.3.2-2. Hullform

	UK/SES	FR SES	US/G SES	SP SES	U.S. Hydrofoil	CA Hydrofoil
Hull Type	Unknown	Unknown	Lenticular	Unknown	Deep Vee	Deep Vee
Deadrise: α_1	45°	25°	45°	33°	23°	20°
α_2	--	--	45°	--	--	--
Keel Flat Width	2.0 m	0.1 m	0.6 m	0.25	0.3 m	0.0 m
Flare Angle: β_1	7°	23°	2.9°	5°	10°	18°
β_2	19°	--	9.5°	10°	--	--

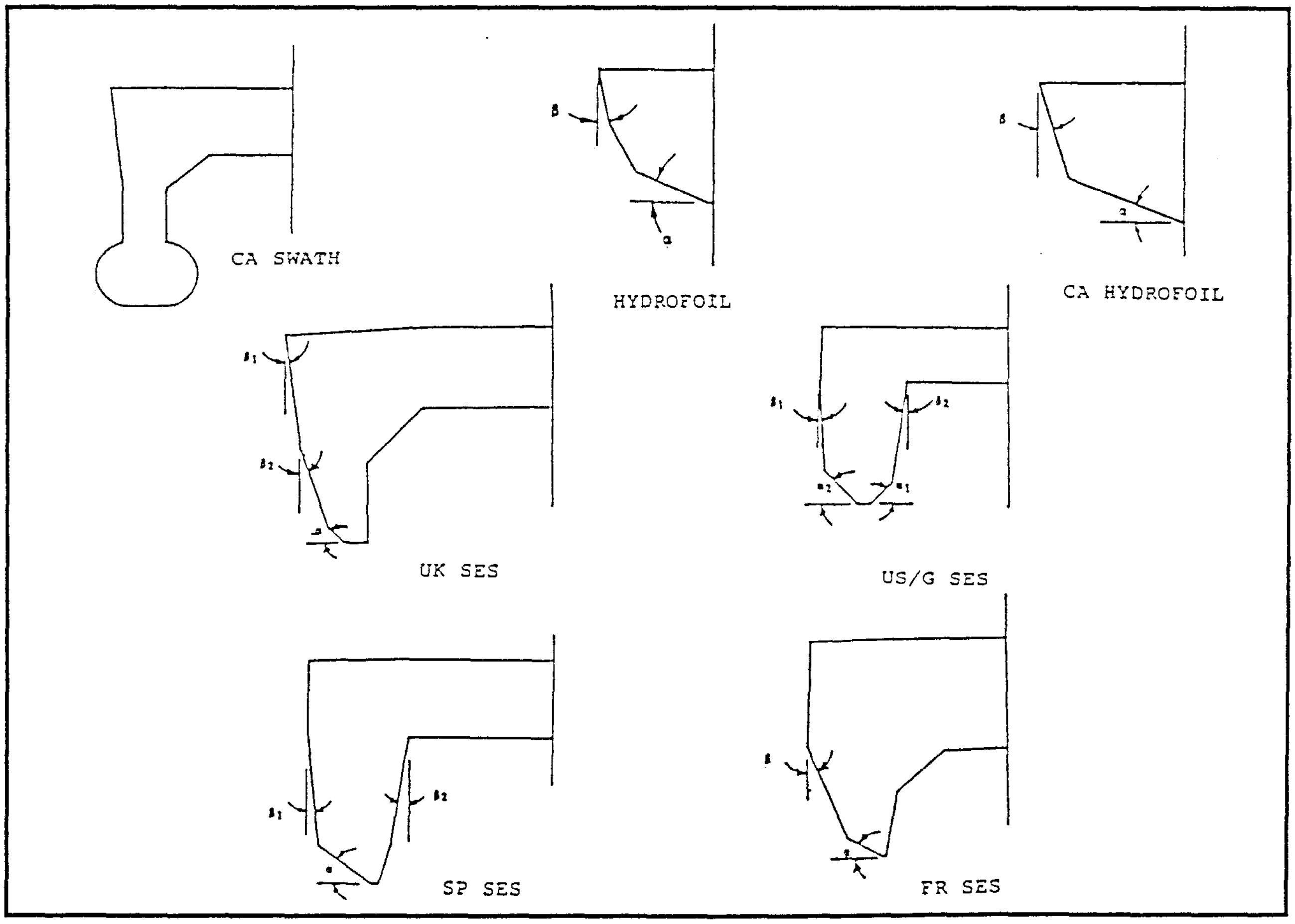


Figure 3.3.2-1. Hullforms

The US/G SES uses a hullform of lenticular shape (all waterlines are arcs of circles), incorporating a 2 ft wide keel flat and a 45^{o} deadrise both inboard and outboard (α_1 and α_2). The flare angle is 3^{o} outboard (β_1) and 9.5^{o} inboard (β_2). The side hulls are connected by a one-deck high (10 ft) box structure. This hullform is better suited to hullborne operation because of the reduced resistance as compared to the other SESs.

The UK Point Design has a 6.5 foot wide flat and an outboard deadrise angle, α, of 45^{o} with vertical inboard sides in way of the cushion.

The FR SES has a small keel flat, primarily for drydocking. A deadrise angle, α, of 25^{o} and a flare angle, β_1, of 23^{o} rise to meet a vertical side shell outboard.

The U.S. Hydrofoil has a high L/B ratio, deep vee, planing hullform similar to the PHM and PXM hullforms and is typical of most Hydrofoils. As a modification to the PHM hullform, it shares not only the L/B ratio but also the high deadrise, the full prismatic coefficient, and the hard chine construction.

The high deadrise at amidships, 23^{o}, continues aft to the transom and increases forward to the bow to reduce both foil and hullborne wave impact loads and accelerations. The flare in the topsides improves seakeeping while increasing the stability and decreasing the RCS signature. Greater flare in the bow reduces deck wetness.

As with the SES, many producibility features were incorporated. These include a double chine and developable surfaces in the aft sections, straight shear and no deck camber, constant deck width aft and straight deck house sides.

The CA Hydrofoil differs from established U.S. Hydrofoil design practice in that it has fixed rather than retractable foils. An extreme canard configuration is used with the main foils, located very close behind the center of gravity of the ship and carrying about 90% of the ship's weight in the foilborne mode. This configuration requires a hull with fine forward lines and a broad transom stern. The deadrise angle of 20^{o} amidships is similar to the U.S. hydrofoil design and is maintained through the hull's length to reduce wave-crest impact when foilborne.

Other characteristics include an average prismatic coefficient, a fairly high L/B ratio, significant sheer at the bow and a flat deck.

The CA SWATH design hullform is typical and consistent with that used in U.S. SWATH designs. The lower hulls feature contours that were derived from the U.S. Navy SWATH Frigate Study. The hulls were designed for lower high-speed resistance, accepting a penalty of a drag hump near its endurance speed. The lower hull cross-section is that of a producible ellipse. This section provides an easier constructed surface, lower draft, and increased heave damping. The eccentricity of the lower hulls of 1.52:1, is also consistent with U.S. SWATH designs of this size. The struts have been offset outboard of the lower hull centerlines to reduce overall beam without reducing transverse GM.

The CA SWATH used a non-overhanging short strut in order to optimize seakeeping with a minimal impact on resistance. This configuration requires a combined rudder and aft fin stabilizer similar to that used on the U.S. Navy T-AGOS-19.

A cross-structure (box) of the SWATH design was sized by structural, arrangement, and damaged stability constraints. The box is two decks high and it underhangs the strut ends. The underhang was included to reduce excess volume, and probability of box slamming. It is tapered upwards from amidships for both slamming and damaged stability reasons. Tapering the box decreases the angle of incidence during slamming, which reduces design pressures and therefore reduces structural scantling requirements. The tapered box also allows higher clearance at the ends for seakeeping while keeping the clearance amidships lower to improve after damage list angles.

The superstructure was designed with an attempt to reduce radar cross-section by eliminating 90° corners and angles on the deckhouse sides. This is common practice on monohulls and is being employed by the U.S. Navy in the DDG 51 design.

3.3.2.2 Arrangements

The arrangement of SES platforms can be divided into three major areas: box or cross-structure, sidehulls, and superstructure. The arrangements within each of these areas is dependent upon the L/B ratio of the platform, hydrodynamically constrained sidehulls and the basic design philosophy.

The box is usually easy to arrange based on sidehull separation and a greater watertight subdivision bulkhead spacing. Combat system and ship support functions requiring large open spaces usually take up prime real estate in the central portion of the box inboard of the longitudinal bulkheads. Depending on sidehull sizes and configurations, the spaces outboard of these bulkheads may be difficult to arrange, especially in the forward and aft portions of the ship. The midship spaces outboard of the longitudinal bulkheads are usually used for propulsion/lift systems and auxiliaries.

The sidehulls below the cross-structure are usually dedicated to main propulsion systems. The remaining spaces may be more difficult to arrange based on the width and height of the sidehulls. Lenticular sidehull configurations, for example, usually result in spaces forward and aft which are useful only as storerooms. Weapons systems located in the sidehulls will also limit the arrangeable area available for other ship support spaces.

Machinery arrangements are generally straightforward with shorter intake/ uptake runs than possible on monohulls. The major considerations in machinery systems layouts are sidehull width constraints and uptakes/ intakes impacts on topside arrangements. Sidehull width can limit the location of machinery systems, and uptakes/intakes must be arranged to minimize impact on flight operations and weapons systems operations.

The size of the superstructure is also a function of the design philosophy. In general, SES superstructures are smaller than those of equivalently sized monohulls because the SES's are generally less volume-limited and more ship functions can be located within the box below the main deck. Drag at high speed, survivability and RCS considerations also tend to drive down superstructure size and configuration.

US SES design practice tends to place as much of the ship volume as possible in the box and sidehulls with a small deckhouse supporting only those spaces which must be above the main deck based on functionality. Resulting SES designs provide sufficient volume within the sidehulls and box to allow extreme reduction of deckhouse size compared to conventional monohull design practice. This results in all combat system spaces on the US/G SES, with the exceptions of ECM, being located in the central box below the main deck and inboard of the longitudinal bulkheads, which provides enhanced protection for these spaces. The galley and mess spaces and a large percentage of living spaces, are also located in the central portion of the box, with minor support spaces and some living spaces located outboard of the longitudinal bulkheads. This arrangement requires some concessions to be made to reduce habitability volume. The ship stores and the remaining crew living spaces are located in the sidehulls. The remainder of the sidehull space is dedicated to propulsion, propulsion support, and auxiliary system spaces. The main propulsion spaces are tight due to the narrow configuration of the sidehulls, but adequate maintenance space appears to have been provided.

The UK design, in contrast, has a much larger superstructure supporting all of the combat-system spaces. While this frees up the central portion of the box for all crew support spaces, it does not provide the survivability inherent in locating the combat systems below the main deck. The sidehulls are dedicated entirely to propulsion, propulsion support, and auxiliary-system spaces.

In the FR design the principal combat system spaces are located approximately amidships in the box structure providing a better protection. C^3 systems, or spaces such as the radio room, antennas and the bridge, are located in the superstructure along with the helicopter hangar. Berthing and crew support spaces are primarily concentrated on the first platform.

The smaller L/B values for the FR, UK and SP SES's result in a less volume-limited configuration than the US/G SES. This configuration would then allow for a larger superstructure from stability considerations, and perhaps allow slightly more flexibility in arrangements.

Hydrofoil arrangements are driven primarily by foil configuration and by their small size relative to their combat system. On a canard-foil configured hydrofoil it is advantageous to locate the center of gravity as far aft as possible in order to maximize the load on the more efficient, and more easily supported, aft foil. For this reason, and the requirement to have the propulsion shafting or ducting running down the aft struts, the machinery is generally located as far aft as possible. Combat systems, with below deck space requirements, and other critical spaces, often fill the remaining prime areas within the hull. The superstructures therefore tend to be relatively large to accommodate the remaining required volume.

The U.S. Hydrofoil machinery spaces occupy most of the aft half of the hull along with the aft part of the deckhouse. They are arranged with the relatively heavy propulsion diesels aft and the lighter gas turbines forward. The gas turbines, along with the ship-service generators, are separated by one watertight compartment to enhance survivability. The VLS module is located amidships, just forward of the machinery spaces, extending through both the deckhouse and the hull to obtain adequate depth. The gun and magazine are placed on the foredeck to keep the KG low while providing a wide arc of fire. The vital command and control spaces are located within the hull to improve their survivability. To reduce airborne noise levels the living spaces are located in the superstructure and the hull at least two compartments away from the machinery spaces. The service and stowage spaces consume the remaining volume.

The CA Hydrofoil follows a different trend in its arrangement. The somewhat more forward location of the aft canard and the lack of foil retraction systems allows for consolidating and locating machinery systems closer to the longitudinal center of gravity. With this configuration, some accommodations are located aft of the machinery box. Additionally, a number of the vital spaces, such as CIC, the radar room and radio central, are located in the superstructure rather than in the hull. This is reflected by the lower ratio of superstructure volume to total volume (28%) as compared to the U.S. Hydrofoil (22%). Other impact of a fixed-foil system on arrangements is the ability to reserve a higher percentage of its full-load displacement for fuel and payload as compared to a hydrofoil with retractable foils.

The CA SWATH arrangements, like most SWATH arrangements, are centered around the box with only tankage, propulsion motors, foam and fin machinery located in the struts and lower hulls. This is due to the unique shapes of the spaces located in the struts and lower hulls, and the access problems associated with locating frequently used spaces in these areas.

The machinery arrangements feature transversely mounted prime movers that allow the use of shorter watertight subdivisions, required for stability performance. The propulsion motors are located in the lower hulls, as far aft as possible to allow shorter shafting runs. The electric propulsion also allows shorter intake/uptake runs due to the prime mover's location in the box as opposed to the lower hulls.

The superstructure was sized to house the officer's living space, 57 mm gun magazine and the helicopter hangars. The balance of habitability spaces are located in the box with crew living fore and aft (permissible because of the SWATH's low motions), machine shops and mess located amidships, for ease of access.

Unique arrangement features of the CA SWATH design include:

- Anchor handling through the lower hull
- Auxiliary machinery located in the haunch (uppermost flared area of the strut)

- Communications and electronics spaces located in the box for protection
- VDS handled through a center well in the box
- Torpedo launchers located aft under the flight deck

The percentage of the total volume used for access and passage can be considered a measure of the efficiency of the space arrangement of a given platform. If located appropriately, however, it can also be used to enhance survivability and to provide better access for maintenance. A comparison of the access volume and percentages for the SES, SWATH and Hydrofoil Point Designs (Table 3.3.2-3) shows that SES point designs, on the average, require less usable volume for access than a U.S. conventional frigate monohull but are comparable to foreign frigate monohulls. It also shows that the Hydrofoils are generally as efficient as the SES's, but that the non-machinery space arrangements require greater access volume on the U.S. Hydrofoil reflecting the basic monohull configuration of these ships. Much of the Hydrofoil inefficiencies are a result of its small size relative to a conventional monohull. The low SWATH percentage indicates the amount of unusable volume present in a SWATH platform.

Table 3.3.2-3. Access Volumes

	Access Volume as Percentage of Total Volume	Access Volume as Percentage of Total Vol Less Machy Vol
UK SES	6.5%	9.7%
FR SES	9.3%	11.1%
US/G SES	9.0%	11.8%
SP SES	9.0%	11.8%
FFG 7	10.8%	14.6%
U.S. Hydrofoil	6.9%	14.1%
SWATH	3.7%	3.9%
CA Hydrofoil	5.1%	5.8%
DD 963	11.8%	14.4%
LUPO	8.6%	10.0%
DESCUPIERTA	6.1%	8.3%

3.3.3 Structure

3.3.3.1 Structural Design Practice

(a) Approach to Ship Structure Design

Each of the point-design hull structures were arrived at through the use of somewhat different structural design philosophies. Various global and local loads, material strength characteristics, applicable structural analysis methods, producibility considerations, and safety criteria were assumed for each point design. Since ship structural design practice has historically been approached in a conservative fashion based on an accumulation of practical experience, and owing to the lack of a reasonable amount of experience with larger ANV structures (such as SWATH and SES), it is expected that considerable verification of structural design practice will be necessary as part of future ANV development.

(b) Hull Loadings

Table 3.3.3-1 summarizes the types of global and local loadings assumed for the point designs. Magnitudes of these loads cannot be compared until more data is made available. Of note in the comparison of assumed governing loads is the inclusion of global hull torsional loading in the UK and FR SES design analyses but not for the US/G SES, probably due to the decreased significance of torsion as a result of its higher L/B ratio. This global torsional loading appears to have governed some transverse bulkhead scantlings of the FR SES and UK SES designs. Also note that in addition to conventional design methods, a reliability based approach is used to design the US/G SES; an approach which tends to govern most scantlings.

Table 3.3.3-1. Hull Design Loads

	Assumed Governing Loads					
Structural Element	FR SES	UK SES	US/G SES	U.S. Hydrofoil	CA Hydrofoil	CA SWATH
Shell/Strength Deck · Global	• Longitudinal bending due to off-cushion static balancing on a wave (5.71 MN-m) • *Transverse bending due to off-cushion static balancing on a wave* (3.57 MN-m) • Longitudinal torsion due to diagonally opposing swells • Transverse bending due to cushion pressure	• Longitudinal bending and shear due to off-cushion static balancing on a wave • *Transverse bending due* to on-cushion wave • Longitudinal torsion due to off-cushion wave load	• Longitudinal bending and shear due to off-cushion slamming • *Transverse bending and* shear due to swells	• None	• None	• Longitudinal bending ignored • *Transverse wave induced* bending moments combined with transverse still water • bending *moments* • Torsion ignored
· Local	• Wave impact on shell and strength deck at bow • On-cushion pressure	• Slam pressure on shell due to waves • Impact loads	• Wave impact on shell • Static head on weather deck due to green seas	• Wave impact pressure due to worst case slamming	• Wave impact pressure due to worst case slamming	• Wave induced impact pressures on the wet deck and inboard strut
Structural Bulkheads	• Shear due to global longitudinal torsion of *hull*	• Hydrostatic pressure due to internal flooding	• N-A	• Static head of water to main deck • *Static head of fuel* where forming a tank boundary • Reaction of shell framing under foilborne wave impact	• Static head of water to main deck • *Reaction of shell* framing under foilborne wave impact	• Hydrostatic heads on the shell
Internal Decks	• Nominal uniform working pressures	• N-A	• N-A	• Nominal uniform working pressures	• Nominal uniform working pressures	• Live and dead loads on deck • Nominal uniform working pressures
Superstructure	• N-A	• Hydrostatic head of water and green seas loading	• N-A	• Hydrostatic head of water • Nuclear airblast overpressure environment	• Fraction of design wave pressure at main deck	• N-A
Mast	• N-A	• N-A	• N-A	• N-A	• N-A	• N-A
Foundations	• N-A	• N-A	• N-A	• UNDEX shock loads	• N-A	• N-A

NOTE: N-A indicates that information is not currently available

Note the omission of global hull loading analysis (justified by the results of a preliminary evaluation) for the Hydrofoils. Most scantlings of the Hydrofoils are assumed to be governed by local loading such as slam pressure and flooding. Other structure of ANVs may be governed by local loads as well.

For the SWATH, global hull loads were governed by transverse wave-induced bending moments. Although it was also recognized in the design that large torsional moments will occur, aggravating transverse bending moments, its effect was neglected during this early phase of design.

The principal hull-girder longitudinal bending moments used in the design of prior SES and ACVs are compared in Figure 3.3.3-1 with those used for the SWG/6 Point Designs. For consistency in the comparison, all margins of safety, for the particular materials used in each case, have been applied to the bending moment so that the non-dimensional values shown in Figure 3.3.3-1 can be compared directly to the material yield strength. Also shown on Figure 3.3.3-1 are curves that represent an approximation to the bending moment derived using the simple $1.1\sqrt{L_{BP}}$ wave-height approach adopted for U.S. Navy standard practice. On this basis of comparison, the bending moments used for the SWG/6 SES designs appear to be very conservative.

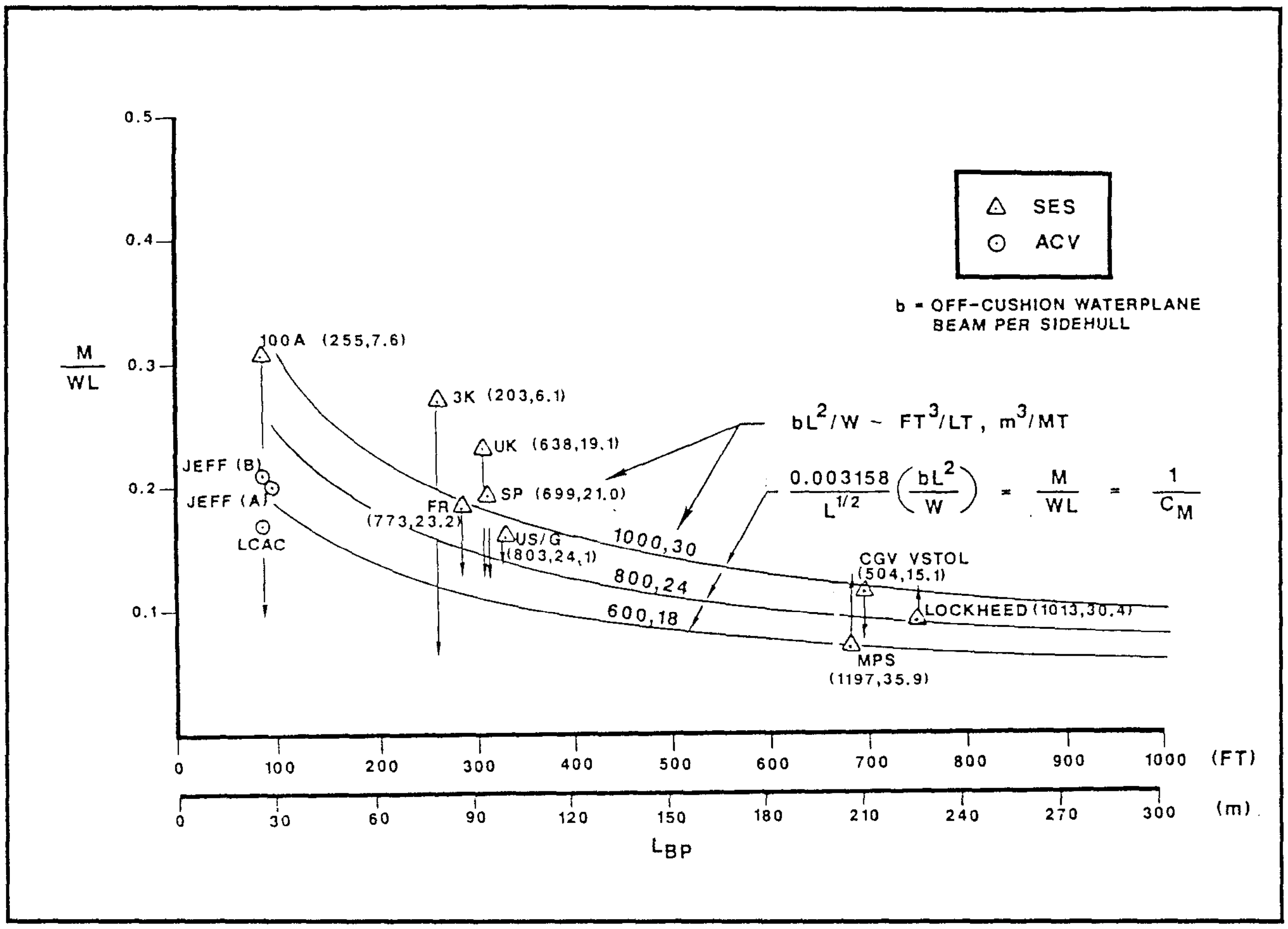


Figure 3.3.3-1. Comparison of Longitudinal Bending Moments Used in Prior SES/ACV Designs

(c) Material Properties

Table 3.3.3-2 summarizes the assumed material characteristics pertinent to structural analysis of each point design. Representative tensile stress-strain curves of some of the materials are shown in Figure 3.3.3-2. Note the respective similarities of the material properties assumed for both the FR SES aluminum and UK SES GRP designs relative to existing US Navy practice. It should be noted, however, that the UK SES material density is approximately 20 percent less than the value specified for US Navy ships. The extensive UK SES fabrication experience has indicated that these lower material densities are necessary for contact molded construction. Also note from the table the disadvantage of using GRP materials for stiffness critical applications.

Furthermore, note from the table the weight advantages which can be expected by using HSLA 80 steel or high strength aluminum alloys for ANV hulls instead of the more traditional ordinary strength steels used for conventional monohulls such as FFG-7. To the extent that elements of the hull structure are governed by strength (and not buckling or stiffness), comparison of the specific strengths in the table shows that HSLA 80 steel or aluminum hulls could respectively be one-half to one-third the weight of a similarly configured ordinary strength steel hull (such as FFG-7). Also, observe by comparison of the specific stability data shown in the table that aluminum and GRP can be expected to be about twice as efficient (and thus half the weight) as steel for structural elements of comparable hulls where those elements are governed by compressive structural stability requirements. Note, by comparison of the global bending design primary stresses in the table, the considerable disparity used for the most basic hull strength parameter. The US/G Hydrofoil uses an aluminum alloy which has a 10% higher yield stress but 100% higher design primary stress than the aluminum alloy used by the FR SES. This can only partly be explained by the use of prime versus welded material properties. These comparisons of ANV hull materials demonstrate the difficulty in attempting to draw optimum material conclusions from the results of the present point designs which are diverse from a hull structural viewpoint.

Table 3.3.3-2. Hull Material Properties

Property	FR SES	UK SES	US/G SES	U.S. Hydrofoil	CA Hydrofoil	FFG-7	CA SWATH	U.S. Navy Ships*	
Material	Aluminum 5086H323 6082T66	GRP E. Glass w.r. Polyester	Steel HSLA 80	Aluminum 5456H116	Aluminum N-A	Steel OSS	Steel HTS	Aluminum 5086H32	GRP E. Glass w.r. Polyester
Ultimate Stress (MPa)	310	227 Tension 186 Comp	620	317	N-A	400	496	276	255 Tension 227 Comp
Yield Stress (MPa)	210	–	551	228	179	234	324	193	–
Design Primary Stress (Global Bending) (MPa)	40	N-A	N-A	76	N-A	116	130	54	57.2
Modulus (GPa)	N-A	13.8	200	73	72	200	200	73	17.2
Density (Kg/m^3)	N-A	1618	7832	2657	2657	7832	7832	2657	1937
Specific Strength**	--	–	71.4	87.5	67.37	30.47	42.18	74.07	--
Specific Stiffness	--	–	2.604	2.8	2.71	2.604	2.604	2.8	0.91
Specific Stability****	--	–	7.51	15.8	15.7	7.51	7.51	15.8	13.4

NOTES:
* References 19, 20 (Note Grade 1 GRP)
** Defined as Yield Stress/Density (m x 10^{-3})
*** Defined as Modulus/Density (m x 10^{-7})
**** Defines as (cubed root of Modulus)/Density $\left(3\sqrt{Kg/m^7} \times 10^1\right)$
N-A Indicates information is not available presently

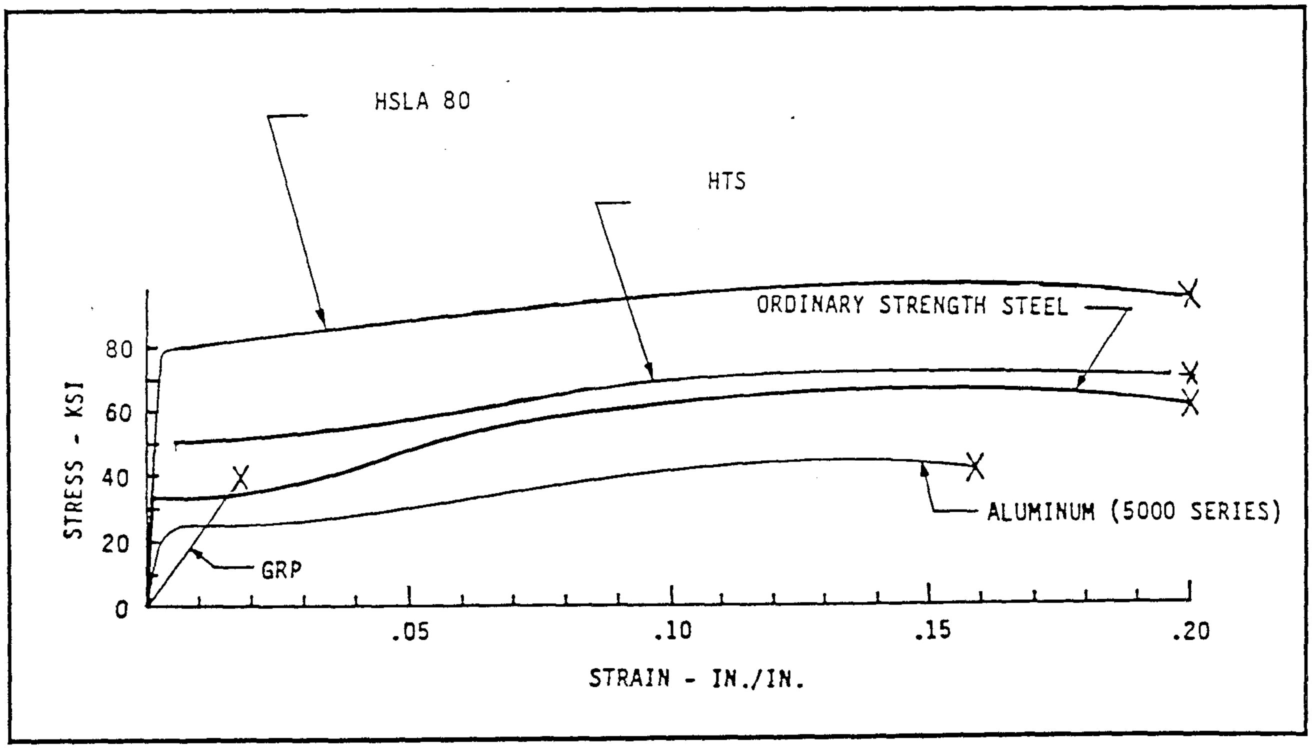


Figure 3.3.3-2. Representative Tensile Stress Strain Curves

(d) Safety Factors

Safety factors on material yield and buckling stress for the steel and aluminum point designs are summarized in Table 3.3.3-3. These factors have been deduced to the extent possible from the design summaries. Note the use of FS=1.3 on yield for local bending of the FR SES shell plating below the waterline compared to plastic design for similar structure of the US/G SES. Since GRP materials exhibit different (typically less ductile) failure mechanisms than do metals, different safety factors are usually warranted. Table 3.3.3-4 summarizes the safety factors used in the UK SES design along with those required by current US Navy specifications [Reference 19].

Table 3.3.3-3. Safety Factors Used for Steel and Aluminum Designs

	Safety Factor*					
Structural Element	FR SES	US/G SES	U.S. Hydrofoil	CA Hydrofoil	CA SWATH***	U.S. Navy Practice**
Shell/Bhd Plating						
- Edge Tension	(Fy/fp) = 5.4	(Fy/fp) = 1.75	(Fy/fp) = 1.8	N-A	N-A	(Fy/fp) = material constant
- Edge Compression	(Fc/fp) = 1.4	N-A	N-A	N-A	N-A	(Fu/fp) - 1.25
- Edge Compression/Shear	(Fy/fs) = 1.67	N-A	N-A	N-A	N-A	(Fp/[fp, fs]) = 1
- Lateral Pressure						
- Below Waterline	(Fy/fb) = 1.3	N-A	$\frac{spacing}{deformation}$ = 200	N-A	N-A	(Fy/fb) = 0.5
- Above Waterline	N-A	N-A	N-A	N-A	N-A	(Fy/fb) = 1.3
- Deflection	N-A	N-A	N-A	N-A	N-A	(span/deflection) = 200
Stiffeners						
- Lateral Pressure/Tension	N-A	N-A	(Fy/(ft + a)) = 1.25	N-A	N-A	Fb/(ft + fa) = 1
- Lateral Pressure/ Compression	N-A	N-A	N-A	N-A	N-A	Fu(Fc/Fy)/(fc + fb) = 1.25$_5$
Internal Decks						
- Lateral Pressure Compression	(Fy/fb) = 2.5	N-A	N-A	N-A	N-A	(Fy/fb) = material constant
Stanchions						
- Compression	N-A	N-A	N-A	N-A	N-A	(Fc/fc) = 1.67
Foundations						
- Elastic Criteria						
- Tension	N-A	N-A	N-A	N-A	N-A	(Fy/fa) = 1
- Compression	N-A	N-A	N-A	N-A	N-A	(Fc/fc) = 1
- Shear	N-A	N-A	N-A	N-A	N-A	(Fy/fs) = 1.67
- Elastic Plastic Criteria						
- Tension	N-A	N-A	N-A	N-A	N-A	(Fy/fa) = 1
- Compression	N-A	N-A	N-A	N-A	N-A	(Fy/fc) = 1
- Bending	N-A	N-A	N-A	N-A	N-A	(Fy/fb) = 0.5
- Shear	N-A	N-A	N-A	N-A	N-A	(Fy/fs) = 0.85

NOTES:
- * For definition of terms see glossary at end of section
- ** Reference 18
- N-A Indicates that information is not presently available
- [ ] Denotes interaction formula
- *** CA SWATH design report indicates use of U.S. Navy Design Criteria, but it is uncertain if this was applied rigidly.

Note from the table that the UK SES typically uses safety factors somewhat less than those required by current USN practice and that deflection limitations are somewhat more restrictive than those imposed by current USN practice. Since GRP material characteristics are similar for both, an SES hull designed to USN current practice can be expected to be somewhat heavier than the UK SES hull. Recognize, however, that UK have considerably more experience than the U.S. in building monohull and SES GRP structures.

Table 3.3.3-4. Safety Factors Used for GRP Design

Structural Element	Safety Factor*	
	UK SES	Current USN Practice**
Solid Laminates and Sandwiches		
• Flat Panels (Static Loads)	(Fm/f) = 3	
- Tension, Compression or Shear on long edge of panel		(Fm/f) = 4
- Compression or Shear on short edge of panel		(Fm/f) = 2
• Stiffeners and Stanchions (Static Loads)	(Fm/f) = 2	(Fm/f) = 4
• Deflection Limitations	(Span/Deflection = 100) (typical)	(Span/Deflection) = 200
• Structures Subject to Impact Loads	(Fm/f) = 1.5	N-A

NOTES: * For definition of terms see glossary at end of section.
** Reference 19.
N-A Indicates information not presently available.

(e) Analysis Methods

Each of the early stage ship structure point designs are based on analyses which ensure that the structure develops the requisite minimum safety factor (Tables 3.3.3-3 and 3.3.3-4) on the applicable material characteristics (Table 3.3.3-2) for each of the assumed critical loadings (Table 3.3.3-1). None of the point designs have been optimized with respect to hull structure weight or survivability and as such, changes in hull structure are expected to evolve for each design. A brief description of the structural analysis methods used to develop many of the point designs are as follows.

Preliminary design practice for U.S. Navy SES hull structures is based on both global hull-girder analyses and local stress/stability analyses. The superstructure is not included in hull girder analyses. Slamming induced longitudinal hull-girder bending is analyzed using engineering beam theory for the entire hull to evaluate the state of stress in plating and stiffeners of the shell and strength deck at the frame station corresponding to the maximum bending moment (usually between the quarterpoint and midship). These globally induced stresses in plating and stiffeners are appropriately combined with stresses developed in the presence of applicable local loadings (such as static head and slam pressures). Local-load stress analyses typically treat a stiffened plate element as a pin-ended or fix-ended beam spanning adjacent structural support points, the degree of end fixity depending on the amount of load continuity beyond the support points. The combined global and local stresses, thus determined, are compared to material yield and buckling stresses in terms of the required safety factors for longitudinal bending. Global transverse bending is similarly analyzed using beam theory for a unit width of structure configured as a portal frame. Applicable local stresses are, again, appropriately combined with globally induced stresses and evaluated. Global hull torsion is not evaluated and global hull longitudinal and transverse bending are treated separately. Note also that grillage analyses are performed and evaluated as required to suit regions such as the innerbottom where considerable interaction of longitudinal and transverse stiffening occurs. Further note that local pressure loads on shell plating below the waterline and plating forming tank boundaries are analyzed using empirical formulas which allow for a limited amount of plastic deformation (about twice the elastic deflection).

The design of the hull structure for the US/G SES was developed using the structural analysis routine contained in the SESDOC computer program. This program, in general, analyzes the hull structure for longitudinal bending as described above. Apparently, no innerbottom grillage analyses or transverse bending analyses were performed. In addition to conventional longitudinal bending analysis, a reliability analysis of the design was also completed using SESDOC to determine the safety margins in the hull structural elements under the presence of extreme off-cushion wave loading. It is not clear whether the conventional or reliability analysis method formed the basis of the US/G SES hull design; the reliability analysis, in general, being the more severe.

The FR SES hull structure design is based on classical preliminary-design level analyses for longitudinal bending, transverse bending and torsion. It is intended by the French to use the comparison of finite element based calculated stresses and actual measured stresses on a smaller SES in an attempt to refine the FR SES hull structure via subsequent finite element based analyses of that hull. Of note in the preliminary FR SES hull structure analyses are the following: the superstructure is assumed to not be engaged in hull girder loadings, and local loading of the helicopter platform and engine foundations have not yet been addressed.

The UK SES hull structure design is based on preliminary structural analyses for off-cushion longitudinal bending and torsion as well as on-cushion transverse bending and local loads. Note that global flexibility analyses and underwater shock-pressure structural analyses for the GRP hull have not yet been considered. Also note that evidently, as a result of preliminary analyses, it has been decided to use a steel insert plate in way of the helicopter platform (likely due to the relatively low impact resistance of GRP).

The U.S. Hydrofoil structure design is based on a series of local load stress analyses using engineering beam theory treating structural elements such as longitudinals, frames, and bulkhead stiffeners as fix-ended beams (typically). The bottom frames are, however, analyzed as statically indeterminant systems subjected to static-pressure loading having some spatial distribution. Elements of the superstructure are designed (typically) for plastic response of varying limits for nuclear airblast loads. Such elements are analyzed as fix-ended beams to determine the fully plastic moment and corresponding resistance.

The CA Hydrofoil structure design was developed using the HANDE ship synthesis model. The structural routine of this computer program is intended to provide input to the module that develops hull weight for the ship. The structure design process of this routine is based on local-load stress analyses using basic fixed end beam formulas. As with the U.S. Hydrofoil, the transverse bottom frames are analyzed as statically indeterminate structures to account for the more complex wave impact pressures. Hull girder bending is not analyzed in this routine because previous hydrofoil experience has indicated that adequate hull girder strength is attained when it is designed for water impact loads.

The SWATH hull structure design was developed using the US Navy's Structural Synthesis Design Program (SSDP). This program is a preliminary design tool that determines a least weight structure for a given set of geometry and specified load condition, using US Navy Strength Criteria. As noted previously, longitudinal bending was ignored because previous SWATH design studies have shown that transverse wave-induced bending moments, combined with the transverse still water bending moments, are the governing loading condition. An innerbottom grillage type structure on the underside of the box was analyzed to account for high wave impact pressure. Superstructure elements were analyzed for blast and fragmentation effects.

Conventional US Navy monohull structure design practice includes global longitudinal hull girder bending analysis in addition to the local loads analyses described above for the Hydrofoil. The global bending analysis is based on engineering beam theory of a hull treated as a beam having stepwise varying inertia properties subject to a parabolic moment distribution (determined by balancing the ship, in both a hogging and sagging mode, on trochoidal waves of height equal to ten percent greater than the square root of the ship's length). For preliminary design, only a midship section is analyzed for this load case. Extreme fiber stresses are evaluated and compared to material dependent allowable design primary stresses (see Table 3.3.3-2). Local buckling of stiffened plating is also evaluated as described previously. Scantlings are modified until the design limiting stress and local buckling criteria are met. Note that a ship growth margin is used by effectively reducing allowable design primary stresses (by 2240 psi (15.6 Mpa) for combatant ships).

(f) **Producibility Aspects**

The US/G SES design intends to employ construction practices which enhance the prospect for existing shipyard structure fabrication. The use of HSLA 80 allows much easier welding than other high yield-strength steels (no preheat is required). However, since HSLA 80 cannot yet be extruded, stiffeners are required to be formed as built-up tees welded from plate. Minimum steel plate thickness has been established as 1/8 inch (3.18 mm) for internal decks and as 3/16 inch (4.76 mm) elsewhere for manufacturing reasons.

Based on early midship section drawings it appears that the FR SES design intends to employ relatively thin (2.5 mm) aluminum alloy 6082 T66 deck extrusions in order to minimize hull-structure weight. This conflicts with subsequent French statements that the minimum hull structure thickness is only 4 mm. It is not clear whether adjacent thin panels will be fastened or welded together. Furthermore, it is recogn[illegible] at a relatively expensive, high quality fabrication process will be required. Also note that US Navy standard practice requires the use of 5000 series aluminum alloys for welding (and corrosion) considerations, with the one exception being aluminum alloy 6061 T6 which is limited to nonwelded hull structure only.

The UK SES design intends to make use of a larger number of separa[illegible] molded GRP hull structural components which will be bolted and/or bonded together during hull assembly. It has [illegible] assumed that (in a large part because of this component approach to hull fabrication) state-of-the-art com[illegible] material marine structure fabrication techniques (primarily contact molding) will be applicable to the UK SES [illegible]ugh the ship would be larger than any GRP ship built to date). Preimpregnated materials cured under pressure [illegible] heat may be used to obtain high quality laminates. However, the size of molded parts will then be limited to [illegible]orded the largest available autoclave (roughly 8 m across at present).

The Hydrofoil design incorporates a number of features based on produc[illegible] rather than minimum weight considerations. Lower strength (and cost) aluminum alloy 5086 will be used for st[illegible] elements governed by stability rather than strength requirements. The superstructure is envisioned as a riv[illegible] assembly of large thin aluminum alloy 6061 T6 panels primarily to maximize producibility. The hull has been re[illegible] to prefabricated, straight sections (no curvature) to enhance producibility. The hull and main deck plating [illegible]m thickness of 1/4 inch (6 mm) was established for producibility. Also, in order to avoid welding heat los[illegible]ems, stiffener web thicknesses were required to be greater than 70% of the plating thickness. The use of lon[illegible]ally framed panels with relatively large web frame and bulkhead spacing was also intended to enhance producib[illegible].

No details of the construction of the CA Hydrofoil are available; howeve[illegible] presumed that some of the constructional details are similar to the U.S. Hydrofoil. An example is the use of [illegible] same stiffener web to plating thickness ratio. A fundamental difference is the minimum thickness of main deck [illegible]g which at 0.16 in. (4 mm). This may result in a somewhat more difficult structure to fabricate.

The use of an HTS structure for the CA SWATH is not expected to in[illegible] any producibility problems. From a producibility standpoint a SWATH hull form should not differ significantly [illegible] that of a conventional monohull. The developed CA SWATH structure was not refined for structural continu[illegible] producibility due to the early stage of design.

3.3.3.2 **Point Design Hull Structures**

Figures 3.3.3-3 through 3.3.3-7 summarize the hull structure midship sca[illegible] for the FR SES, UK SES, US/G SES and U.S. Hydrofoil and SWATH designs, respectively. Hull structure m[illegible] section scantlings of the CA Hydrofoil are unavailable. The structural weights of these designs are summarized [illegible]le 3.3.3-4.

Note the following observations from a comparison of the resulting point [illegible] hull structures and structural weights. The FR SES uses very thin (2.5 mm) plating for the strength deck and [illegible] sideshell of aluminum alloy 6082 T66. The thin plate is not comparable to the 3/16 inch (4.76 mm) HSLA 80 [illegible] plate of the US/G SES and may prove unsatisfactory for local deflection and fragmentation protection consid[illegible]s while the alloy chosen may make superstructure attachment to the hull difficult. More information is required to describe the UK SES midships section. Note the use of solid laminates on the shell and sandwich laminates for internal structure. (Note, for the US/G SES wet deck, the use of 3/16 inch (4.76 mm) thick HSLA 80 plating with 20 inch (0.5 m) frame spacing, and 12 inch (30.5 cm) stringer spacing which is comparable to the 8 mm thick aluminum stiffened plating for the FR SES and 9 mm inch thick GRP skin with 0.5 m frame spacing of the UK SES.) The midship section presented for the SWATH is not the baseline SWATH but was taken from an earlier slightly smaller variant. The outer side shell is primarily .25 inch (6.35 mm) plate with heavier inserts (0.625 in., 2.46 mm) located at the transverse bulkheads. The wet-deck shell thickness varies from .344 inch (8.7 mm) to 0.43 inch (11 mm) plate with the thicker plate located near the centerline. This structure is generally heavier than that used in the other ANV point designs.

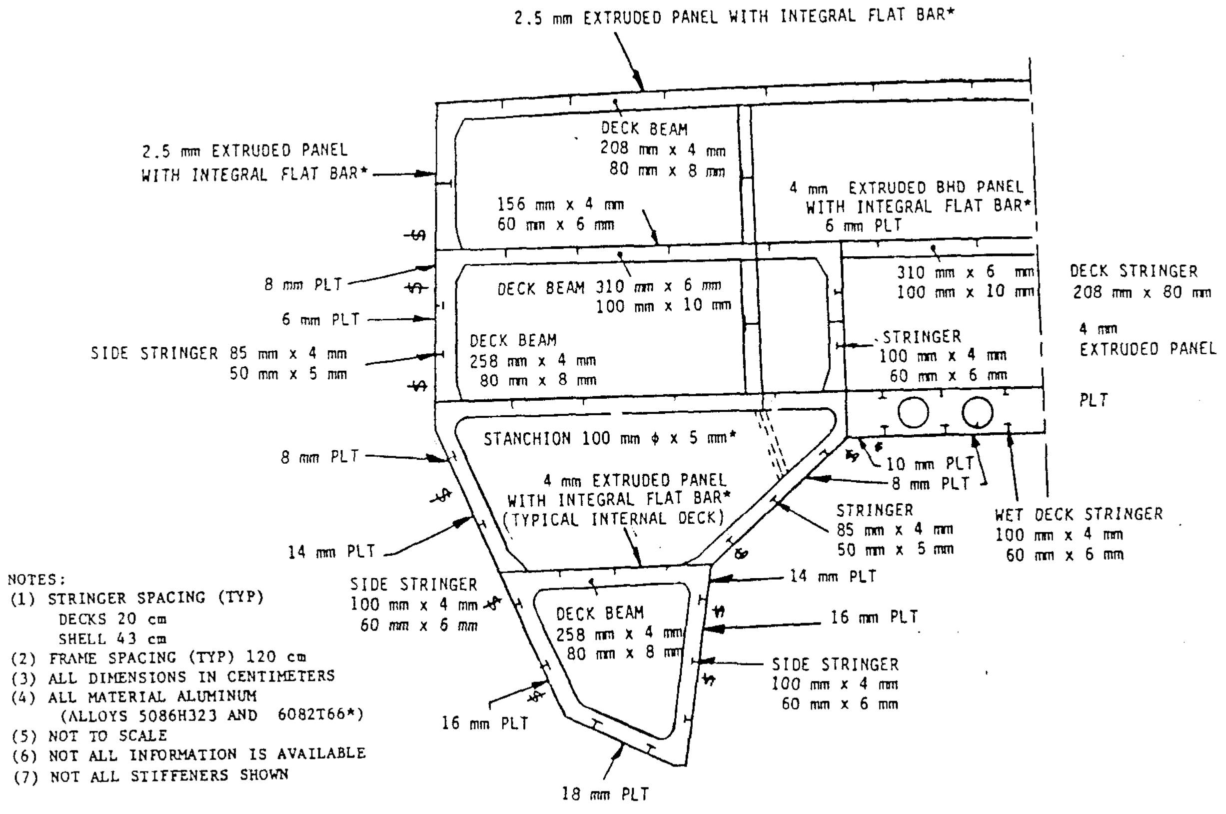


Figure 3.3.3-3. FR SES Midship Section

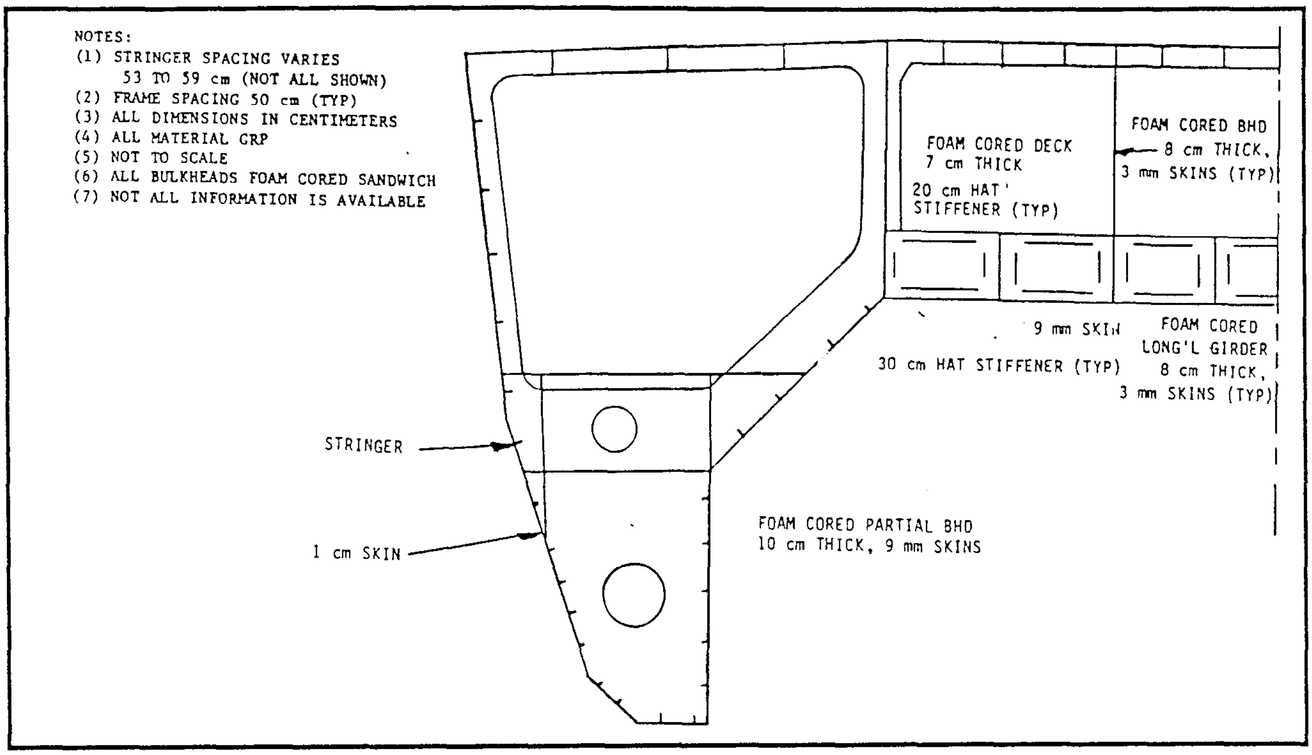


Figure 3.3.3-4. ~~US/G~~ UK SES Midship Section

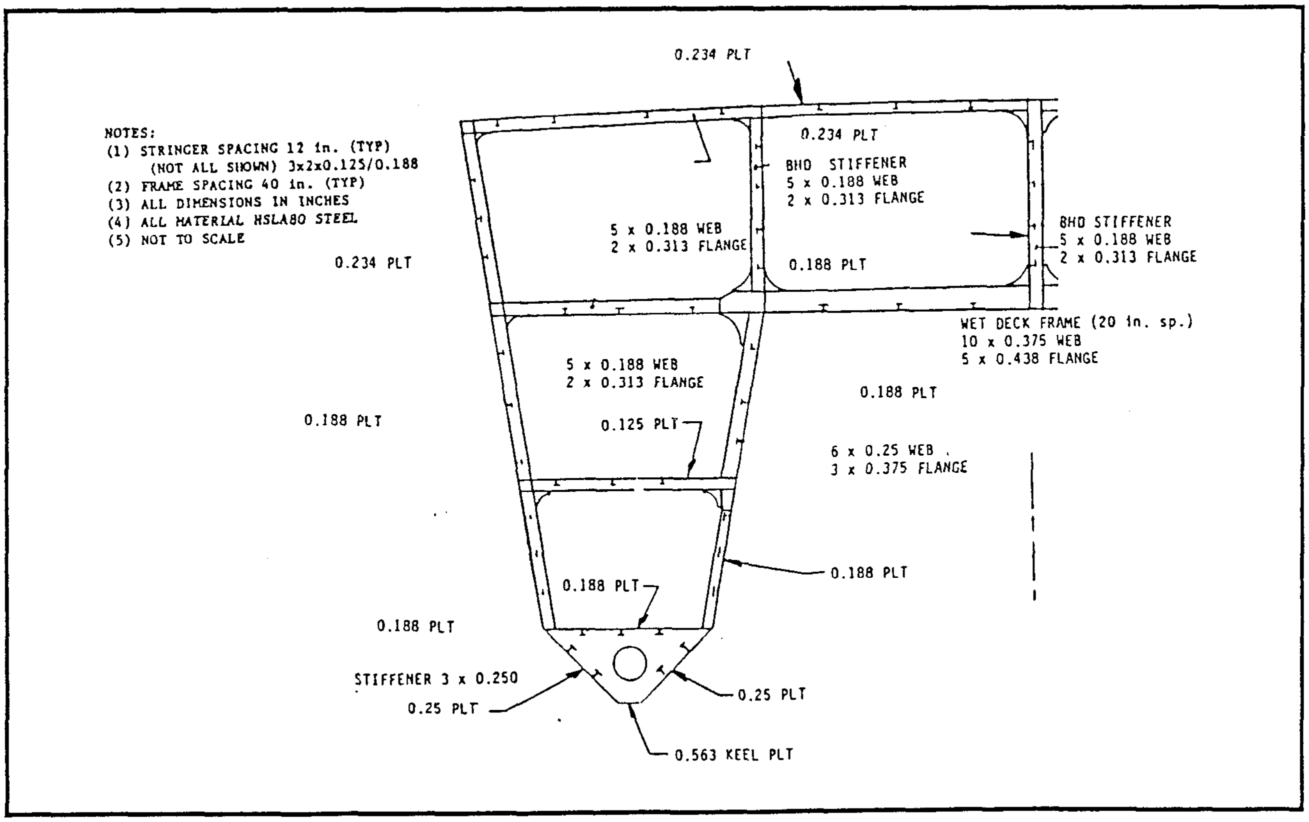


Figure 3.3.3-5. US/G SES Midship Section

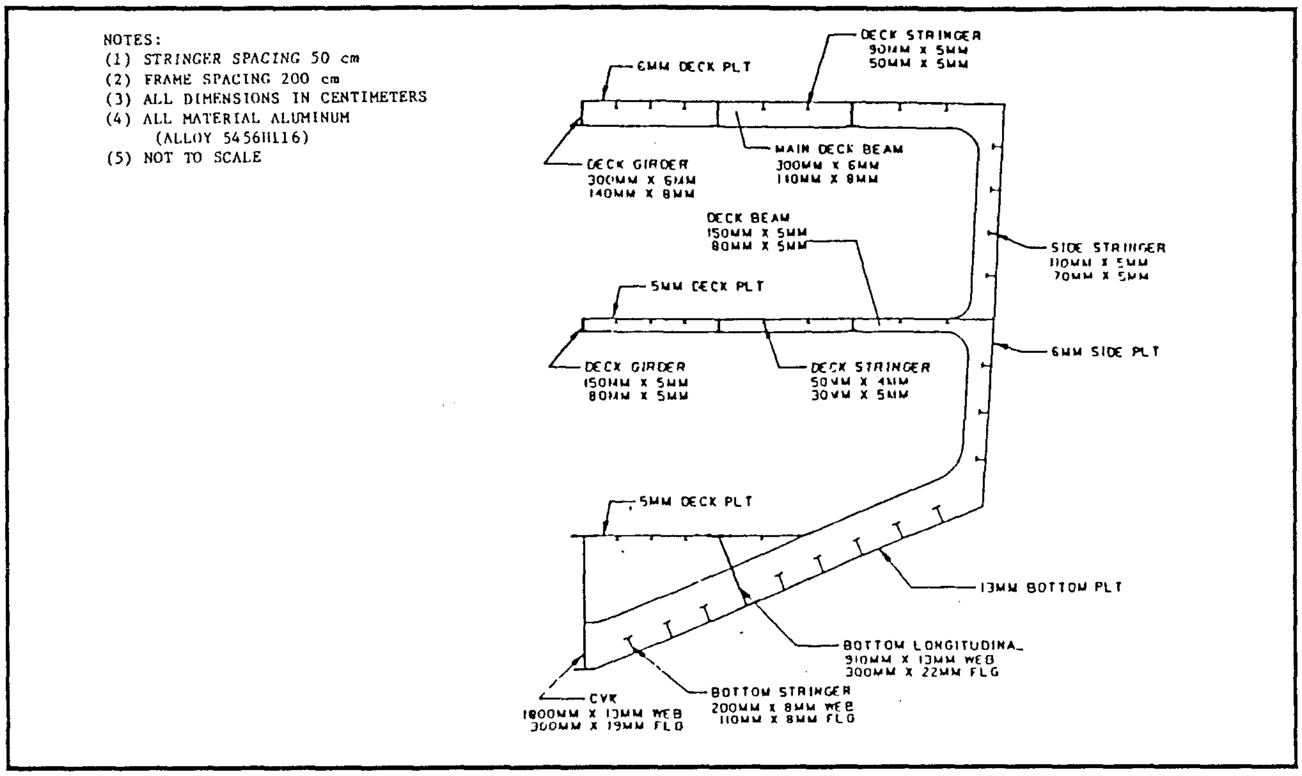
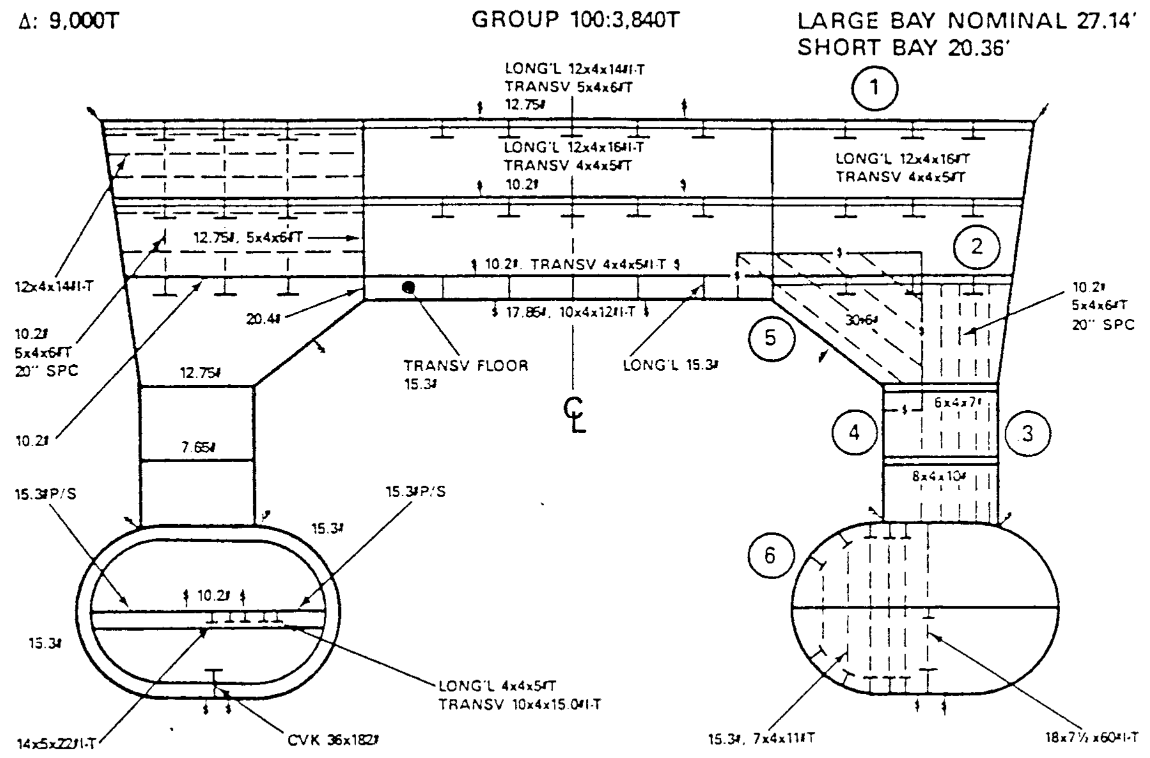


Figure 3.3.3-6. Hydrofoil Midship Section

The structural density versus full-load displacement of each of the point designs along with other ships is shown in Figure 3.3.18-3. Note the relatively low structural density of the FR SES and UK SES designs. While the FR SES would be expected to be relatively light due to the use of relatively higher allowable stresses and thin extruded deck panels, the UK SES is just as light due to the extensive use of a foam cored sandwich construction as well as to the higher volumes within this vessel resulting from a smaller L/B ratio. Standard GRP hull structures would typically be expected to weigh about the same as standard aluminum structures, but not lightweight aluminum structures. Also note from the figure the favorable comparison of the steel US/G SES structural density to the U.S. AMK and PXM CONFORM Point Designs as well as to the PCG. The somewhat higher structural density of the US/G SES, AMK, and PXM SES Point Designs relative to the PCG monohull seems to indicate that a monohull might be somewhat more structurally efficient than an SES. However, the generally lower structural densities of the aluminum FR SES, US/G SES variant, and PXM Point Designs relative to the PHM, PGM84 and PGG seems to contradict this trend. In general, it is expected that a monohull yields a lower structural density than an SES of the same material because of the box-like shape of the midsection and the lack of longitudinal bulkheads which add extra weight.

Figure 3.3.3-8 shows the expected hull girder structural weight per unit ship length versus a ship size parameter for all the point designs, a few other ships and box beam idealizations (using US Navy Criteria) corresponding to the subject point designs and ships. This figure shows that the present ANV hull structure designs are not completely governed by overall hull girder longitudinal bending, but rather by other factors such as minimum scantlings, producibility, local loadings, or transverse bending. (This is evident by the discrepancy between the applicable box beam idealization and current results for all the point designs.) The figure indicates that the point designs together with the three actual ships show a well defined trend of expected hull structure weight normalized to ship length versus the ship size parameter. The SWATH normalized hull structure weight falls significantly above the curve defined by ship size parameter. This is likely due to the large degree to which transverse bending and other secondary loads govern ship structure.



(1) INSERTS @ TRANSV BHDS 25.5#, 5x4x6#T, 18' WIDE INSERTS OTHERWISE 11.475#, 5x4x6#T LONG'L 12x4x19#I-T

(2) INSERTS @ TRANSV BHDS 14.025#, 18' WIDE INSERTS OTHERWISE 10.2#, 4x4x5#T LONG'L 12x4x16#, I-T

(3) INSERTS @ BULKHEADS 25.5#, 6x4x7#T, 11' WIDE INSERTS OTHERWISE 10.2#, 8x4x10#I-T

(4) INSERTS @ TRANSV BHDS 40.8#, 7.0' WIDE INSERTS OTHERWISE 14.025#, 12x4x14#I-T

(5) INSERTS @ TRANSV BHDS 45.9#, 7.0' WIDE OTHERWISE 14.025#, 12x4x14#I-T

(6) LARGE RADIUS 21x8-3/8x83#I-T WEB FRAMES, 2 BTWN BHDS, SMALL RADIUS 18x7-1/2x60#I-T LONG FR, 12x4x16#I-T, 20" SPC FOR LARGE 23" SPC FOR SMALL

Figure 3.3.3-7. Midship Section of an Earlier SWATH Variant

3.3.3.3 Assessment of ANV Structures Development

Development of reliable ANV combatant hull structures depends on establishing a unified approach to design (including established material properties, loads, criteria, assumptions, analysis methods, objectives, and constraints) prior to selection of a platform for final design and construction. To this end it appears necessary to carefully establish quantified relative importance factors for ANV hull weight, cost, producibility, signatures (magnetic and radar), and fragmentation protection. Also, any restrictions on material selection for hull structure components due to the threat of fire should be established. Due to anticipated departures from conventional ship design and construction, ANV hull structure design will require validation.

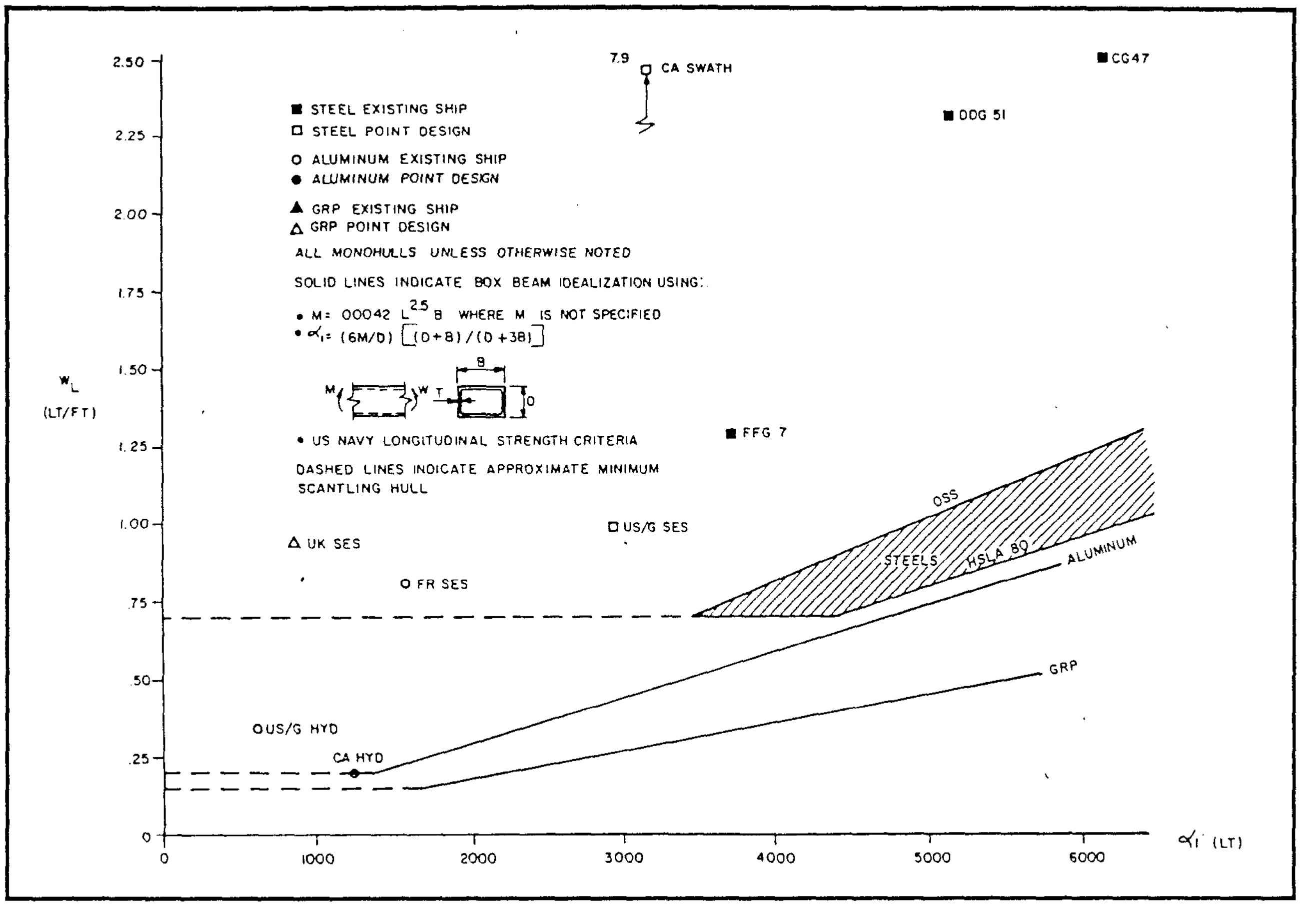


Figure 3.3.3-8. Normalized Longitudinal Structural Weight Versus Ship Size Parameter

In general, probably due to differences in design practice and minimum scantling requirements, the European Point Design hull structures are lighter than called for by US standard practice. This difference requires further investigation. Also, it is not apparent if all the point designs reflect scantlings for superstructure, weather decks and shell above the waterline which have been hardened to the required nuclear airblast design environments nor is it clear that foundation weight estimates in all cases represent UNDEX shock design criteria. Furthermore, the applicability of existing foundation shock design values for SES hullforms needs further investigation.

The US/G SES relies on the use of HSLA 80 steel to provide a more robust, less expensive, high fire resistant hull structure at the expense of some additional hull weight. The FR SES aluminum hull minimizes hull-structure weight in part through the use of thin extruded panels at the expense of more advanced fabrication techniques and possible fire hazards.

The UK SES GRP hull provides for low maintenance cost, a low magnetic signature and better fire retardant characteristics than aluminum with possible risks which include:

- globally flexible hull posing possible difficulties to combat-system and shafting alignments
- need for relatively stringent quality control measures
- potential degradation due to airblast thermal pulse
- quantified joints of high integrity
- UNDEX shock pressure degradation to wetted hull and internal foundations, analytical solutions to which push the state-of-the art (in the U.S.)
- additional materials characterization for the marine environment

In addition, the UK SES uses safety factors one-half those required by US practice presumably because of the more extensive experience available in the UK on large GRP marine structures. The Hydrofoil design of aluminum places emphasis on producibility at the expense of additional hull structure weight. Also the design calls for a riveted aluminum panel superstructure which is susceptible to lower durability.

The diversity of design goals put forth by these hull structure point designs underscores the need for a consolidated approach to hull structure design prior to further cooperative ANV development within the NATO community.

Glossary of Terms

f_a = calculated tensile axial stress from local load (P/A) or design primary stress.

f_t = calculated tensile bending stress due to local loads (M/Z).

f_c = calculated compressive axial stresses from local load (P/A) or design primary stress.

f_b = calculated compressive bending stress (M/Z from local load).

f_p = calculated compressive stress as plate panel (design hull bending primary stress).

f_s = calculated shearing stress on plate panel.

F_c = column strength

F_b = allowable axial/bending strength excluding buckling (1/2)[(Fy/1.25) + (Fu/2.15)]

F_u = ultimate strength of plating (buckling)

F_y = yield strength.

Fp = plate buckling strength.

F_m = ultimate tensile strength of material

K_s = Slenderness coefficient 0.67 for L/r > 60
0.80 for L/r $\leq$ 60
where L/r = slenderness ratio

B = plate buckling coefficient = (b/t) (Fy/E)

b = plate breadth, or off-cushion waterplane width per sidehull

t = plate thickness

E = Young's Modulus

C_m = Bending Moment Coefficient = (ΔL/M)

Δ, W = ship displacement

L, L_{BP} = ship length

M = design bending moment

3.3.4 Seals (SES)

3.3.4.1 System Description

Each SES is equipped with flexible seals which are compliant to wave action and extend across the cushion beam between the sidehulls at the bow and the stern to impede the flow of cushion air fore and aft. The seals are designed to offer minimum resistance to forward motion with the SES on-cushion and are retracted to the wet deck in each case when the SES operates off-cushion. The seals are also designed to respond favorably to wave impact and wave-following-dynamics to minimize the seals contribution to ship motions and accelerations while at the same time providing a contribution to the ship's pitch and roll restoring capabilities. The seals must also have an acceptable life and be easily maintained and replaced. The leading particulars of the bow- and stern-seal systems proposed for each point design are given in Table 3.3.4-1. Their configurations are illustrated in Figure 3.3.4-1 in comparison to seals which are considered to represent the current state-of-the-art (Reference Appendix E).

Table 3.3.4-1. Leading Particulars of SES Bow and Stern Seals.

		UK SES	FR SES	US/G SES
Bow Seal				
Type		Full-Depth Finger Seal	Multiple Bag Finger Seal	Transverse Stiffened Membrane (TSM) Seal
Depth	m	7.8 to 9.5	5.17 to 9.96	6.7 to 8.0
Width	m	20	13	15
Material	-	Neoprene Coated Nylon Fabric (3500 g/m^2)	Coated Fabric	Coated Nylon Fabric and GRP Battens
Air Supply	-	Cushion	Cushion	Separate
Operating Pressure	-	Cushion Pressure	0.2, 0.6 & 1.0 of Cushion Pressure	1.04 of Cushion Pressure
Weight Including Attachments and Retraction System	kg	8325	7400	15605*
Retraction System	-	Cables and Hydraulic Winch	Cables and Electric Winch	Straps and Winch
Stern Seal				
Type	-	VHL Unblown Drag Sheet	Multiple Loop Planing Seal	Bag Supported Planing Seal
Depth	m	7.8	5.65 to 6	6.7
Width	m	20	13	15
Material		Neoprene Coated Nylon Fabric (2800 g/m^2)	Coated Fabric & Composite Planers	Neoprene Coated Nylon Fabric and GRP Planers
Air Supply	-	Cushion	Separate	Separate
Operating Pressure	-	Cushion Pressure	1.1 of Cushion Pressure	1.09 of Cushion Pressure
Weight Including Attachments and Retraction System	kg	7675	3600	Included in Bow-Seal Weight
Retraction System	-	Cable and Hydraulic Winch	Cables and Electric Winch	Straps and Winch
Retraction Time	mins	4	Unknown	Unknown
Auxiliary Seals				
Type	-	Transverse Inflated Seal	None	None
*Bow and Stern Combined Weight = 15605 kg				

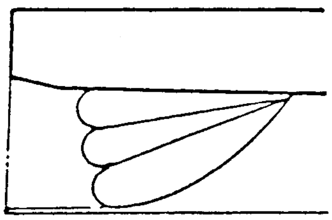
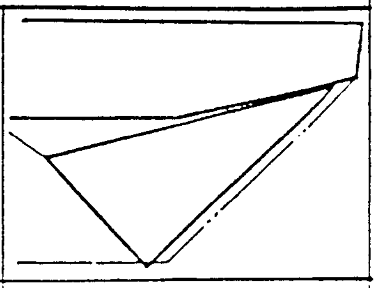
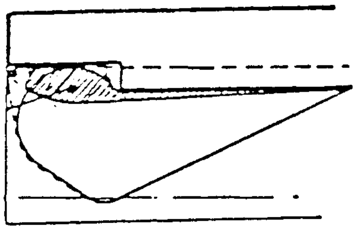
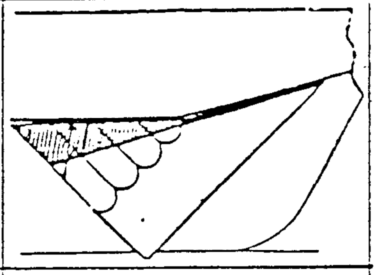
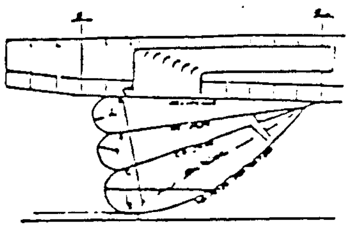
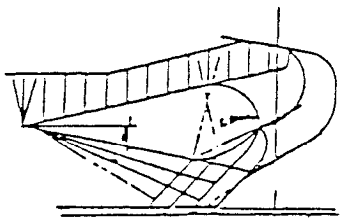
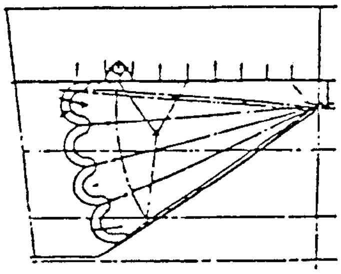
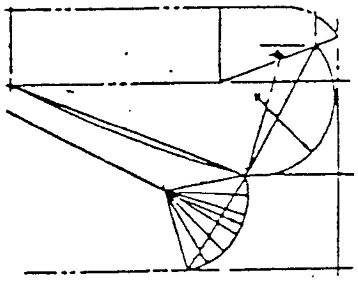
Design	Seal Types	
	Stern Seal	Bow Seal
State-of-the-Art Seals Stern seal - triple loop fabric seal pressurized. Bow seal - full depth segments unblown.		
UK Seals Stern seal - segment and drag sheet assembly. Unblown. Bow seal - full depth segments unblown.		
French Seals Stern seal - triple loop seal with planing plate. Pressurized. Bow seal - double (tandem) segments and double loop. Unblown.		
US/G Seals Stern seal - quadruple loop seal with full depth planer. Pressurized. Bow seal - bag and transversely stiffened membrane. Blown.		

Figure 3.3.4-1. Comparison of SES Cushion Seals (Appendix E)

3.3.4.2 Technology Assessment

The bow and stern seals proposed for each of the three SES Point Designs are assessed here based on the UK assessment contribution of Appendix E. The seals are examined with particular reference to their durability, producibility, maintainability, and the likely associated risks.

The seal system is fundamental to the SES principle and all the proposed designs represent some risk, this risk being assessed as high for certain of the proposed configurations. Particular emphasis has been placed on the survivability of the seal in higher sea states.

(a) Durability

(i) Calm Water Wear Rate

For bow seals, all three designs use a lower skirt element which has a free edge (rather than loop) in contact with the water surface. The mechanism by which seals wear in calm water is principally by progressive fraying of the free end as it flagellates in contact with the water surface. Wear due to abrasion with the water and any suspended particles is very much a secondary effect. Therefore, all three of the proposed designs are likely to suffer from progressive flagellation erosion.

The unique design of the US/G TSM seal with a stiffening member very close to the free edge is likely, however, to give a response characteristic which would limit the flagellation effect compared to the other two designs. This likely low rate of calm water wear is identified as a positive feature of this design.

The French design, although essentially similar to the UK design in that it features free-ended open segments, has potential advantages over the UK system because two segments, one in front of the other, are used at each location. This will result in a lower pressure differential across each element which should reduce the flagellation wear effect when compared with a single-segment design. It is also considered likely that such an arrangement could suffer a higher amount of erosion, while maintaining a reasonable seal, than a single system for the same level of cushion air leakage. However, France claims that since their bow seal will track the local water (wave) surface with a nominal (small) air gap, this will limit the flagellation and reduce wear.

For the stern seals, the French and US/G designs use a multilobe loop seal. This is the most common form of stern seal fitted to SES worldwide, and is selected, amongst other reasons, for its very low wear rate. In addition, both the French and US/G multilobe stern seals terminate in a non-flexible planing plate, which it is believed should further reduce calm-water wearing behavior. The UK stern seal design departs from current established UK practice and uses an unblown drag sheet. This seal is still under development at model scale and HM2 scale in the UK and it is not possible to predict its long-term wear rate with the same confidence as for closed rear loops. Although early results are promising, it must be expected that there is some risk in terms of wear rate with this seal because it consists of a multiplicity of elements including some of segmented form.

(ii) Rough Water Damage

The large amount of SES operational experience with UK built craft has shown that damage in rough water is almost always associated with skirt tearing where high local loads are imposed at joints between the elements forming the seal. (Similar experience has also been recorded for amphibious craft.) In particular, it has been found that when scaling from smaller to larger craft (e.g., HM2 to HM5) these effects become more pronounced even in scale sea states. Current UK practice for new designs is to produce seals of the simplest form using the minimum number of elements. Multi-element designs utilizing many joints are regarded as suspect for use in higher sea states. In the light of the above comments, both the French and US/G designs of bow seal would be regarded as representing a higher degree of risk. The French bow seal design uses two upper loops with pairs of segments suspended below. This is essentially similar to the bow seal design used on HM5 craft and which was particularly susceptible to damage in sea states with a significant wave height of two thirds cushion depth or more. The French bow-seal design is likely to be more responsive than that fitted to HM5 and therefore, may not suffer from impact in the same way, but it is felt that this advantage is outweighed by the additional number of elements and inevitable introduction of high local loads which can initiate tears. Similar remarks apply to the US/G TSM design.

In contrast, the UK design uses the well proven full-depth segments for the bow seal. Most new craft built since 1980 use this system and segments of this type fitted to the BH110 craft operated by U.S. Coast Guard have claimed 1500 hours between replacements. It is understood, from Avon Industrial Polymers, that replacement is usually on the basis of wear rather than rough water (tearing) damage. Since the BH110 craft spent a high proportion of their time in slow speed patrol off cushion, or on partial cushion without seal retraction, then the figure of 1500 hours augurs particularly well for resistance to rough-water damage.

The stern seals fitted to the French and US/G designs are based on configuration which have survived well in a variety of craft up to a size of 200 tonnes. However, the use of a full-depth planer on the US/G design must be regarded as potentially compromising resistance to rough-water damage because of the high local loads it can impose on the rest of the four lobed, flexible structures. The small local semi-rigid feather fitted to the French design is not thought to detract significantly from the good rough-water experience with similar multi-lobed designs not having such a feather. The unblown stern seal fitted to the UK design has large forward opening vents through which it is inflated from the main cushion. It is felt that such a design is potentially hazardous in very rough conditions where water may enter the drag sheet loop in large quantities and be slow to drain, thus causing a sea-anchor effect, imposing very high loads at the forward attachment point between the drag sheet and the main hull.

(iii) Survival After Damage to One Element

The very high flow rates and relatively low pressures used in SES designs generally implies that the craft can still operate effectively on cushion even when the bow and stern seals are damaged. This is particularly the case with multi-element designs where the removal of one element may have little effect on the rest of the seal. The bow seals of the UK and French designs both use finger-type segments and it is well known that complete removal of one segment will have little effect on seal performance since segments adjacent to the one missing will virtually reseal the gap. In contrast, the TSM seal used by the US/G design would be likely to suffer progressive tearing following damage, which could extend across the whole element instead of being restricted to one small element as with the segmented designs. Following such progressive tearing and partial, or complete loss, of a TSM element, a craft equipped with such a seal would be unable to take evasive action at high speed to protect itself against further damage and would probably be reduced to operating in the cushionborne mode.

None of the stern seals proposed have design features which would give automatic resealing of the cushion following damage. Multi-lobe loop stern seals are susceptible to progressive tearing in a similar way to that described for the TSM bow seal. It is possible that following damage to a lower lobe, a craft equipped with a multi-lobe stern seal could continue to operate at lower speed with a reduced cushion depth, but tests simulating this at sub-scale have not been identified. Damage to the drag-sheet design featured in the UK Point Design would be likely to have a more serious effect. Damage to the outer drag-sheet element would almost certainly result in a scooping of water by the internal elements and consequent inability of the craft to operate without retracting the seal and reverting to hullborne operation.

Seal damage may occur as a result of combat, caused, for example, by splinters. It is important that such minor damage should have a minimal effect on craft operation.

(b Producibility

No seals of the sizes proposed for any of the NATO Point Designs have ever been constructed. However, full depth bow segments and multi-lobed stern seals have all undergone exhaustive testing on craft with displacements up to 200 tonnes. Some further development of these seals would be required before full-scale application, particularly in the areas of hull attachments and skirt retraction gear.

The innovative seal designs proposed will require more development work. In particular, the TSM bow seal and its retraction requires further development. The use of loop-segment bow seals is established design practice but the French bow seal is unusual in that the loops are not fed by an independent air supply. Full-scale development work would be required to ensure that the correct pressures are achieved in the loops. Recent experience with HM5 craft has shown that loop-segment bow seals can work efficiently without an independent air feed. The craft was originally designed to have an independent feed, but it was found that the seal operated best with a pressure ratio between the loop and the cushion of 1.0 so the independent feed was removed and the loop fed through enlarged openings in the rear of the forward loop element. The French design features two loops at different pressures and so the problem in this case is more complex.

The planer fitted to the multi-lobed stern seal on the US/G design has undergone significant theoretical and model-scale development during the 3K SES program and has been operated on U.S. Navy manned test craft. This seal, however, will require development effort before the hardware can be built for the proposed Point Design. The UK drag-sheet, stern-seal, design features a very large flexible element bounding the whole of the stern seal. This will involve the use of many joints in the flexible materials which will require development effort before the seal can be produced at full scale.

(c) Maintainability

One of the most critical parameters for commercial SES is the effect on total operating costs of skirt maintenance and the consequent slipping or drydocking which is required to undertake repair or replacement. Intervals between segment repair or replacement for craft operating at high speeds may be as low as 400 to 500 hours. Large commercial SES need to be slipped or drydocked at intervals between 6 weeks and 2 months. The cost of the replacement elements is not significant but the associated labor and dock charges may be very high. A possible feature of the very large craft proposed for the NATO ASW role should be their ability to have seal elements replaced while they are still afloat. Nevertheless, these maintenance activities would still have to be carried out in harbor at a suitable maintenance base as a seal element replacement at sea is not considered to be a viable proposition. In harbor the seal elements of some of the proposed designs could be replaced from launches or floating pontoons moored between the hulls and making use of the relatively high wet-deck clearances in the hullborne condition.

The aft seal elements are almost certainly too large to handle in this way. Loop-type seals at sub-scale, however, have lives as high as 7000 hours (HM2 and HM5 double-lobed stern seal configurations) and so this should not be a problem since maintenance can be carried out during refit periods. Bow seals have shorter lives and maintenance will have to be carried out many times between refits. This effect is alleviated in designs which use multi-element bow seals allowing replacement of small handleable units. In this respect, it is considered that all maintenance on the UK design full-depth-segment bow seal could be carried out afloat and that the lower segmented elements of the French design can also be handled in this way. The French bow loop and the whole of the US/G bow seal are considered to be too large to be handled in this way and slipping or drydocking would be necessary to replace these elements. Once again, the lives of these particular elements are predicted to be much longer than that for the forward segments and it may be possible to carry out this work on approximately an annual basis.

The ability to maintain bow and stern seals without significant craft down-time is considered to be of critical importance for the development of large ocean-going SES and development effort will be required to specifically address this problem. In the commercial market, seal maintenance problems have had a significant effect, increasing sales of catamaran designs and decreasing the market share for SES.

(d) Seal Resistance

In calm water, minimum seal resistance is achieved by seals having minimum contact and a uniform seal for cushion air across the beam of the craft. In flat calm conditions this will be best achieved by the US/G TSM bow seal, but in high frequency small waves, the superior sealing qualities of the French bow-seal design should have advantages over the other two. Of the stern seals, the US/G and French designs, which both feature a bottom planing member, will have lower resistance than the drag-sheet skirt fitted to the UK design. A systematic series of tank tests on an SES model in the UK clearly shows that minimum resistance was achieved with this seal type, with clear advantages over double segments, multi-loop seal bag and multi-loop ventilated bag configurations. In rough water, minimum resistance depends on the ability of the seal to respond to and contour the disturbed surface. The tank tests referred to above indicated that seals featuring rigid planing members gave higher resistance than those featuring all flexible elements. Because of the relatively small size of the planing member fitted to the French design, it is not considered that this seal will suffer in this respect and it is expected that this seal would be superior to the other two national designs in rough water. UK experience is that not only does rough-water resistance increase with semi-rigid planing type seals, but that vertical accelerations will also be higher and it is considered that further large-scale development work would be necessary before incorporating a seal of the type proposed for the US/G design on a large, ocean-going SES. Uncertainties concerning the response and possible water scooping of the UK drag sheet design make this a less desirable first choice than a multi-lobed type loop.

3.3.4.3 **Risk Assessment**

Figure 3.3.4-1 illustrated a comparison between the seals proposed for the NATO SES Point Designs. They are compared with a State-Of-The-Art (SOTA) seal which represents the most commonly adopted seal arrangement on SES craft now operating. Seals are qualitatively compared with the SOTA seal on the basis of factors which are likely to affect cost, durability, maintainability, ride quality, resistance and technical risk. The results of this comparison are found in Table 3.3.4-2 and Table 3.3.4-3. On each of several criteria each seal is rated as better (+), worse (-), or the same (0) as the SOTA seal. This method of comparison is not intended to give a precise numerical rating of one seal against another but rather to establish which trends in seal design may have advantages and may be worthy of future development. The pluses and minuses are summed for each seal and give an indication of the best choices.

Table 3.3.4-2. Assessment of SES Bow Seals (Appendix E)

Basis for Comparison		Seal Types			
		Control	UK	France	USA
1.	Calm Water Wear Rate	0	0	0	+
2.	Rough Water Damage	0	0	-	--
3.	Survival After Damage to One Element	0	0	0	-
4.	No. of Attachments and Probability of Local Tearing	0	0	-	-
5.	Vibration in Calm Water	0	0	0	-
6.	Maintainability (afloat)	0	0	-	-
7.	Maintainability (drydock)	0	0	-	-
8.	Response in Rough Water	0	0	++	0
9.	Air Leakage	0	0	+	-
10.	Resistance (Calm)	0	0	+	0
11.	Resistance (Rough)	0	0	+	-
12.	First Cost (Seal Only)	0	0	-	-
13.	Weight	0	0	-	-
14.	Separate Air Feed Required	0	0	0	-
15.	Large Scale Experience	0	0	-	0
16.	Technical Risk	0	0	-	--
17.	Pressure Control Independent of Cushion	0	0	0	+
	TOTALS	0	0	-8 +5	-14 +2

For the bow seal, the well established UK design scores the highest although the significant number of positive features associated with the French design would certainly render this worthy of further development effort. It is considered that the large number of negative features associated with the US/G design combine to make this seal an area of higher risk. For the stern seals the French design is very close to the established SOTA seal and achieves an almost identical score. It is superior to the SOTA seal in calm conditions, but there may be some limitation to its response in rough water. Both the UK and US/G designs have a large number of negative features which make their potential development costs and associated risks high.

Table 3.3.4-3. Assessment of SES Stern Seals (Appendix E)

Basis for Comparison	Seal Types			
	Control	UK	France	USA
1. Calm Water Wear Rate	0	-	+	+
2. Rough Water Damage	0	-	0	-
3. Survival After Damage to One Element	0	0	0	0
4. No. of Attachments and Probability of Local Tearing	0	-	0	-
5. Vibration in Calm Water	0	0	-	0
6. Maintainability (afloat)	0	0	0	-
7. Maintainability (drydock)	0	-	0	-
8. Response in Rough Water	0	+	-	-
9. Air Leakage	0	0	0	0
10. Resistance (Calm)	0	-	+	+
11. Resistance (Rough)	0	-	0	-
12. First Cost (Seal Only)	0	-	0	--
13. Weight	0	-	0	-
14. Separate Air Feed Required	0	+	0	0
15. Large Scale Experience	0	-	-	+
16. Technical Risk	0	-	0	--
17. Pressure Control Independent of Cushion	0	-	0	0
TOTALS	0	-11 +2	-3 +2	-10 +3

When comparing SES, SWATH, hydrofoil and monohull designs, cushion air supply and seals are unique features of the SES. The positive attributes claimed for the SES (low resistance, low powering, high speed, acceptable motions, shock alleviation) are achieved at the expense of the these systems which represent a significant technical risk in the development of large ocean-going vessels.

In assessing vehicle types for further development, these risks may be perceived as unacceptable unless the correct lower-risk choice of seal design is made.

3.3.5 Resistance Prediction

3.3.5.1 SES

(a) SES Resistance On-Cushion

Figure 3.3.5-1 compares the drag predicted for the four SES operating on-cushion in calm water. The drag curve for the French SES exhibits a double-peak hump while curves for the UK SES, US/G SES and the Spanish SES exhibit no hump. At a speed of 50 knots, the UK SES and Spanish SES are predicted to have a drag-to-weight ratio which is 10 percent lower than the drag-to-weight ratio of the French SES while the drag-to-weight ratio of the US/G SES is predicted to be 25 percent lower than the drag-to-weight ratio of the French SES.

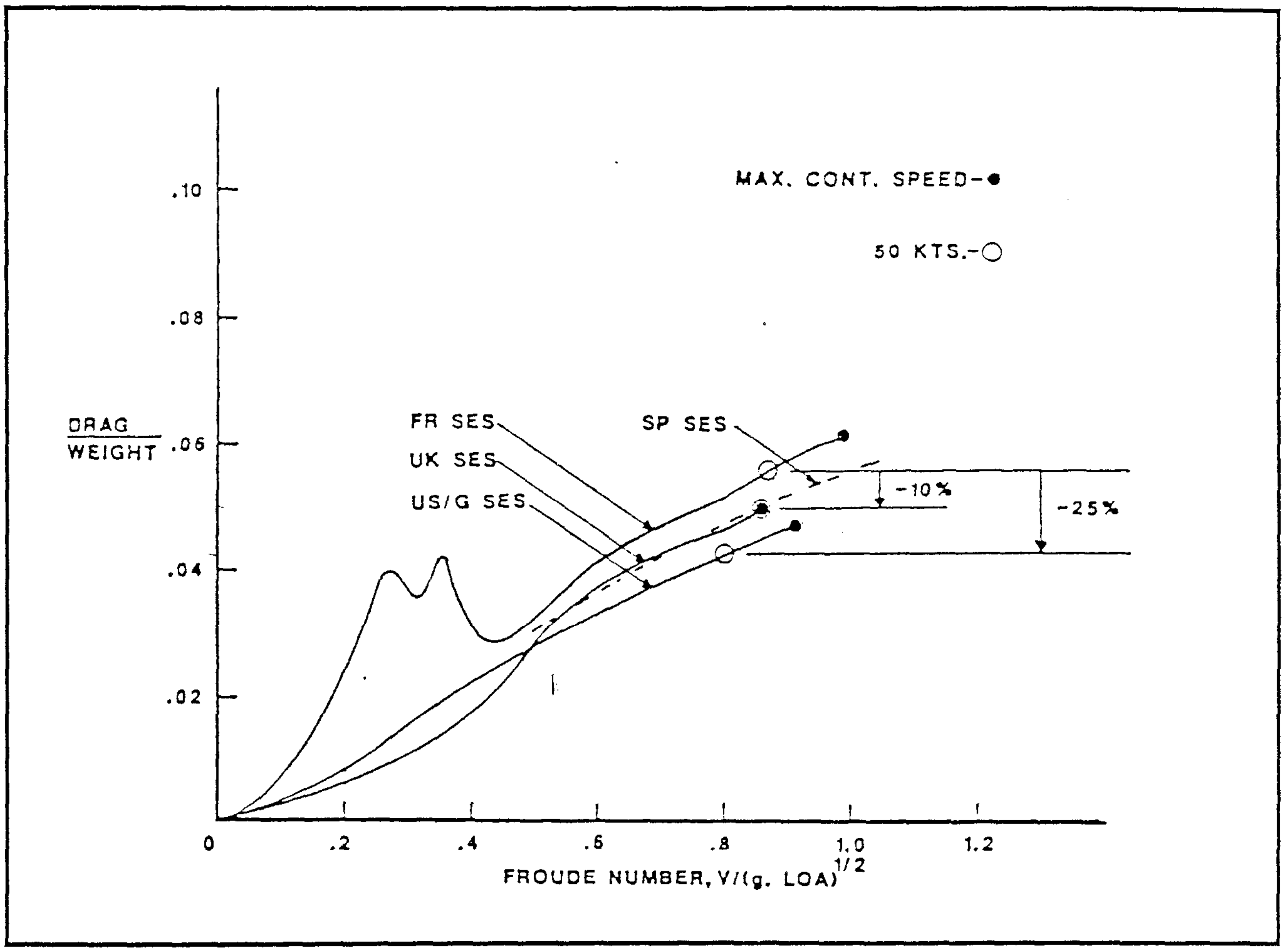


Figure 3.3.5-1. Comparison of SES On-Cushion Drag in Sea-State 0.

The UK assessment of Appendix E examined the published resistance curves for the UK SES, FR SES and US/G SES, and observed that, although the designs have many different features, such as variations in L/B ratio, displacement, cushion density, sidewall shape, etc., the resistance characteristics are remarkably similar, particularly in the speed range from 50 to 60 knots. This conclusion was made on the basis of using a common computer model to predict the resistance of each SES.

Figures 3.3.5-2, 3.3.5-3 and 3.3.5-4 show the resistance characteristics as presented in the Point Design Reports compared with resistance of the same vessels calculated using the UK computer model. It can be seen that the correlation is remarkably good on the UK and French designs and has a close correspondence on the US/G design, being very accurate at 20 and 50 knots, but with somewhat less correlation between those speeds. Figure 3.3.5-3 presents the correlation for the French design and shows a marked hump in the published resistance curve at about 20 knots, which was evident in the French model data but not present in the characteristics from the UK computer model.

It was concluded that the correspondence between all of the published curves and the UK computer model were good enough to proceed with using the computer model to investigate variations in hull parameters.

(i) **Effect of Displacement**

The three designs cover the displacement range from 1400 to 1937 tonnes and since displacement has a profound effect on resistance, it was decided to examine the effect of running the three designs through the computer model at a common displacement. This common displacement assumed that the hull structure would be built of a lightweight material (aluminum alloy or composite) and the average of the UK and French designs of 1500 tonnes was chosen.

This resulted in the resistance of the FR SES increasing slightly, the UK SES resistance decreasing slightly and the US/G SES resistance decreasing significantly. At 50 knots, the resistance of the FR SES design, now operating at an overload condition, was now some 48% higher than that of the US/G design, whereas previously the French design was some 5% lower.

To refine the analysis, the craft weights were averaged to derive comparable weights for the three craft assuming that they used the same machinery, electrical installation, armament, etc., but still maintained their own overall dimensions and hullforms. It was further assumed, for the purpose of this comparison, that all three SESs would be built of composite materials. Structure weights for the French and US/G SES were scaled for the UK SES structure weight using a surface numeral method. The resulting weights were 1587 tonnes for the UK design, 1516 tonnes for the US/G design and 1494 tonnes for the French design. Figure 3.3.5-5 is a plot of the resistance of the three designs at these calculated comparable weights, and therefore illustrates the effect of hullform design features while eliminating effects due to differing weights of equipment. Figure 3.3.5-6 is a comparative plot of the three designs analyzed at their published weight and including their different equipment specifications.

From Figure 3.3.5-6 it is seen that there is a total of 10% difference in total drag at 55 knots across the three designs. The drag of the US/G SES design is a little higher than the other two, mainly because of its high cushion pressure caused mainly by the choice of steel as a structural material. The large wetted surface area at this high displacement causes high sidewall drag.

If the resistance characteristics of the three craft at the derived comparable weights are compared at a speed of 55 knots, it is seen in Figure 3.3.5-5 that the US/G SES design now has the lowest drag which is mainly due to a significant decrease in cushion wave-making drag, sidewall-friction drag and sidewall wave-making drag terms. The magnitude of these terms has reduced from those for the actual US/G SES design because the cushion pressure has reduced. The US/G SES design, at the scaled displacement of 1516 tonnes, has the lowest cushion density of all the designs and the benefit of this is seen in the total drag.

The total resistance of the FR SES is very much the highest of the three shown in Figure 3.3.5-5 and this is due to the scale increase in weight of some 100 tonnes over the actual design weight. This has increased the cushion pressure, which was already high, and caused the cushion wave-making-drag and sidewall-drag terms to increase.

The drag of the UK SES design is roughly midway between the "GRP" FR SES and the "GRP" US/G SES on Figure 3.3.5-5. It is interesting to note that the resistance of the UK SES design is 90% of that of the FR SES design, even though it has a higher displacement, which is due to a lower cushion density.

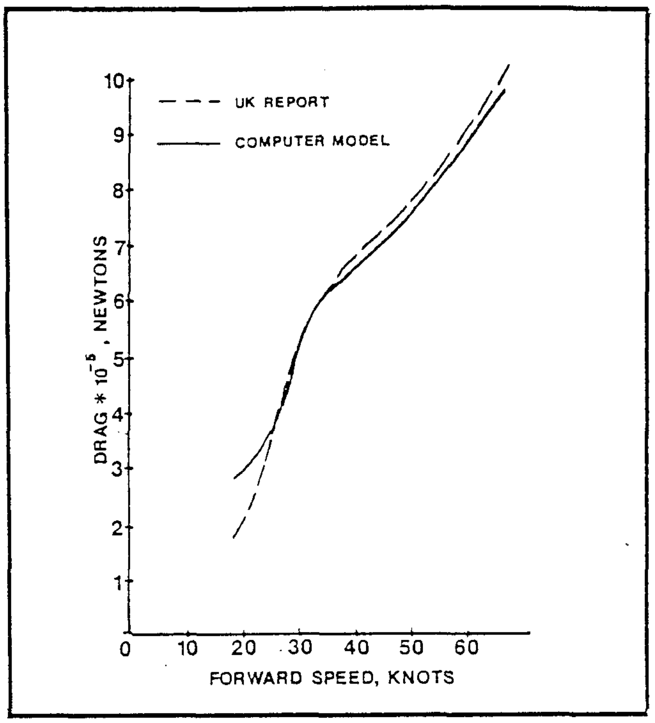


Figure 3.3.5-2. Comparison of Drag Predicted and that Presented in UK SES Report

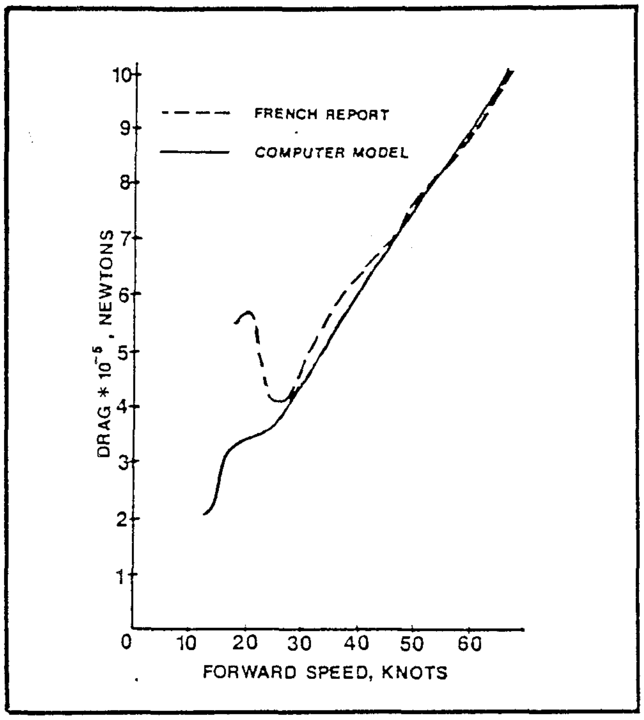


Figure 3.3.5-3. Comparison of Drag Predicted and that Presented in FR SES Report

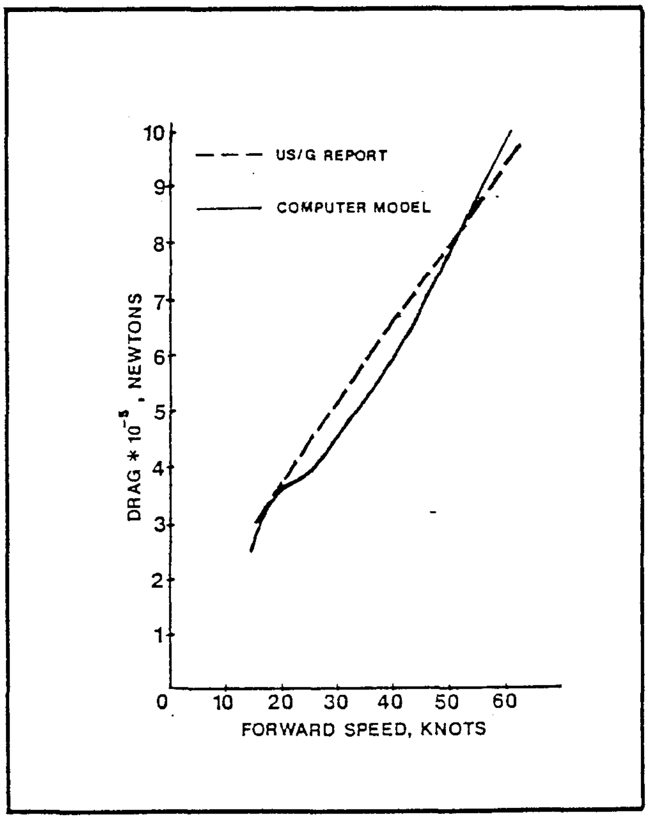


Figure 3.3.5-4. Comparison of Drag Predicted and that Presented in US/G SES Report

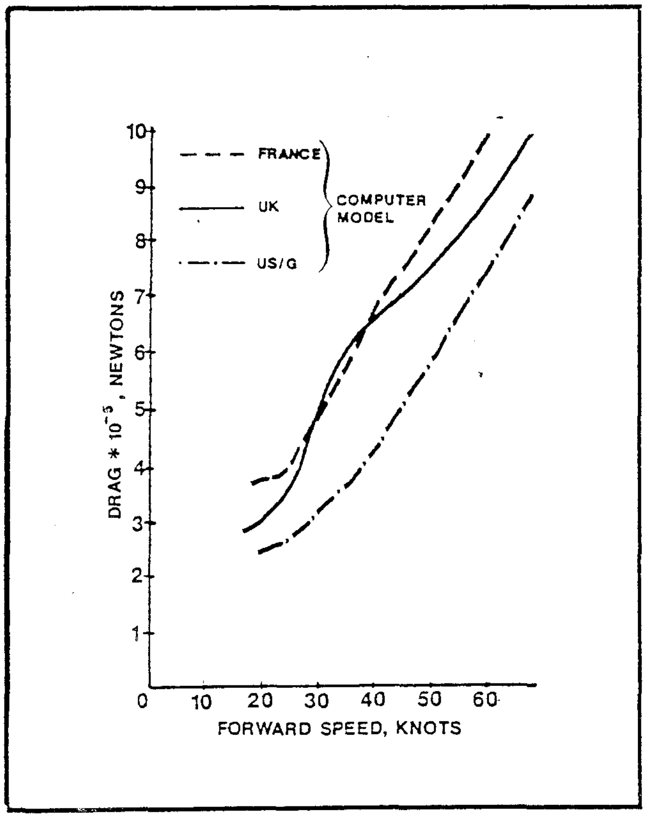


Figure 3.3.5-5. Comparison of Predicted Drag of SES Point Designs at Comparable Weights

The major conclusion drawn from the above analysis is that there appears to be advantages in choosing a high L/B ratio for craft of these weights and speeds, providing cushion pressure can be kept reasonably low. It is therefore of interest to examine the effect of changing the L/B ratio of the three designs at their derived comparable displacements. If the L/B ratio of the three designs are compared, it is seen that the US/G SES has the highest value at 6.33 and the UK SES the lowest at 3.45. It was decided to examine the drag characteristics for the three designs at L/B ratios of 3.45 and 6.33. The distortion was achieved by simply changing L/B ratio at constant cushion area while maintaining sidewall section. Allowance was also made for the consequent change in sidewall length and craft frontal area.

Figure 3.3.5-7 is a comparison of the three designs at low (3.45) L/B ratio. It is seen in this figure that, once again, the US/G SES design shows the lowest drag. Inspection of the data showed that although cushion wavemaking drag for the US/G SES design is similar to the UK SES design (similar cushion pressure) the sidewall drag is significantly less. This is because the sidewalls of the US/G SES are shorter for a given cushion length. The design of the stern seal on the UK SES is such that it requires a larger sidewall overlap to contain the cushion and this must be seen as a disadvantage in resistance terms. The FR SES design at this L/B ratio has a significantly higher drag and this is due almost entirely to the much higher cushion pressure which, in turn, is due to the smaller and much denser planform of this design. This causes large increases in cushion-wave and skirt-spray components. The FR SES also has wider sidewalls which results in higher sidewall drag components.

Figure 3.3.5-8 shows a comparison of drag for the three Point Designs at comparable weights and at high L/B ratio (6.33). From this figure it is seen that, once again, the US/G SES design has the lowest resistance. It is lower than the UK SES design mainly because of a shorter sidewall. The FR SES design has the highest drag for the reasons quoted above.

(ii) **Speed/Payload Trade-Off**

An assessment was also made of the speed possible at various weights for the three designs in order to determine how much extra weight a particular design could carry if operating at the same speed as the other designs.

A common thrust line was used in this analysis and was derived from a shaft power of 20,000 kW (100% MCP) and an associated propulsive coefficient of 0.6, which is an approximate mean of the quoted waterjet and propeller efficiencies. A constant efficiency was assumed for speeds between 50 and 60 knots and the thrust characteristic was assumed to follow a mean line between the published waterjet and propeller thrust characteristics below this speed.

Figure 3.3.5-9 is a plot of the resistance for the three designs having their weights adjusted to give the same speed for the given thrust line. Weights were adjusted using the UK SES design as a basis and adjusting the displacements of the other designs to give the UK SES "matched-speed" of 56.4 knots. At this speed the weight of the US/G SES can increase by 264 tonnes and the FR SES design must decrease by 130 tonnes. If this change in weight is applied to the fuel load, then the US/G SES could carry 664 tonnes of fuel against 400 for the UK SES and 270 for the FR SES. These changes in weight could equally be applied to weapons payload instead of fuel, though the effects on stability must be reconsidered as weapons tend to be sited higher in the ship than fuel stowage.

Based only on resistance and excluding other factors, the figures for the calm water resistance of the designs at comparable displacements clearly show that a long length/beam ratio coupled with a low density cushion has significant advantages over other hull factors. The potential disadvantages of a ship of higher length/beam ratio are the lower cushion depth (reduced over-wave clearance) or, by maintaining higher cushion depth, the potential for roll stability problems.

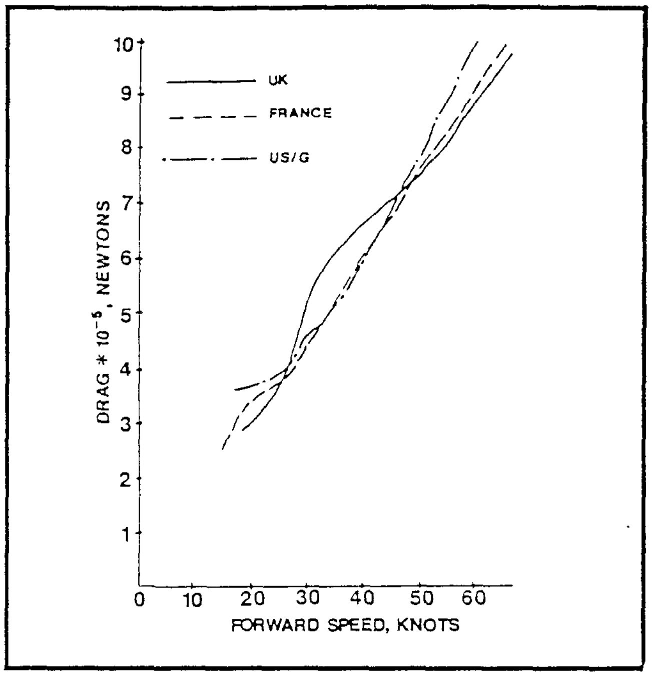


Figure 3.3.5-6. Comparison of Predicted Drag of SES Point Designs

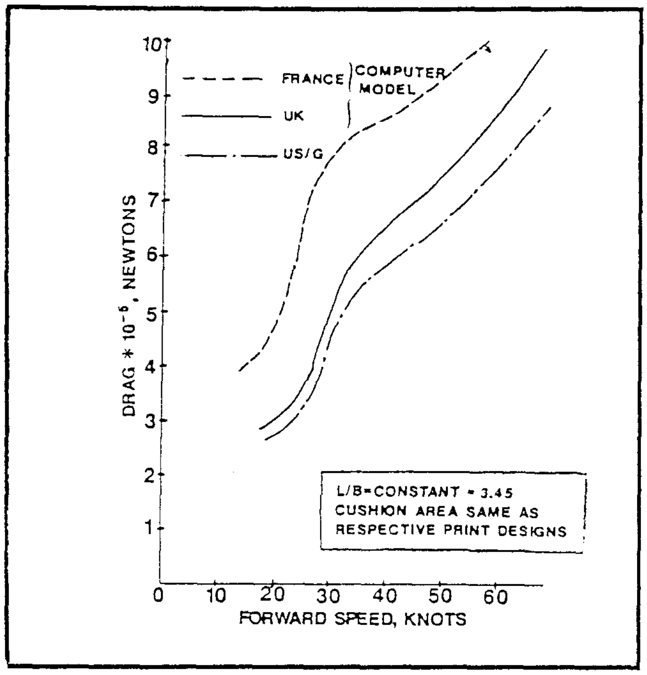


Figure 3.3.5-7. Comparison of Predicted Drag of Low L/B Version of SES Point Designs at Comparable Weights

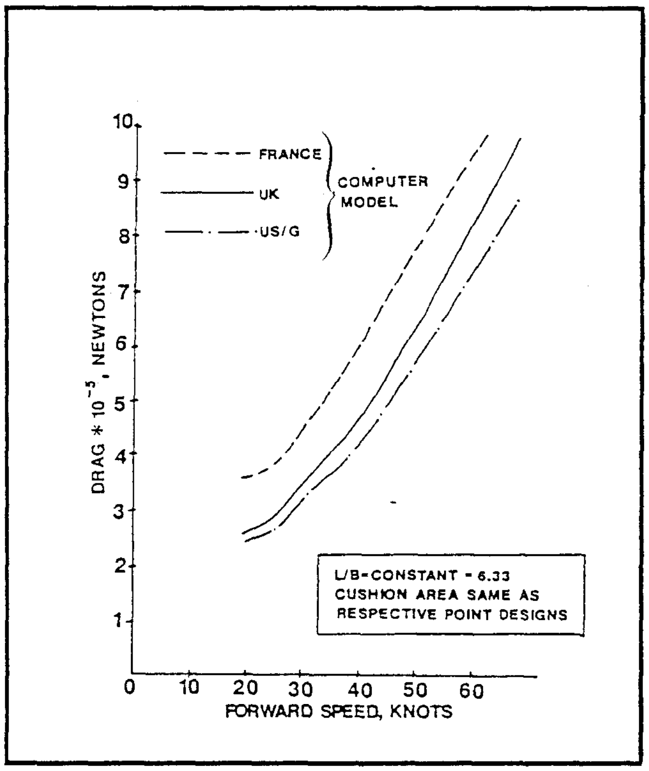


Figure 3.3.5-8. Comparison of Predicted Drag of High L/B-Versions of SES Point Designs at Comparable Weights

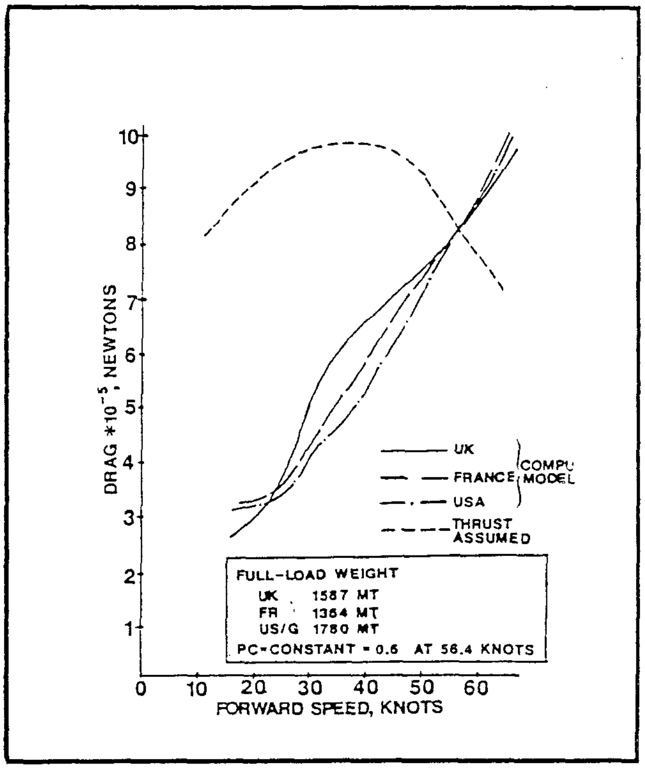


Figure 3.3.5-9. Comparison of Predicted Drag of SES Point Designs at With Weight Adjusted to Give a Common Speed of 56.4 Knots

(b) SES Resistance On-Cushion in Rough Water

Figure 3.3.5-10 compares the drag predicted for SES on-cushion operation in Sea-State 6. At a speed of 30 knots, the FR SES is predicted to have a drag-to-weight ratio 16 percent less than those of the UK and US/G SES. Note that the prediction for the UK SES allows for the air drag caused by a 37.5-knot head wind corresponding to Sea-State 6 since the drag-to-weight curve does not pass through the origin. The other drag curves are drawn through the origin which indicates that the French and US/G have not included this head wind drag in their predictions.

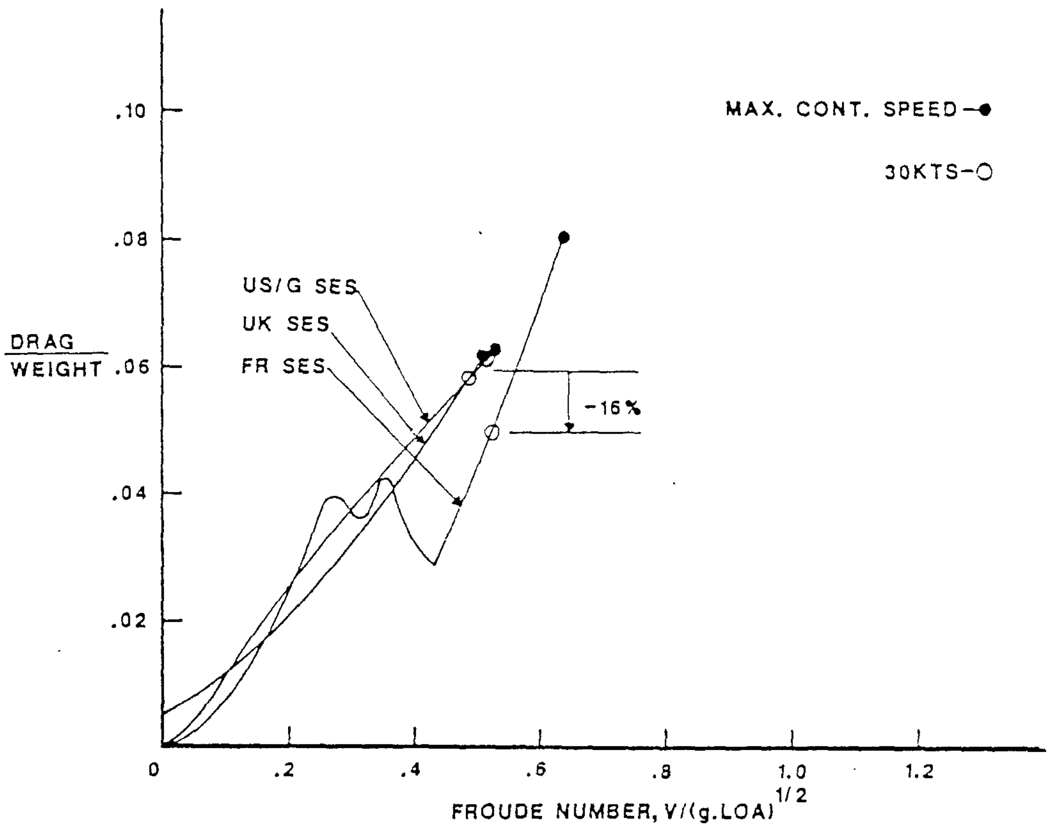


Figure 3.3.5-10. Comparison of SES On-Cushion Drag in Sea-State 6.

(c) SES Resistance Off-Cushion

Figure 3.3.5-11 shows the drag predicted for SES hull-borne operation in calm water. Here the UK and FR SES have similar drag while the drag predicted for the US/G SES is considerably lower. At 20 knots, the US/G SES is predicted to have a drag-to-weight ratio which is about 55 percent less than the drag of the French and UK designs.

When operating in the hull-borne mode with the seals retracted, the SES is, in effect, a catamaran. In Figure 3.3.5-12, therefore, the specific, low-speed-mode resistances of the NATO ANVs are compared with those of catamarans, existing monohull and prior SES concepts. It should be noted that no prior or existing SES has been designed to be operated in hull-borne mode for extended periods of time. The UK SES and FR SES appear to be well within the range of prior experience with catamarans, the SP SES and US/G SES are more optimistic. The low "specific resistance" of the US/G SES is claimed to be due to (a) the use of low-drag lenticular sidehulls, and (b) the use of marine screws which operate at higher efficiencies than waterjets, particularly at low speed.

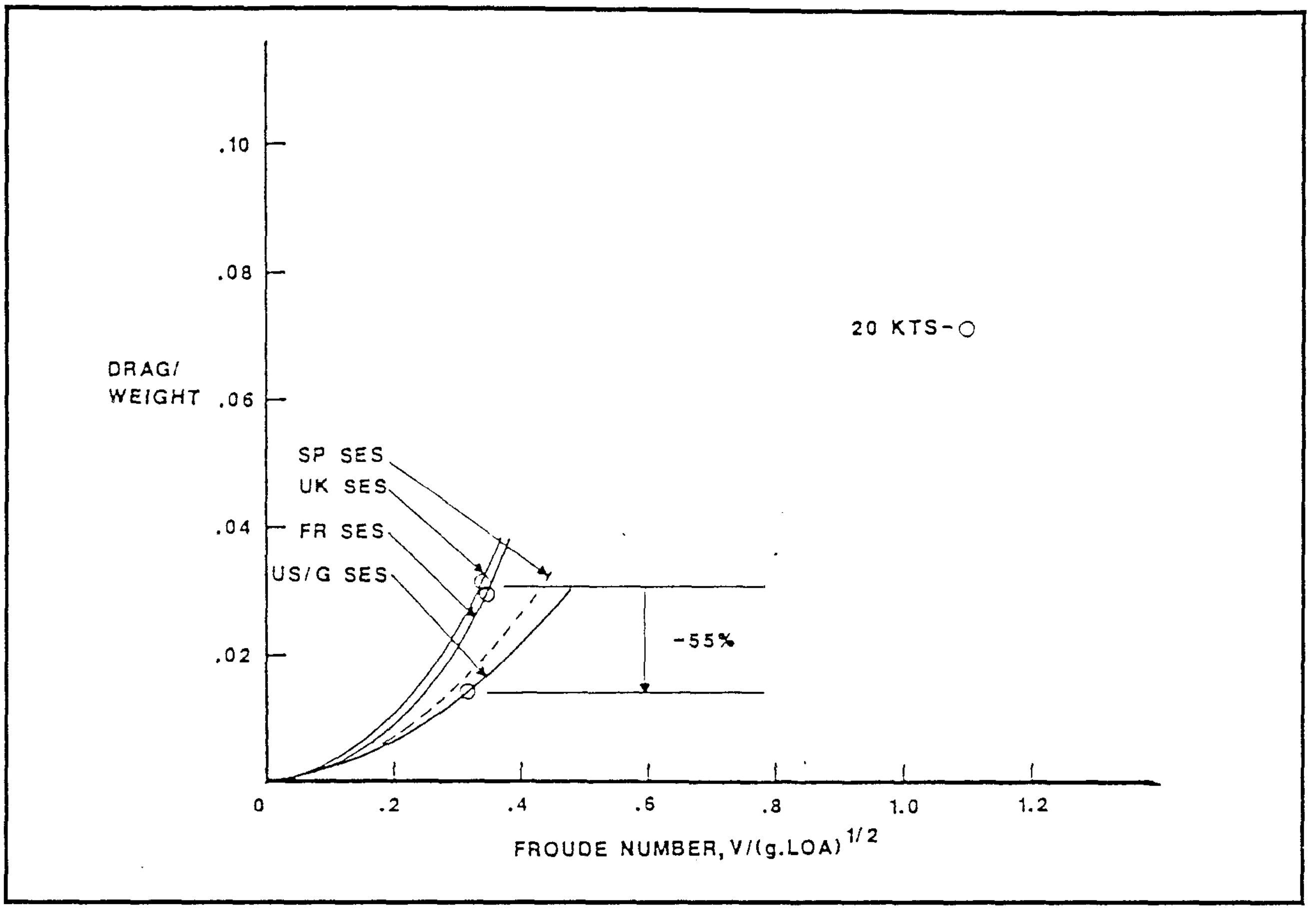


Figure 3.3.5-11. Comparison of SES Off-Cushion Drag in Sea-State 0.

In this low-speed mode, the SES is operating as a displacement catamaran and existing test data on catamaran hullforms can be used to help assess the validity of the performance of the hullborne SES.

A study of the calm-water drag of catamaran and monohull hullforms was conducted by Band, Lavis & Associates, Inc., where the hullforms analyzed were chosen for their similarity to possible SES hullforms and for their representation of possible competitive hullforms. The exact geometric configurations and hull lines included were dictated by the availability of well-documented low-speed test data. Figure 3.3.5-14 taken from the study, presents the specific resistance of comparative hullforms in calm water.

The model hullforms of Figure 3.3.5-13 were scaled to a common displacement of 365,120 lb (163 L. tons) This displacement was chosen due to the availability of full-scale hullborne performance data on the SES 200 at this displacement.

From Figure 3.3.5-13 it is seen that the symetrical lenticular and asymmetrical lenticular hullforms realize a significant reduction in specific resistance, compared to the prismatic hullform of the SES 200. This is particularly true for the region of interest for evaluating the hullborne operations of the SES, compared to low-speed operations of other platforms, which is at Froude numbers of 0.3 and below.

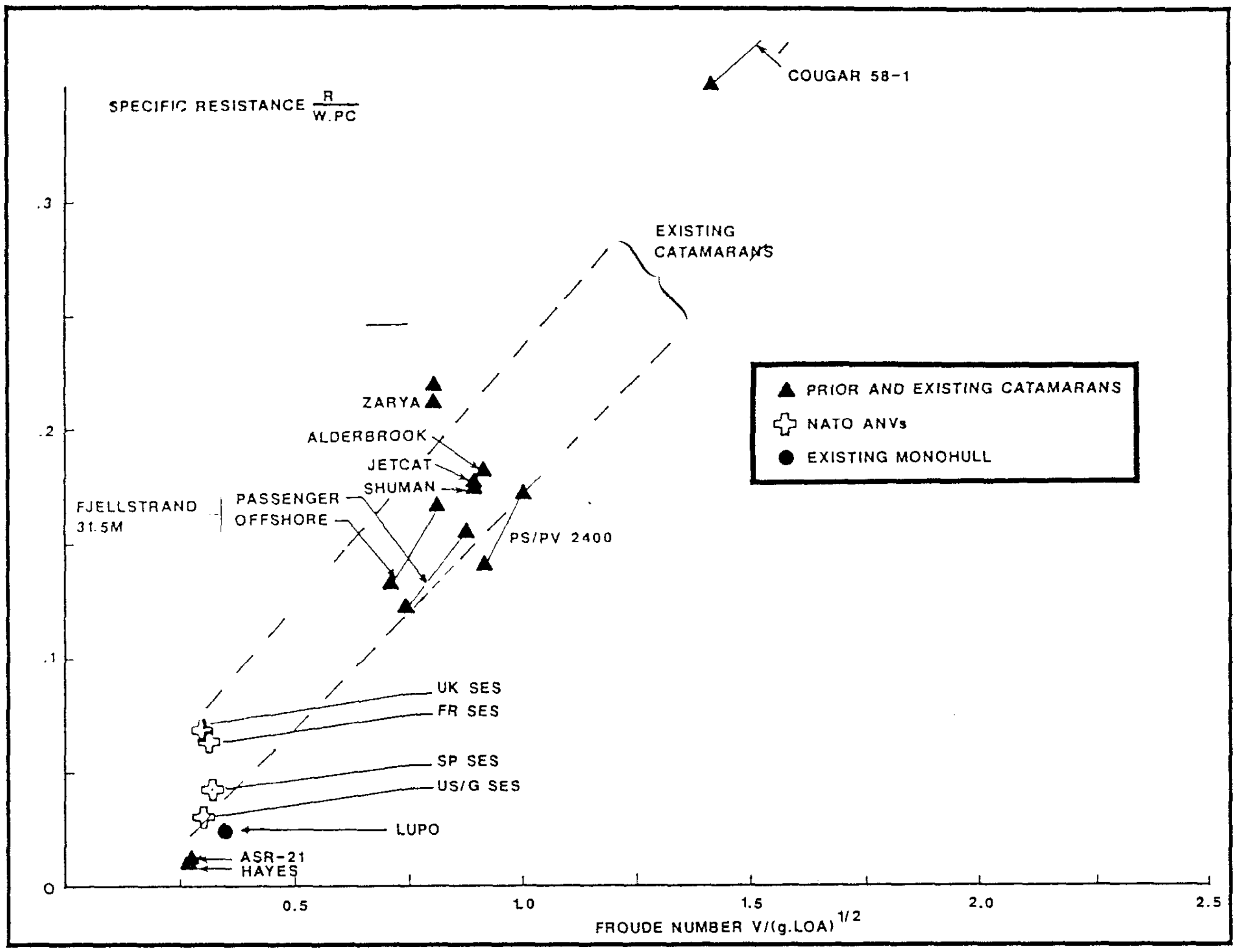


Figure 3.3.5-12. Specific Resistance for Prior, Existing and Conceptual SES Operating in the Hullborne Mode and for Catamarans

(c) Comparison of On-Cushion Resistance of SES Point Designs with Other Craft

The drag curves for the SES in Figures 3.3.5-1, through 3.3.5-9 do not include any representation of the lift power required. Lift power requirements are discussed in Section 3.3.7 but, insofar as lift and propulsion power must both be considered in SES operation, Figure 3.3.5-14 is provided to compare the total installed power levels of the NATO SESs with those of prior and existing SESs and other projected SESs. The ordinate in Figure 3.3.5-14 is "specific resistance", DE/(FLD.PC), which is derived from the equation:

$$DE/(FLD.PC) = 0.198\ PI/(FLD.VMCP)$$

where

DE is total effective drag including an allowance for the lift power

FLD is the full-load displacement (metric tons)

PI is total maximum continuous installed power (MCP) for both lift and propulsion (KW)

VMCP is the calm-water speed at MCP and at FLD (knots)

PC is the overall propulsive coefficient.

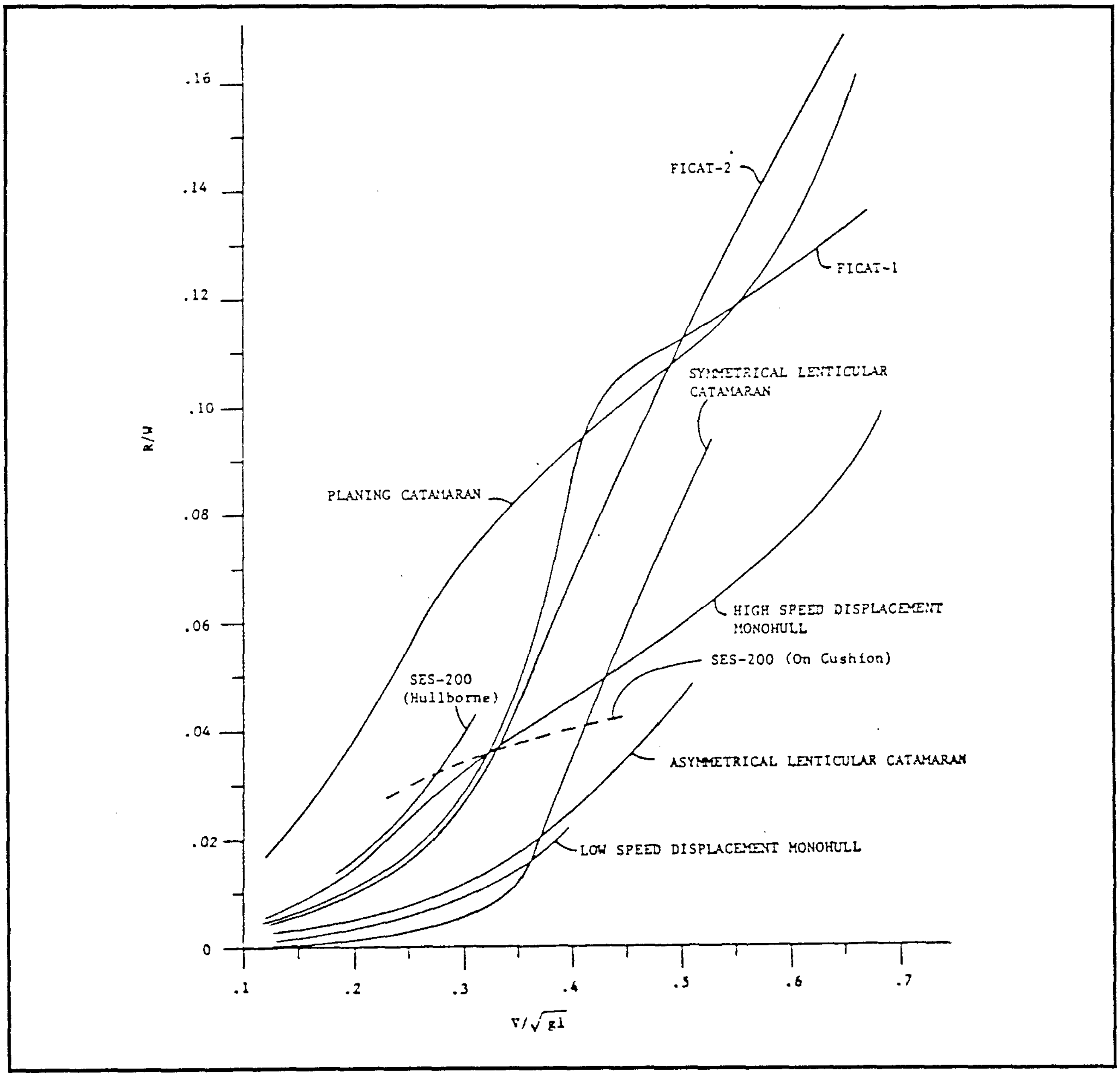


Figure 3.3.5-13. Specific Resistance of Comparative Hullforms in Calm Water

The specific resistances of the UK SES, FR SES and SP SES are seen to fall well within the range of previous and current experience. The US/G SES has considerably less installed power. This design is consistent with a number of projected U.S. designs for large SES but none of these have yet been confirmed by full-scale experience. The lower installed power of the US/G SES is largely due to the lower level of lift power.

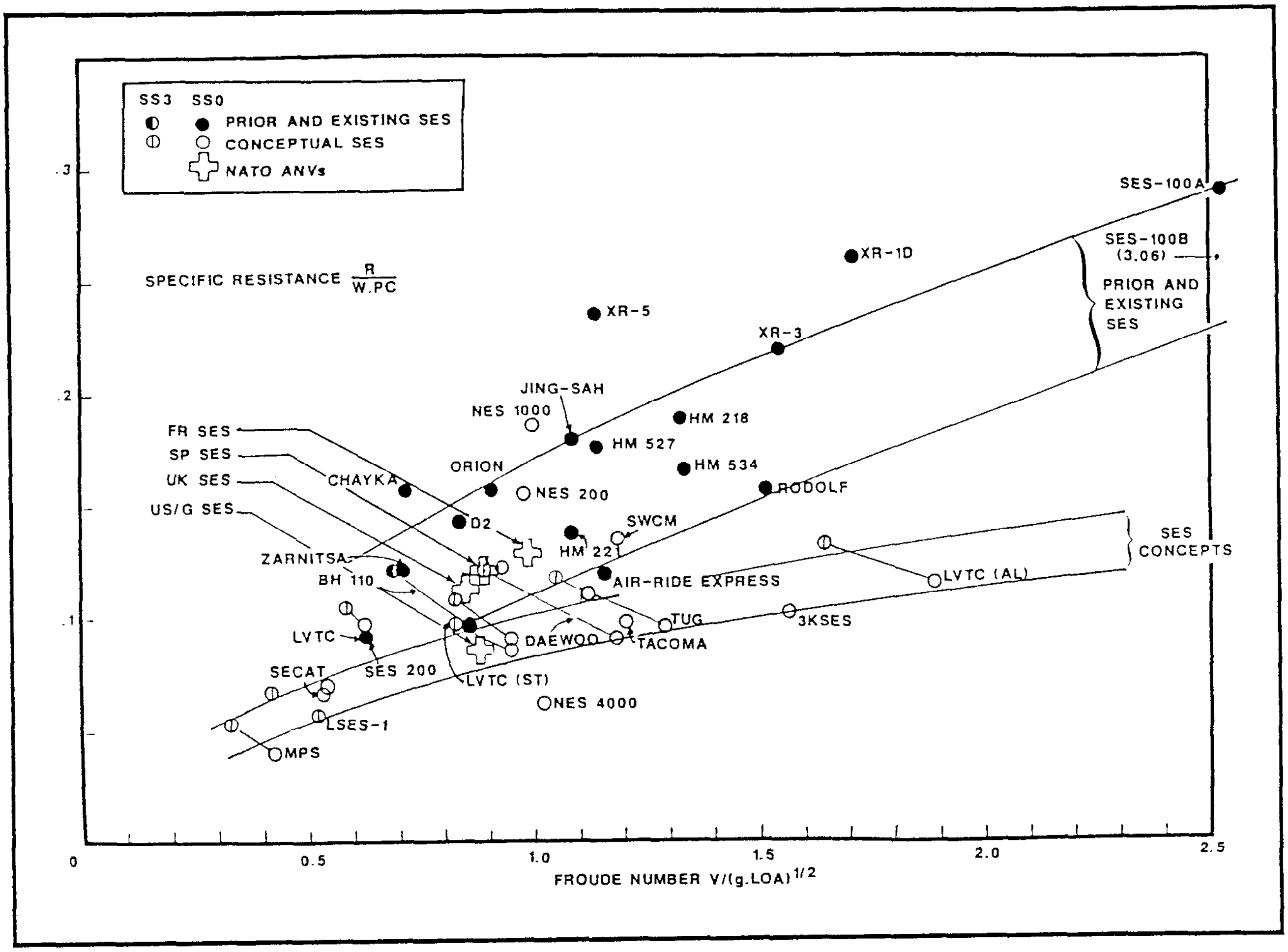


Figure 3.3.5-14. Specific Resistance for Prior, Existing and Conceptual SES in the High-Speed, On-Cushion Mode of Operation

3.3.5.2 Hydrofoils

The NATO hydrofoil report presented only one drag curve and the applicable sea state was not quoted. Therefore, non-dimensional drag curves, similar to those presented for the SES, for the hydrofoil have not been included in this report.

Specific resistance for hydrofoil craft are presented in Figure 3.3.5-15. Craft with both surface-piercing and fully-submerged foils are included on this figure.

With one or two exceptions, the craft with fully-submerged foils have lower specific resistance than those with surface-piercing foils. On the basis of specific resistance the NATO Point Design and the Canadian low-cost option lie within the zone of prior experience with fully submerged foils.

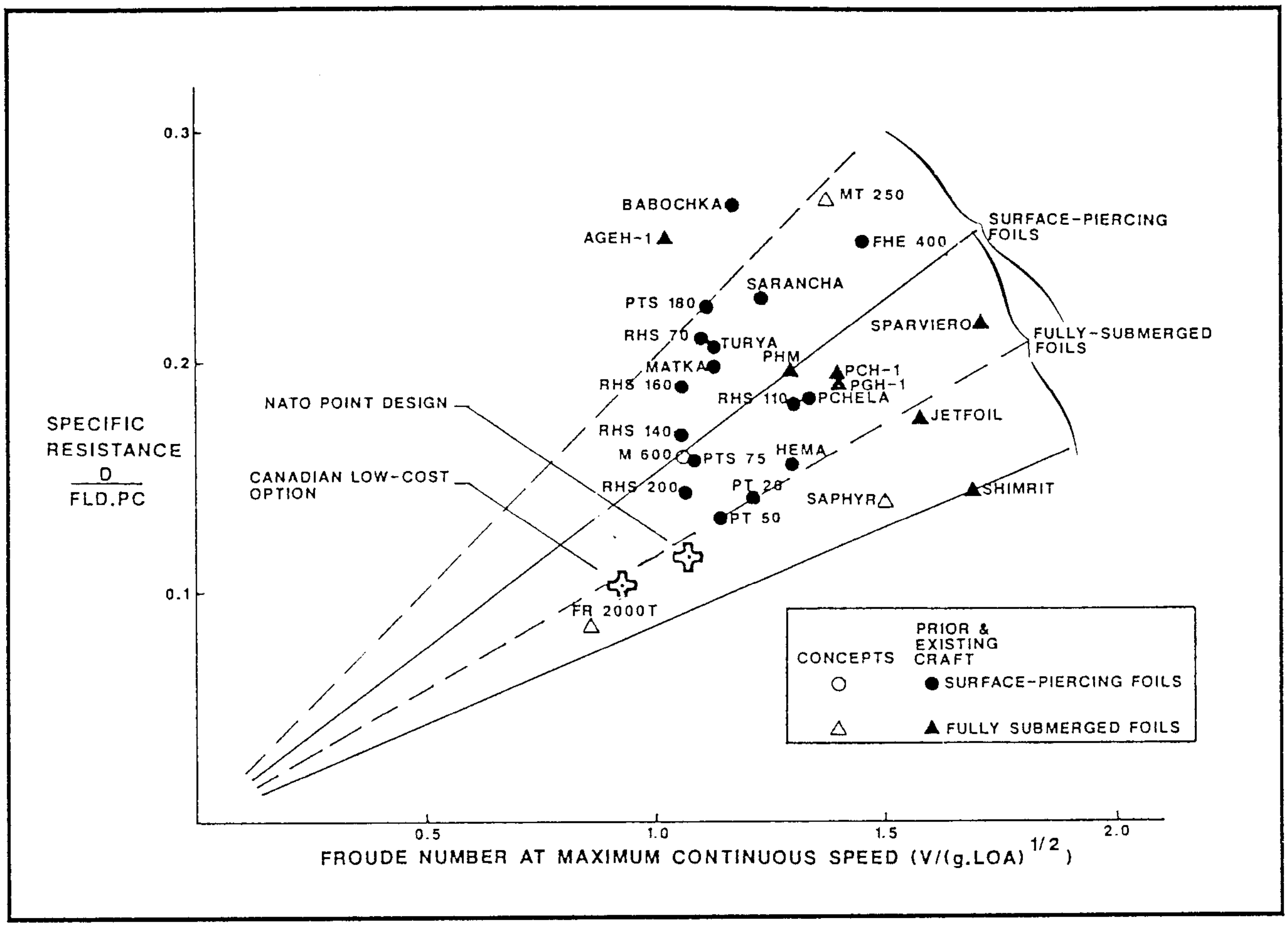


Figure 3.3.5-15. Specific Resistance of Hydrofoil Craft

3.3.5.3 SWATH

The predicted resistance for the NATO SWATH is compared with that for the FFG 7 in Figure 3.3.5-16. From this figure it is seen that the drag-to-weight ratio for the NATO SWATH is essentially the same as that for the FFG 7 at a typical ASW towing speed of 10 knots. At 20 knots, a typical endurance speed for an FFG 7 size frigate, the drag-to-weight ratio for the NATO SWATH is approximately 14 percent greater than that of the FFG 7.

Figure 3.3.5-17 compares the specific resistance of SWATH ships. Included on this figure are existing SWATHs and various proposed SWATH design points. The DD-963 and FFG 7 are also included on Figure 3.3.5-17 for comparison. Note that the specific resistance of the SWATH ships were determined using the same approach as that used in Section 3.3.5.1 for SES except that PI for the SWATH ships is defined as the total maximum continuous installed power (MCP) for propulsion only.

Two regions of specific resistance are seen to exist in Figure 3.3.5-17. One encompasses most of the existing SWATH ships which are all relatively small craft, displacing less than approximately 300 tonnes. The second region encompasses SWATH ships which displace 1000 tonnes or more. The DD 963 and FFG-7 also appear in this region of specific resistance. The vast majority of SWATH ships in this region are projected U.S. designs. However, three SWATH ships of particular interest appear in the upper half of the region of specific resistance for SWATH ships displacing 1000 tonnes or more. They are the DUPLUS, the KAIYO and the U.S. Navy T-AGOS. The KAIYO, which is the largest SWATH in the world at 3500 tonnes, and the DUPLUS are both existing ships. The U.S. Navy T-AGOS is a mature design with the ship currently under construction. Based on these three points it would appear that the predicted specific resistance for the NATO SWATH is achievable. Note that the specific resistance of the NATO SWATH is somewhat less than either the FFG 7 or the DD 963. This is due, in part, to the higher propulsive coefficients which can be achieved with a SWATH as discussed in Section 3.3.6.

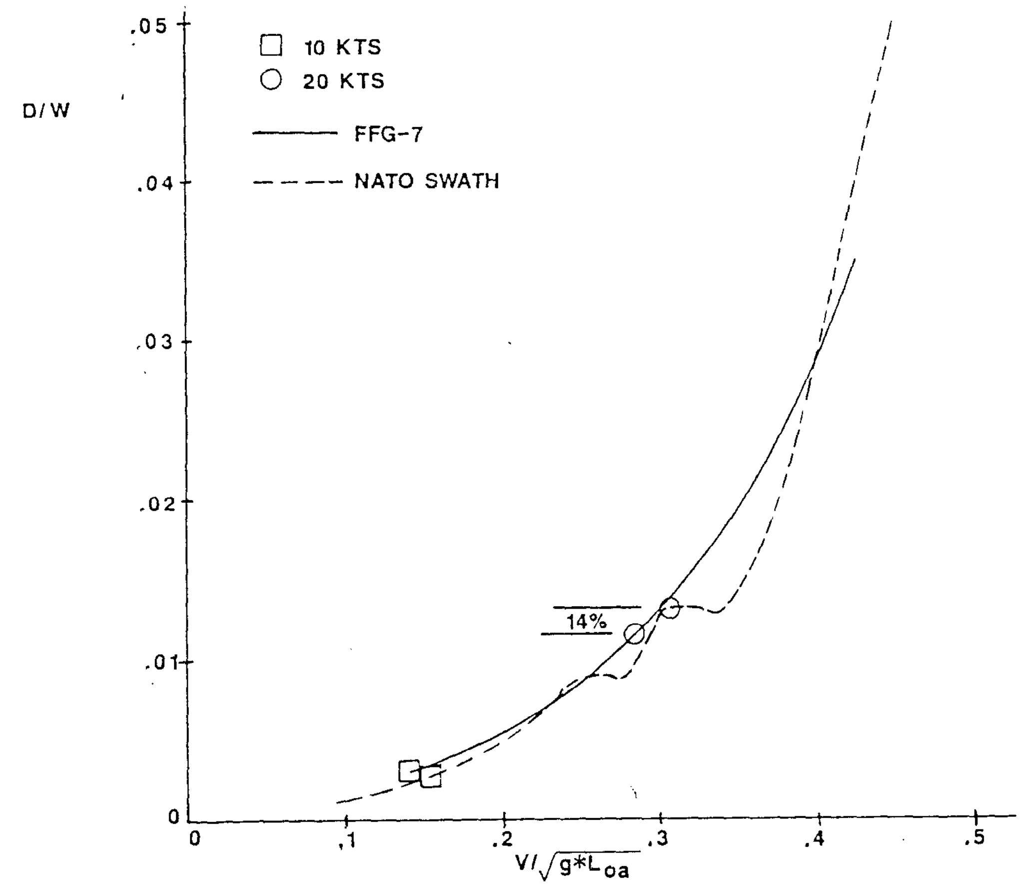


Figure 3.3.5-16. Comparison of NATO SWATH and FFG 7 Non-Dimensional Drag in Calm Water

3.3.5.4 **ANV and Monohull Comparisons**

An overall comparison of the drag/weight performance of the SES, hydrofoil, SWATH, and comparative monohulls can be seen in Figure 3.3.5-18.

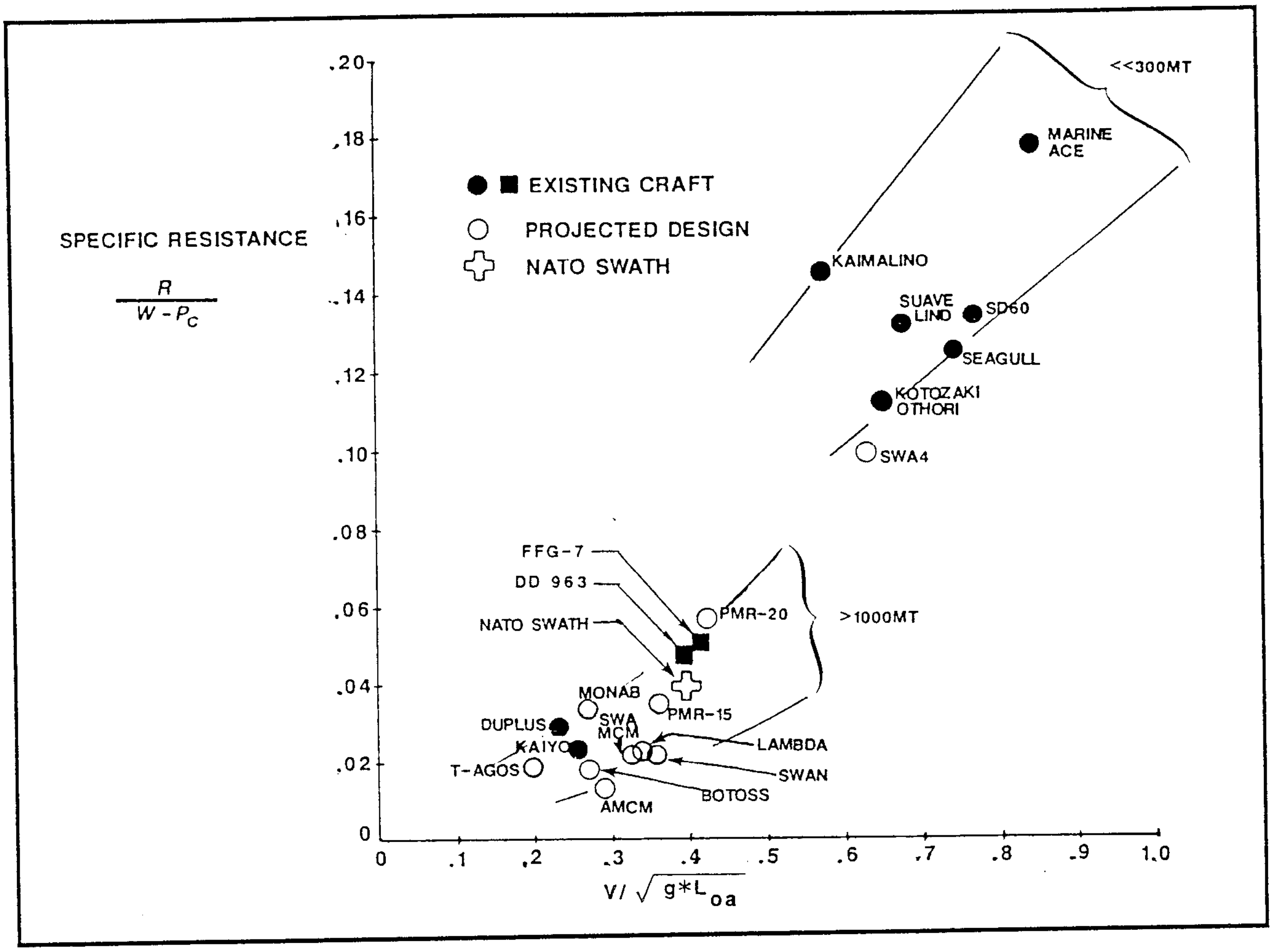


Figure 3.3.5-17. Specific Resistance of SWATH Craft

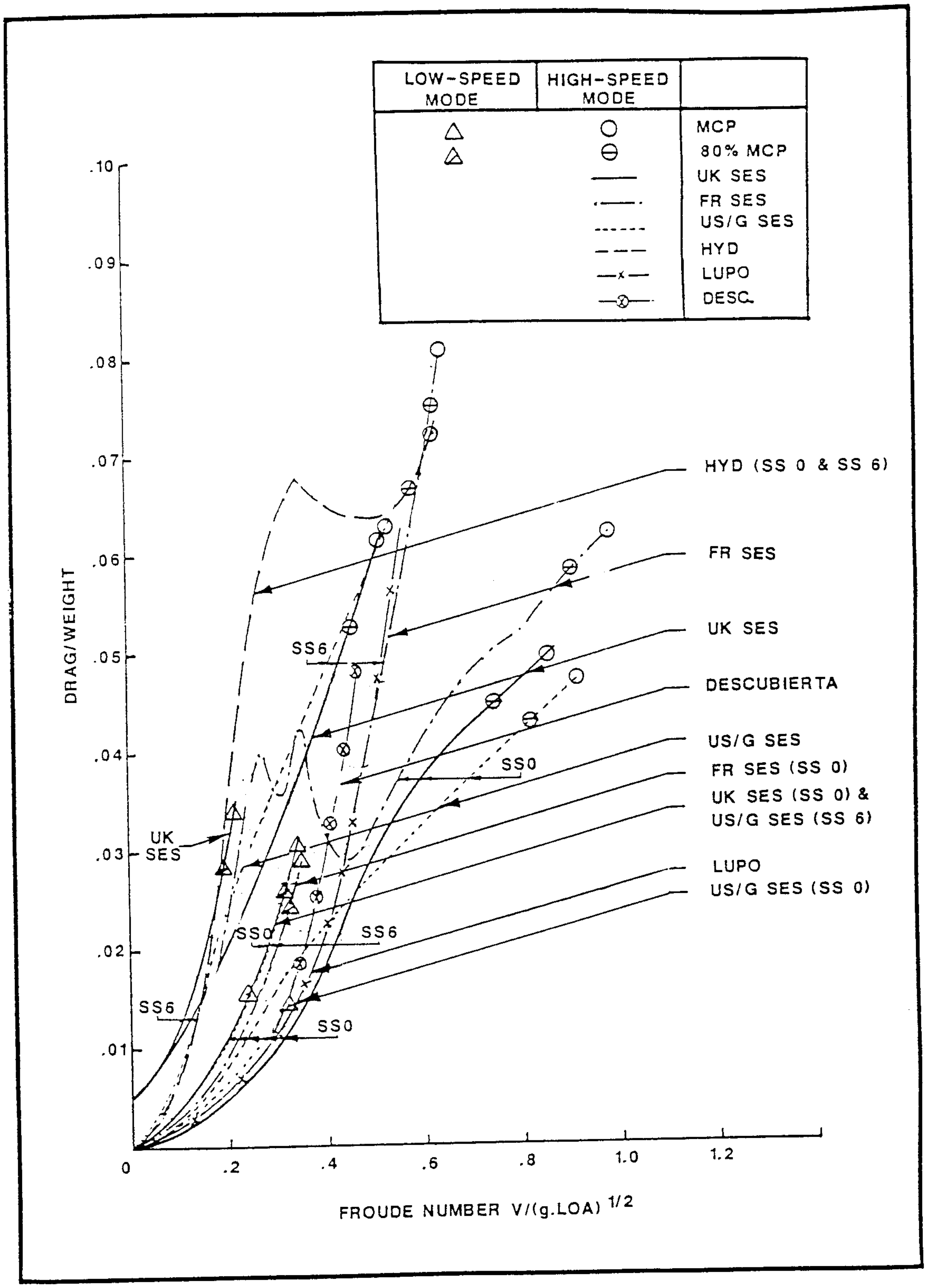


Figure 3.3.5-18. Resistance Comparisons of ANVs and Monohulls

3.3.6 Propulsors

3.3.6.1 Subsystem Description

The NATO ANV point designs propose the use of a variety of propulsors: waterjets, partially-submerged super-cavitating controllable reversible-pitch propellers, fully-submerged transcavitating controllable reversible-pitch propellers, and fully-submerged fixed pitch subcavitating propellers. Table 3.3.6.1-1 lists the leading particulars of these propulsors.

It should be noted that the characteristics listed for the US/G SES propellers are those of a Bell Aerospace designed propeller described in Appendix H of the US/G SES report. Although reference is made to Sulzer-Escher Wyss in the report, Appendix I of the report (which details a proposed Excher Wyss partially submerged supercavitating propeller design) describes a 3 m diameter propeller operating at 75% submergence, while the propeller chosen for the US/G SES is characterized as 4.4 m in diameter and operating at 50% submergence (on-cushion). This appears to be the Bell Aerospace propeller described in Appendix H and it is presumed that its characteristics are very similar to the propeller proposed for the US/G SES.

Detailed information on the flow rates and inlet and discharge velocities of the KaMeWa waterjets proposed for the UK SES and French SES were not available in the point-design reports. Sufficient information was available from KaMeWa literature to estimate some parameters of the proposed jets, such as specific speed, but these are approximations which would ultimately depend upon the exact inlet and waterjet design.

The propulsion system efficiencies which are presented in Table 3.3.6.1-1 are defined in the footnotes for that table. The design efficiencies are the efficiencies which must be obtained by the propulsion system and the propulsors in order to achieve the predicted point design performance and are based on:

- Installed power as identified in the design reports
- Predicted speed as identified in the design reports
- Predicted drag as identified in the design reports
- Required 8% power margin per the NATO Point-Design Study Guidance Document

If all of the installed power (for either hullborne or cushionborne/foilborne operation) is not proposed (by the designers) to be utilized, then all design efficiencies would need to be higher than those calculated.

3.3.6.2 Waterjet Propulsor Efficiencies and Operational Experience

Both the UK and FR SES designs use the same waterjet unit. This waterjet is a mixed-flow axial jet, type 160-S62/6, which has been designed and would be manufactured by the UK owned Swedish company KaMeWa, who are well known as a leading manufacturer of controllable pitch propellers and waterjet units. The 160-S62/6 unit would have a 1600 mm diameter impeller and be fitted with an integral steering and reverse thrust unit. The intake pipe from the hull opening to the impeller housing would be designed based on model experiments at KaMeWa's own test facilities for each individual application. There are three main differences between the UK and FR installations. The FR waterjet is mounted lower down on the transom than the UK design so that the FR waterjet, except at high forward on-cushion speed, is always working with both inlet and outlet submerged as opposed to the UK design which discharges the outlet water well above the waterline when on-cushion, similar to U.S. SES practice on the SES 100A and 3K SES designs. Although the higher positioning of the waterjet in the UK design incurs greater intake and head losses than the FR design, these were thought by the UK to be small compared with the increase in drag caused by the bulging of the lower hulls in order to accommodate the waterjet units. The UK waterjet units are also angled inboard at the top of the unit at 15 degrees to the vertical such that when helm is applied an inward banking moment is created by the thrust.

The size, speeds, thrusts and efficiencies for the UK design were supplied by KaMeWa and it is thought that the data for the FR design would also have been provided by KaMeWa. The performance figures provided by KaMeWa are the result of experience gained through model experiments and full size installations of various smaller units.

Table 3.3.6.1-1. Propulsor Characteristics

Type	UK SES	French SES	US/G SES	Hydrofoil	SWATH
	Mixed Flow Axial Waterjet	Mixed Flow Axial Waterjet	Semi-Submerged CRP Propeller	Transcavitating CRP Propeller	Skewed Blade Fixed Pitch Propeller
Design Speed CB/FB	50 Knots	57 Knots	55 Knots	50 Knots	NA
Design Speed HB	18 Knots	18 Knots	18 Knots	15 Knots	25.3 Knots
Design Thrust per Propulsor CB/FB	390 KN	420 KN	438 KN	275 KN	NA
Design Thrust per Propulsor HB	210 KN	187 KN	114 KN	110 KN	1237 KN
Design Power per Propulsor CB/FB	18,000 KW	22,100 KW	20,142 KW	11,200 KW	NA
Design Power per Propulsor HB	5400 KW	4420 KW	2235 KW	1570 KW	22,000 kw(6)
Design RPM CB/FB	500	473	290	800	NA
Design RPM HB	290	?	120	300	120
Propeller/Impeller Diameter	1.6 m	1.6 m	4.4 m	1.8 m	6.1 m
Design Advance Coefficient CB/FB(1)	NA	NA	1.32	1.06	1.08
Design Thrust Coefficient (2)	NA	NA	NA	.145	0.22
Specific Speed CB(3)	.84	.79	NA	NA	NA
Specific Speed HB(3)	.42	?	NA	NA	NA
Submergence CB/FB(4)	NA	NA	0 m	3.5 m	NA
Submergence HB(4)	0 m	1.8 m	3 m	8.6 m	6.2 m
Design Propulsion System Efficiency CB/FB(5)	.60	.63	.66	.68	NA
Design Propulsion System Efficiency HB(5)	.39	.42	.51	.58	.80
Design Propulsor Efficiency CB/FB(7)	.63	.66	.69	.72	NA
Design Propulsor Efficiency HB(7)	.41	.44	.54	.61	.80(6)

(1) $\frac{V}{nD}$

(2) $\frac{T}{\rho n^2 D^4}$

(3) $\frac{nQ^{1/2}}{(g\ H_{sv})^{3/4}}$ (Estimated based on available information)

(4) from propeller/impeller centerline

(5) Propulsion System Efficiency - $\frac{EHP}{SHP}$,

where: EHP = V x D/constant
SHP = Design (Installed) Power x 0.92 (8% Margin)

(6) Based on power from drive motors (no power train losses)

(7) Propulsor Efficiency = $\frac{\text{EHP}}{\text{SHP at Propulsor Shaft}} = \frac{\text{Propulsion System Efficiency}}{0.95}$

(assumes 95% drive train efficiency)

The KaMeWa waterjet is based upon their production jets of lower horsepower and would be a basic scale up of these jets retaining the same relative performance and stress parameters of the smaller jets. The 160-S62/6 would be a 1.42 linear size scale up and an approximate factor of 2 power scale up from the largest KaMeWa jet operating to date, a 10,300 KW model 112-S62/6. At the time KaMeWa manufactured this 112-S62/6 jet, it was a 1.87 linear scale up and a factor of 8.4 power scale up from their previous largest waterjet. The 112-S62/6 has operated as predicted and without problems for the four years since its installation aboard a 230-ton 45-knot private yacht. The successful acceptance tests of the U.S. PHM Hydrofoil 18,000 hp waterjet also indicated the adequacy of the scale-up procedures used in designing and predicting performance for large jets from sub-scale model data. The proposed power levels of the French and UK waterjets are about 50% higher than those of the PHM Aerojet waterjets. Both KaMeWa and Riva Calzoni have stated, however, that a period of approximately two years will be necessary for the development of the steering and reversing nozzles required by the waterjet-driven SWG/6 SES. Table 3.3.6.2-1 compares the proposed design efficiencies of the French and UK SES designs with existing waterjet operations. The FR design exhibits better efficiencies than the UK design and this disparity is likely due to the different intake losses of the two designs.

Table 3.3.6.2-1. Waterjet Operations and Characteristics.

Ship/Craft	UK SES	French SES	Shergar	PHM	Boeing	SES NORCAT
Power per Waterjet	18,000 KW	22,100 KW	10,350 KW	11,920 KW	2,690 KW	1100 KW
Speed	50 Knots	57 Knots	44 Knots	48 Knots	42 Knots	43 Knots
Propulsion System Efficiency $\left(\frac{EHP}{SHP}\right)$	.60	.63	.68(1)	.41(2)	?	.63(1)
Specific Speed	.84	.79	? .32(3)	.35(3)	?	
Total Operational Hours			500	13,795	250,000	?
Waterjet Manufacturer	KaMeWa	KaMeWa	KaMeWa	Aerojet	Rocketdyne	KaMeWa

(1) Based on KaMeWa data

(2) Corrected for Strut Head Loss

(3) Estimated from available data

The industrial capability to fabricate waterjets of sizes proposed for the French and UK SESs has been corroborated by the Italian waterjet manufacturer Riva Calzoni. Riva Calzoni has a stated capability to design and manufacture waterjets up to 25,000 KW. Initial Riva Calzoni sizing indicates a 180 cm diameter impeller with a unit weight of 15 tons (+17 tons entrained water). Riva Calzoni pumps do not involve castings but are fabricated from CRES plating. Riva Calzoni estimates a requirement for two years developmental engineering given a customer for an LM 2500 pump.

The propulsive efficiencies proposed for the KaMeWa 160 waterjets appear to be achievable, relative to reported KaMeWa operational experience, but corroborative data from operations of large waterjets at high speeds does not exist. The 68% propulsion system efficiency reported for the Shergar and the NORCAT are believed to be based on model-scale-hull drag data and engine manufacturer's power data, not on full-scale drag (thrust) measurements and power train torque and rpm measurements.

The estimated specific speed of the proposed KaMeWa 160 waterjets is higher than those of the PHM and Jetfoil and higher than those of typical small (<500 hp) commercial waterjets. During a March 1986 presentation to NAVSEA, KaMeWa recommended the use of their larger 180 S62/6 unit for powers of 20,000 KW at speeds of 50 knots but in an August 1986 letter to NAVSEA, the 160 S62/6 was recommended for a 20,000 KW U.S. SES design. Use of the 180 unit would increase group 200 weights by about 10 tons and reduce the waterjet specific speed by about 25%.

Waterjet inlet design will be important to both of the SES waterjet installations. Cavitation at some operating conditions can result in reduced impeller life and air ingestion can result in power train overspeed and reduced propulsion efficiency.

Broaching and cushion air ingestion by the waterjet inlets, in both calm and rough water, was experienced on the U.S. SES 100A after it was retrofitted with flush waterjet inlets and when it operated with minimum sidehull immersion for minimum drag. As a result, cushion-crossflow fences, which extended below the keel in the vicinity of each inlet, were successfully developed for this craft, and for the 3KSES, in order to minimize the ingestion of cushion air which would otherwise unload the pumps and cause engine overspeed and a net loss in propulsive efficiency. The fences represented an additional component of drag but resulted, for the SES 100A, in an ability to operate the sidehulls at a more optimum immersion for best performance. Concern for the 3KSES was not primarily performance degradation, but the impact of inlet emmergence on the power-train system.

The SES Norcat also experienced inlet broaching when KaMeWa waterjets were installed, though the problem was reportedly eliminated after "inlet modifications" and installation of the Ride-Control System. The French test craft Molenes has experienced waterjet broaching, in scale sea states equivalent to Sea-State 6 for the NATO SES, on the order of 30 per hour. Model tests of the German 700 Ton SES have indicated acceptable waterjet performance without the need for fences for inlets mounted in the sidehull outboard deadrise surface.

There has been a very significant amount of development work conducted in flush inlet design supporting the US 3KSES Program which should be of extreme value in the development of any future waterjet systems.

3.3.6.3 Partially Submerged Super Cavitating Controllable Pitch Propellers Propulsor Efficiency and Operational Experience

The US/G design is fitted with partially or fully submerged (depending upon hull mode) supercavitating, controllable, reversible pitch propellers (CRP). These propellers have six controllable pitch blades which are adjusted by hydraulically operated pistons within the propeller hub.

Partially submerged supercavitating propellers of the type proposed for the US/G SES have been the subject of a great deal of sub-scale testing and have been operated at forward speeds up to close to 100 knots on the SES 100B. Figure 3.3.6.3-1 summarizes the results of some of these tests conducted at DTNSRDC from 1968 to the present. Model tests of these propellers have also been conducted recently at Escher Wyss. These tests indicate that the propulsive coefficients predicted for the US/G SES are achievable.

The only large-scale operations of surface piercing props has been on the SES 100B at power levels of 5000 KW and advance coefficients up to 1.3 (85 knots). Figure 3.3.6.3-2 summarizes the results of the SES 100B propeller design and test program. It can be seen that propulsor efficiencies close to the 0.69 predicted for the US/G SES were acheived, but that the efficiency of the props at the advance coefficient of interest was less than that predicted by model tests and the Bell Aerospace SSCP computer program. The propulsor efficiency of the 100B propellers was calculated using full-scale thrust and engine power measurements.

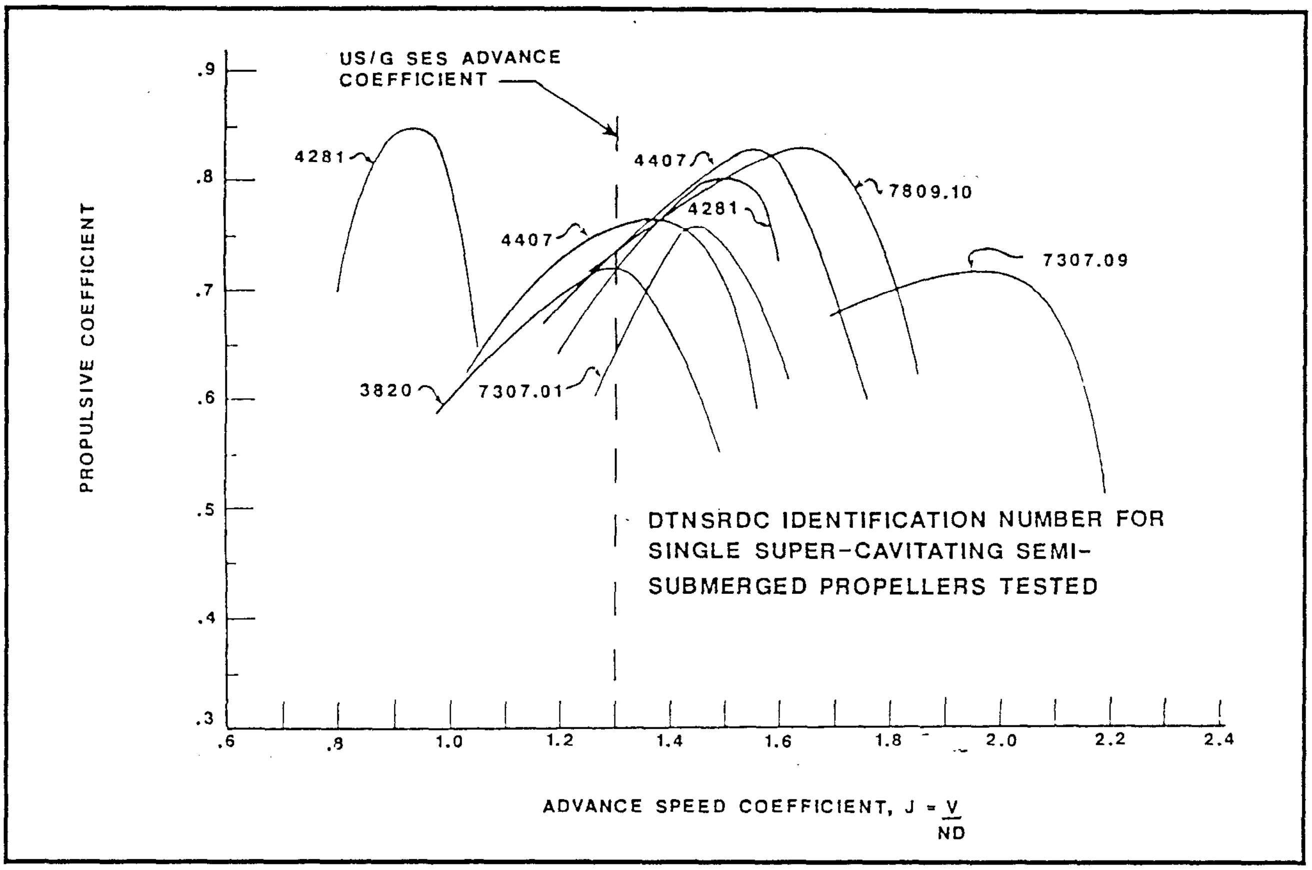


Figure 3.3.6.3-1. U.S. Surface Piercing Supercavitating Propeller Model Tests. (The above curves are respresentative of numerous DTNSRDC propeller tests run at various speed coefficients, depth of submergence, shaft inclination angle and propeller pitch.)

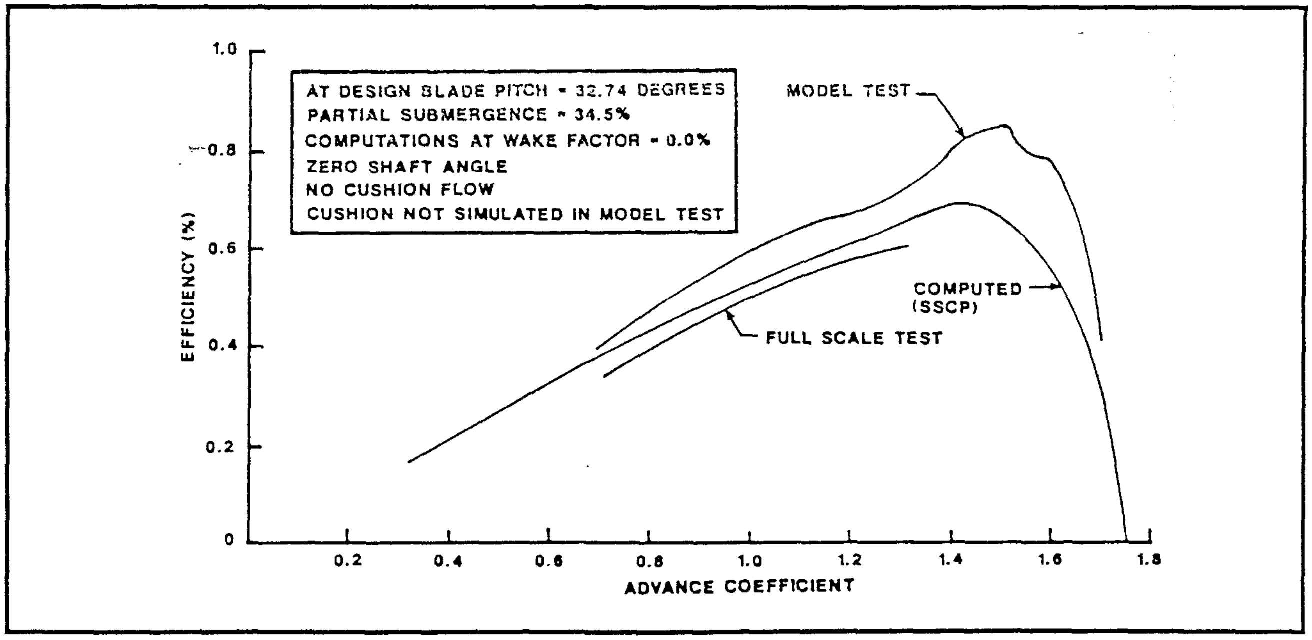


Figure 3.3.6.3-2. SES 100B Propeller Performance

The propellers proposed for the US/G SES would be a 4.1 linear scale up and a scale factor of 4 power increase over the largest surface piercing supercavitating propellers operated to date. In order to reduce the weight of the partially submerged propeller, the US/G SES propeller would be fabricated from the high strength-to-weight-ratio material, titanium.

Table 3.3.6.1-1 shows the superior efficiencies of the CRP propeller in both the semi-submerged (55 knots) and the submerged (18 knots) condition when compared to the waterjet units of both the UK and FR designs. CRP propellers are ideally suited to craft which require both high and low speed operation since, by their variable geometry, they can maintain good efficiency over a wide range of forward speeds.

3.3.6.4 Comparison of SES Propulsors

A propulsor characteristic which is important for the ASW role is low noise levels. In a comparison conducted by KaMeWa for a 400t naval vessel between their own fully submerged controllable pitch propellers and waterjets, the waterjet was shown to give lower hydro-acoustic noise levels at moderate speeds. However, very little test data exists for comparing the high-speed or low-speed acoustic signatures of waterjets, surface piercing propellers and conventional propellers. Also, it is difficult to assess how propeller silencing techniques utilized on conventional propellers, such as air masking, might effect the comparison.

In Appendix E, waterjet vibration levels are judged to be very low, leading to lower hull dissipated noise and increased shaft life. Waterjets also have a lower magnetic profile than an equivalent sized CRP propeller.

The complexity of the engineering involved in a CRP propeller design is greater than that of waterjets. The mechanical and hydraulic systems required to adjust the angle of the propeller blades of a surface piercing CRP propeller design of this size and speed have not been proven at full scale and may be more suspect in terms of reliability than the waterjet unit, and might require more intensive maintenance. The 112/S62/6 waterjet unit mentioned earlier has proved extremely reliable in its current four year installation life. Waterjets, however, have poorer performance when going astern than conventional or CRP propellers and the US/G CRP would have far better reverse thrust than either the UK or FR waterjets.

Draught is decreased by the waterjets for the UK and FR designs and this also simplifies drydocking procedures since there are no protrusions below the keel line. However, it is possible that "fences" would have to be fitted to the inboard, underside of the keel to prevent the flow of cushion air into the waterjet intake. If these fences were required they could cancel out some of the advantages in draught and drydocking mentioned above.

A waterjet impeller suffers insignificant variation in thrust and torque loads compared with the very high variations which occur on the blades of a semi-submerged CRP propeller. Because of this, it is thought that the blade/impeller and unit life would be greater for the waterjet. It is possible that this effect could be exaggerated since the US/G design uses titanium for the propeller blades. Recent investigations into the failure of titanium propeller shafts on HM5 ferries have shown that there is a possibility of the expected fatigue life decreasing due to surface corrosion of titanium in a salt-water environment.

The ratio of thrust produced to the weight of the propulsor unit is higher for the CRP propeller, 16.6 kN/t (UK = 10.6 kN/t, FR = 11.35 kN/t). However, the UK and FR weights include the steering equipment and if the rudder weight is added to the US/G weight then the thrust/weight ratio is reduced to 13.9 kN/t.

Table 3.3.6.4-1 summarizes the advantages and disadvantages of both the CRP propeller design and the waterjet for various aspects of their design considered to be of importance to the ASW role. Although it is realized that this assessment is purely qualitative it does indicate that additional quantitative data is required to provide guidance in selecting the waterjet or the CRP propeller as a propulsor for the SES Point Designs.

Table 3.3.6.4-1. Comparative Assessment of Propulsors for the SES Point Designs (Appendix E)

Characteristics	Unfactored Results		Factor of Importance	Factored Results	
	WJ	CRP		WJ	CRP
Propulsive Efficiency	2	4	7	14	28
Noise and Vibration	3	2	5	15	10
Maintainability	3	1	3	9	3
Cost	2	1	4	8	4
Reverse Thrust	2	4	2	4	8
Reliability	4	2	6	8	12
Thrust/Weight	1	3	1	1	3
Technical Risk	3	1	8	24	8
TOTALS	22	18		83	76

Rating	
1	Worst
2	
3	
4	Best

WJ = Waterjet (UK/FR)

CRP = Semi-Submerged Controllable Pitch Propeller (US/G)

3.3.6.5 Transcavitating Propeller Propulsor Efficiency and Operational Experience

The propeller proposed for the Hydrofoil is of the Newton-Rader series, developed in the early 1960's for high speed craft. The performance predictions for these propellers are supported by model tests and performance predictions have been validated at power levels to approximately 5000 KW for fast patrol boat applications. Over one hundred Vosper Hovermarine HM-2 and HM-5 series SES have logged hundreds of thousands of hours with transcavitating propellers at power levels below 1500 KW and speeds below 35 knots. The U.S. Navy has experience with transcavitating propellers operated on the fast patrol boat CPIC at 45 knots and 5000 KW.

Fully-submerged supercavitating propellers have been successfully operated on the hydrofoils AGEH-1, Denison, PGH-1 and Bras D'or at power levels of 5000 KW, 6000 KW, 2200 KW and 4100 KW respectively. Transcavitating propellers were selected for the Hydrofoil because of slightly superior efficiencies, relative to supercavitating propellers, over the entire speed range. Table 3.3.6.5-1 compares characteristics of the proposed U.S. Hydrofoil propulsor with reported operational experience on similar propellers.

Table 3.3.6.5-1. Fully Submerged Cavitating Propeller Operations and Characteristics.

Ship/Craft	NATO Hydrofoil	AGEH-1	Dennison	PHG-1	Bras D'or	HM 527
Speed	50 Knots	50 Knots	60 Knots	45 Knots	60 Knots	40 Knots
Advance Coefficient	1.06	0.74	0.87	1.16	0.93	1.36
Power Per Propulsor	11200 KW	5000 KW	6000 KW	2200 KW	4100 KW	1400 KW
Propulsion System Efficiency $\left(\frac{EHP}{SHP}\right)$	.68	.44	.30	.65	.61(1)	.53
Propulsor Type	Trans-cavitating	Super-cavitating	Super-cavitating	Super-cavitating	Super-cavitating	Trans-cavitating

(1) Estimated from Available Data

The hydrofoil propeller would be of conventional manufacture with stainless steel, Inconel or nickel-aluminum-bronze (Nibral) the probable material utilized. Blade erosion of high tensile Nibral Newton-Rader propellers in-service has been minimal even for operational speeds to 55 knots. Vosper Hovermarine has eliminated cavitation erosion on their HM-2 and HM-5 series SES propellers by use of a propeller hub air injection system, but the effect on propulsor efficiency, if any, is not known.

The hydrofoil propeller would be a factor of 2.2 power scale up and a 1.5 linear scale up from the largest cavitating propellers operated to date.

3.3.6.6 <u>Fully-Submerged Fixed-Pitch Skewed Blade Propeller</u>

The propeller selected for the SWATH design is a conventional seven-bladed fixed-pitch fully submerged propeller reflecting the trend of military and commercial propellers towards more highly skewed blades. Table 3.3.6.6.-1 compares the SWATH propeller to propellers of similar SHP, speed of advance, and thrust loading operating on U.S. Navy ship's.

Considering the efficiency improvements which may be expected from improved flow into the SWATH propeller, the 0 degree propeller-shaft angle, and continued improvements in conventional-propeller designs, the propulsor efficiency predicted for the SWATH propeller appears to be achievable. The SWATH propulsor efficiency is also supported by model tests.

The highest powered propellers operated on a SWATH ship to date are those of the 27 kt Japanese SWATH Seagull, which absorb about 3000 KW.

Table 3.3.6.6-1. Conventional Fully-Submerged Propeller Operations and Characteristics

Ship	NATO SWATH	GG 47	FFG 7	AO 177	DD 963
Speed	25.8 kts	30 kts	27 kts	17 kts	34 kts
Power Per Propeller	22,000 KW	20,840 KW	30,586 KW	17,904 KW	29,840 KW
Propeller Diameter	6.1 m	5.2 m	5.0 m	6.4 m	5.2 m
Number of Blades	7	5	5	7	5
Propeller RPM	120	155	149	73	181
Advance Coefficient (1)	1.08	1.14	1.06	0.87	1.15
Thrust Coefficient (2)	0.22	0.22	0.23	0.24	0.22
Propulsor Efficiency (3)	0.80	0.73	0.75	0.72	0.75

(1) $\frac{V}{nD}$

(2) $\frac{T}{PN^2D^4}$

(3) $\frac{EHP}{SHP}$ *at propeller*

3.3.7 Lift-Air Supply System (SES)

3.3.7.1 Sub-System Description

Each SES is equipped with lift-air supply fans which are driven by diesel engines and which supply air to the cushion. The leading particulars of each system are compared in Table 3.3.7-1.

3.3.7.2 Lift Power and Cushion Air-Flow-Rate Requirements

In the following discussion an attempt is made to assess the validity of the values that have been selected for cushion air flow rate and lift power for each of the SES designs. It is understood that for each design, the power and cushion flow rates selected were based on the results of subscale model tests conducted, at the speeds and in the sea states of interest, specifically for each respective design, or for a ship of similar geometry and system characteristics.
In each case, the models were of relatively small scale but behaved satisfactorily with the cushion flow rates used. However, since a significant data base of much larger and successful full-scale craft is also available, this has been used, herein, to develop trends to further help substantiate the flow rates and lift-power levels selected for each point design.

Table 3.3.7-1. SES Lift-System Particulars.

		UK SES	FR SES	US/G SES
Number of Diesel Engines	--	2	2	3
Type of Diesel Engine	--	MTU 20V 1163 TB 83	UD 33V2D M9	UD 33V16 M5
Total Installed Lift Power at MCP	KW hp	10,800 14,500	8,840 11,850	6,714 9,000
Full-Load Displacement	MT	1601	1400	1936.5
Installed MCP Lift Power Per Ton	KW/MT	6.75	6.31	4.65
Power Used for Lift	KW	10,000	6,836	5,640
Design Maximum Cushion Air Flow Rate	m^3/sec cfs	900 31,780	368 13,000	340 12,000
Cushion Length	m	69	76.5	95
Cushion Beam	m	20	13	15
Cushion Depth	m	7.5	5.4	6.7
Number of Fans	--	6	2	6
Type of Fans		Airscrew Howden HEBA(B)	NEU-Rotoline 218-084-GIPS	Aerophysics RD-DWDI
Rotor Material		FRP	Steel	Steel
Diameter of Rotor	m	2.5	2.47	1.12
Rotor Rotational Design Speed	rpm	1160	1260	2470
Rotor Design Tip Speed	m/sec ft/sec	152 498	163 534	146 478
Active Control of Lift Air		Yes	No	Yes

(a) Lift-Power

According to the laws of dynamic similitude, lift-power should vary in proportion to the linear scale raised to the power of 7/2 or to the displacement raised to the power of 7/6. However, a number of factors are involved which interfere with this strict scaling law for an SES.

Lift power is approximately proportional to the product of cushion pressure and cushion air flow, and cushion air flow, in turn, is proportional to cushion escape area, which varies directly with the time-average height of the air gap between the water surface and the bottom of the bow and stern seals. If geometric scaling is followed directly, the air gap should vary as the linear scale. This, in practice, is not realistic.

The trend of variation of lift power with displacement is shown in Figure 3.3.7-1 which includes only SES which have separate lift and propulsion systems. The prior and existing craft follow the same trend as the conceptual designs developed in the U.S. The difference in scale between the existing SES and the conceptual designs is very apparent in this figure. The cushion length-to-beam ratios are included in parentheses.

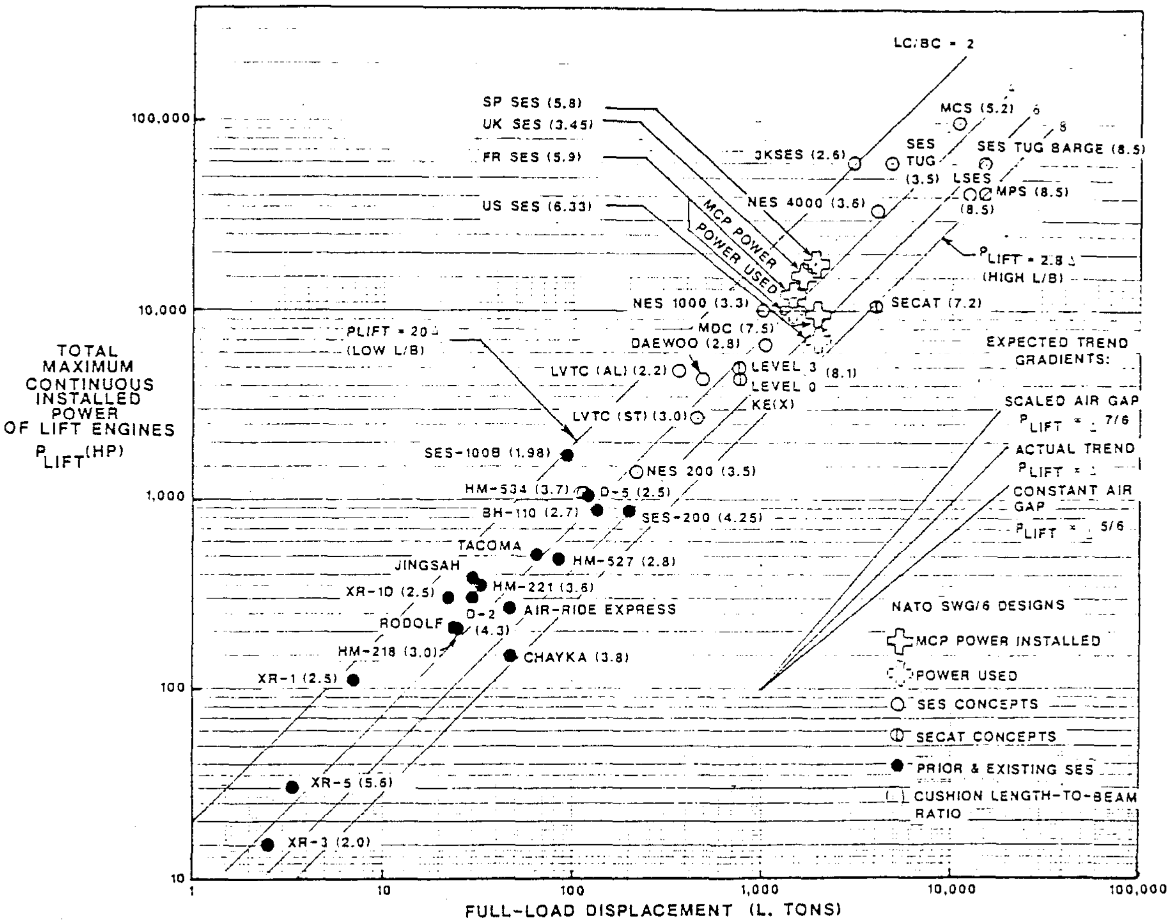


Figure 3.3.7-1. Variation of Installed Lift Power with Displacement for Prior, Existing and Conceptual SES With Non-Integrated Lift Systems.

The lift power is seen to vary quite consistently as displacement to the first power, which lies between the "scaled air gap" trend (power 7/6) and the "constant air gap" trend (power 5/6). Also apparent is a fairly well-marked trend with cushion length-to-beam ratio, and the installed lift power selected for each of the SES point designs fits reasonably well with this trend. The largest disparity occurs with the French and US/G SES designs which appear to have more lift power installed than the trend lines suggest would be necessary. Indeed, both designs are projected to use less than the continuous power available in each case as indicated by the dotted crosses on Figure 3.3.7-1. The power used by the U.S. designs, at an L_c/B_c of 6.33, is almost exactly at the power level projected by the trend lines.

It should be noted, however, that in the development of Figure 3.3.7-1, the trend lines have been drawn to recognize the lift power projected for conceptual designs to be as equally valid as the lift power installed in existing successful designs. Thus, the trend lines are significantly influenced by the lift-power levels previously projected for U.S. SES conceptual designs of very large size which have not been operated. Also, the effect of different design speeds, or Froude Number, is not-accounted for in Figure 3.3.7-1. In the next approach, which examines cushion air flow rate, trend lines are established from only craft that have sucessfully operated and the effect of forward speed, as well as sea-state, is included. As a result, the conclusions drawn are decidedly different from those derived from Figure 3.3.7-1.

(b) Cushion Air Flow Rate

The alternative assessment of lift system-powering is made by examining total cushion air flow requirements since the lift power required is proportional to this flow rate. In rough water the lift-fan system must deliver sufficient air to the cushion to:

(1) provide the desired air gap beneath the seals to minimize resistance and maintain the cushion
(2) provide the desired ride quality and ship motions in all required sea states and
(3) replenish the cushion swept by wave action.

The flow required for each of these is not additive but interelated in a complex manner depending on the dynamics of the ship and seal system which makes precise prediction difficult and dependent on the results of model tests or experience from prior craft.

Figure 3.3.7-2, for example, shows prior experience for cushion air flow related to a term which is the maximum possible wave pumping requirements in head SES, given as:

$$Q_p = K_p [B_c H_w (V_c + V_w)], \text{ ft}^3/\text{sec.}$$

where

B_c = Cushion beam, ft

H_w = Significant wave height; ft taken as 0.78 H_c

H_c = Cushion depth, ft

V_c = Craft forward speed, ft/sec achievable in the corresponding sea state

V_w = Average wave speed (celerity), ft/sec of corresponding waves

K_p = Wave-pumping coefficient

The data points shown on Figure 3.3.7-2 distinguish, where possible, between what was considered to be:

(a) the maximum cushion flow available
(b) the design cushion flow rate with active control of cushion air, and
(c) the design flow rate without active control of cushion air.

Several of the craft represented by data on Figure 3.3.7-2 were experimental craft (e.g., SES 100A, SES 100B, SES 200) where this distinction is particularly important since more cushion flow than necessary was made available for these craft for the purpose of R&D.

In the case of the SES 200 for example, the craft (with ride control) first operated with essentially the same cushion flow-rate capacity as the shorter BH-110 from which it was derived. In 1985, additional lift fans were added to the SES 200 for the purpose of R&D to double its flow-rate capacity from approximately 2000 to 4000 cfs. In calm and moderate sea states the SES 200 still operates effectively with just over 2000 cfs. In very rough water, however, it appears that the operators, much prefer a minimum flow rate closer to 3000 cfs with the ride-control system active.

Increasing the flow rate on the SES 200 to the maximum (4000 cfs) available appears to be unnecessary. Similar experience was gained with testing the experimental R&D craft, SES 100A and SES 100B, both of which were equipped with ride control and excessive lift-air capacity.

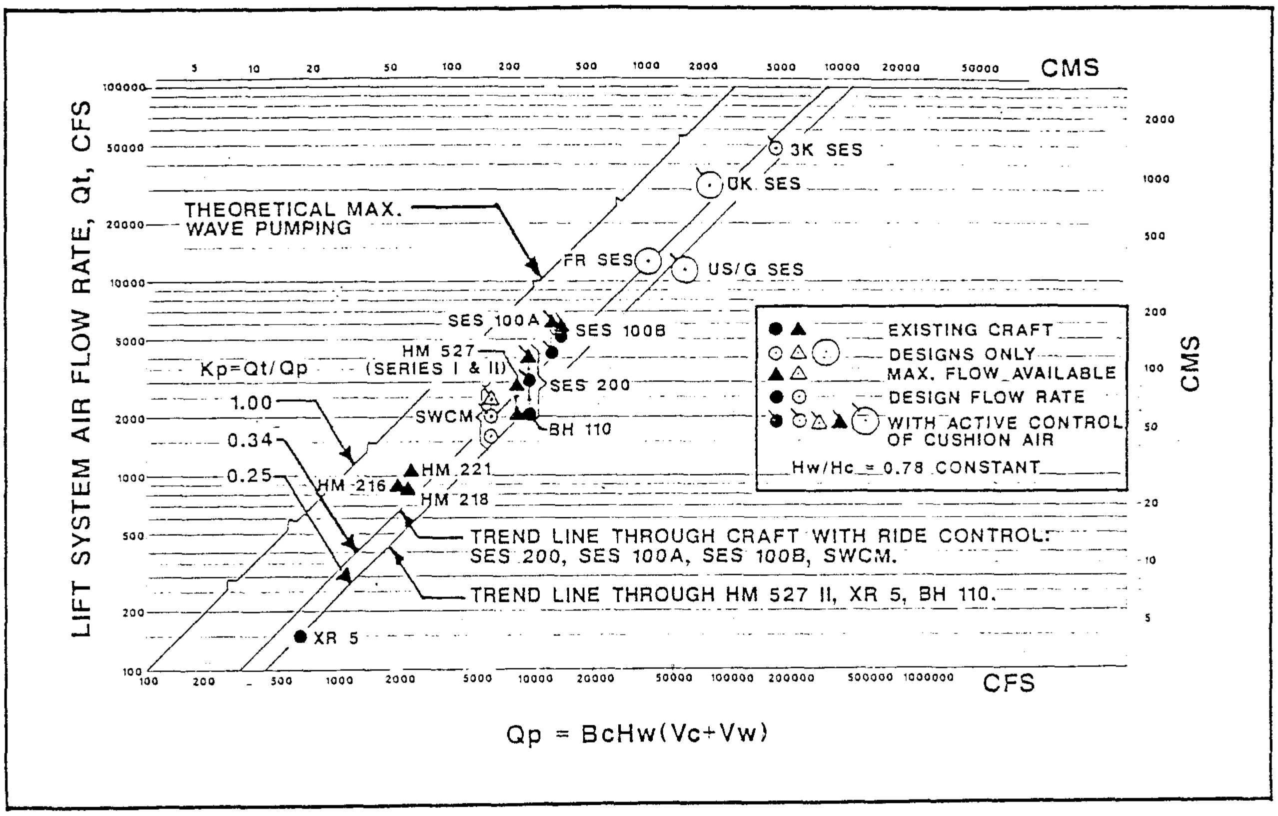


Figure 3.3.7-2. SES Cushion Air Flow Rate Trends Relative to Wave Height, Speed and Cushion Beam

In recognition of such trends, mean lines have been drawn through the data points on Figure 3.3.7-2 to show that only about 25% (K_p = 0.25) of the theoretical maximum wave-pumping flow rate is normally considered to be necessary as a minimum for successful operation with no active system to control cushion air. With current-day systems used for active control of cushion air to improve ride quality, it appears from the data that for very rough-water operation (H_W = 0.78 H_c the minimum acceptable flow should be increased to about 34% (K_p = 0.34) of the theoretical maximum wave pumping flow rate.

Table 3.3.7-2 shows the results of these factors applied to each of the SES point designs.

The upper portion of Table 3.3.7-2 shows what is considered (on the basis of Figure 3.3.7-2) to be the minimum cushion flow rate necessary with and without ride control to accommodate seas having significant wave heights which are 78% of the cushion depth. The lower portion of Table 3.3.7-2 shows similar results for a significant wave height of 5m which is the design sea state for each SES design.

On the basis of this comparison it would appear that, as a minimum (with no margin), the UK SES, which has ride control, needs only about 70% of the cushion flow rate that was proposed for the design. For the French SES, which has no active control of cushion air, a minimum of 82% of the proposed flow could be used. For the US/G SES, which uses cushion air control, however, a 44% increase in flow rate would appear to be a more appropriate minimum requirement.

Table 3.3.7-2. Comparison of Proposed and Recommended Minimum Cushion Flow Rate Requirements for SES Point Design

	UK SES		FR SES		US/G SES	
	Min. Flow Rate Required (H_W/H_C = 0.78), CFS (CMS)					
Proposed in Design Rpt	31,780 (900)	100%	13,000 (368)	100%	12,000 (340)	100%
For K_p = 0.25 No Ride Control	19,000 (538)	60%	9,000 (255)	69%	13,500 (382)	112.5%
For K_p = 0.34 With Ride Control	26,000 (736)	82%	12,500 (354)	96%	18,000 (510)	150%
	Min. Flow Rate Required (H_W = 5m), CFS (CMS)					
For K_p = 0.25 No Ride Control	16,240 (460)	51%	10,700 (303)	82%	12,920 (366)	108%
For K_p = 0.34 With Ride Control	22,220 (629)	70%	14,240 (403)	110%	17,220 (488)	144%

In comparing the conclusion drawn from Figure 3.3.7-1 with that drawn from Figure 3.3.7-2, it appears that in both cases the UK and French SES designs have either close to sufficient or more than sufficient lift power while the US/G SES has more than enough power on the basis of a power projection but insufficient on the basis of a flow-rate projection which should be examined carefully during the next phase of design. Since the installed maximum continuous power of the three diesels of the US/G design is 6714 KW, a power margin of 19% exists over that which is claimed to be necessary which could be used to help make up (but not completely) the apparent flow-rate deficiency.

An alternative assessment of cushion air flow has been provided by the UK (Appendix E). Their choice of design parameters for the lift system was based on many years experience of craft in operation as well as information derived from tank tests of small models, tests on experimental craft and performance trials on full-scale craft such as the HM2 (30t) and the HM5 (100t).

Within this scope of knowledge, the UK adopted a non-dimensional factor "K" which relates to the total air flow to the cushion system and takes into account the craft dimensions and cushion pressure. Generally, this has proved appropriate up to Froude Nos (based on cushion length) of 1.5 and skirt systems comprising individual finger/ segment seals at the bow (which may or may not be suspended from an upper loop) and for stern multi loop seals.

The factor "K", adopted by the UK, is expressed as follows:

$$K = \frac{Q}{B_c} \sqrt{\frac{\rho_\omega g}{P_c S_c}}$$

Where Q is the total volume flow installed (CMS)

B_c is the cushion beam (m)

S_c is the cushion area (m^2)

ρ_ω is the density of water (kg/m^3)

P_c is cushion pressure (pascals)

g is the acceleration due to gravity (9.81 m/sec^2)

The UK claims that reasonable drag levels and ship motion response in waves are achieved with a value of K of approximately 1.0. Their experience shows that substantially less airflow than this will compromise drag both in calm water and waves and will considerably effect the craft's capability to recover from plough in or hard impacts that may occur in conditions where the significant wave height is in excess of two thirds of the cushion depth.

The comparison of the "K" factors for the three designs are as below:

	UK	France	US/G
Airflow m^3/sec	900	368	340
Cushion Pressure KPa	9	12.3	11.9
Cushion Area - m^2	1380	948	1425
Cushion Beam - m	20	13	15
"K" Factor	1.28	0.829	0.552
Flow for			
K = 1.0 - m^3/sec	703	444	615
ft^3/sec	24,826	15,680	21,718
Proposed FLow / Flow With K = 1.0	128%	83%	55%

On the basis of this comparison the UK SES has 28% more flow than necessary, while the French and US/G SES require an additional 17% and 45%, respectively. This result is surprisingly similar to the conclusion drawn from Figure 3.3.7-2 and Table 3.3.7-2 except for the fact that, because of its seal design, the FR SES required no cushion-air control and thus relatively less cushion-air flow rate.

Operational craft built to date and advanced SES design concepts would also suggest an order of installed lift power which may be defined empirically as:

$$\text{Installed Lift Power} = C_{PL} \; x \; \frac{(All\ Up\ Weight)^{1.5}}{L_{OA}}$$

where the lift power is in kW, All-Up-Weight is in Tonnes, L_{OA} is in meters, and where C_{PL} spans values generally between 13 and 15.

The installed lift-system powers proposed in the Point Designs compare as follows:

	UK	France	USA
Lift Power Installed (kW)	10800	8840	6714
Power at C_{PL} = 13	8964	7651	10648
Power at C_{PL} = 15	10343	8828	12286
$\frac{\text{Proposed Flow}}{\text{Flow With } C_{PL} = 13}$	120%	116%	63%
$\frac{\text{Proposed Flow}}{\text{Flow With } C_{PL} = 15}$	104%	100%	55%

This also gives similar results to those presented above. The "K" factor for the US/G SES of 0.55 and C_{PL} of approximately 9 indicates very low installed airflows and power to the lift system. This conclusion is also supported by a separate analysis conducted by Spain, the results of which are shown in Figure 3.3.7-3. This may reflect the adoption of the athwartships stiffened bow seal arrangement for the US/G SES which no doubt is a very efficient seal in calm conditions but would appear not to provide any vertical shear freedom across the beam in waves. This in the past has been considered very desirable in reducing airflow escape and also in reducing drag in waves.

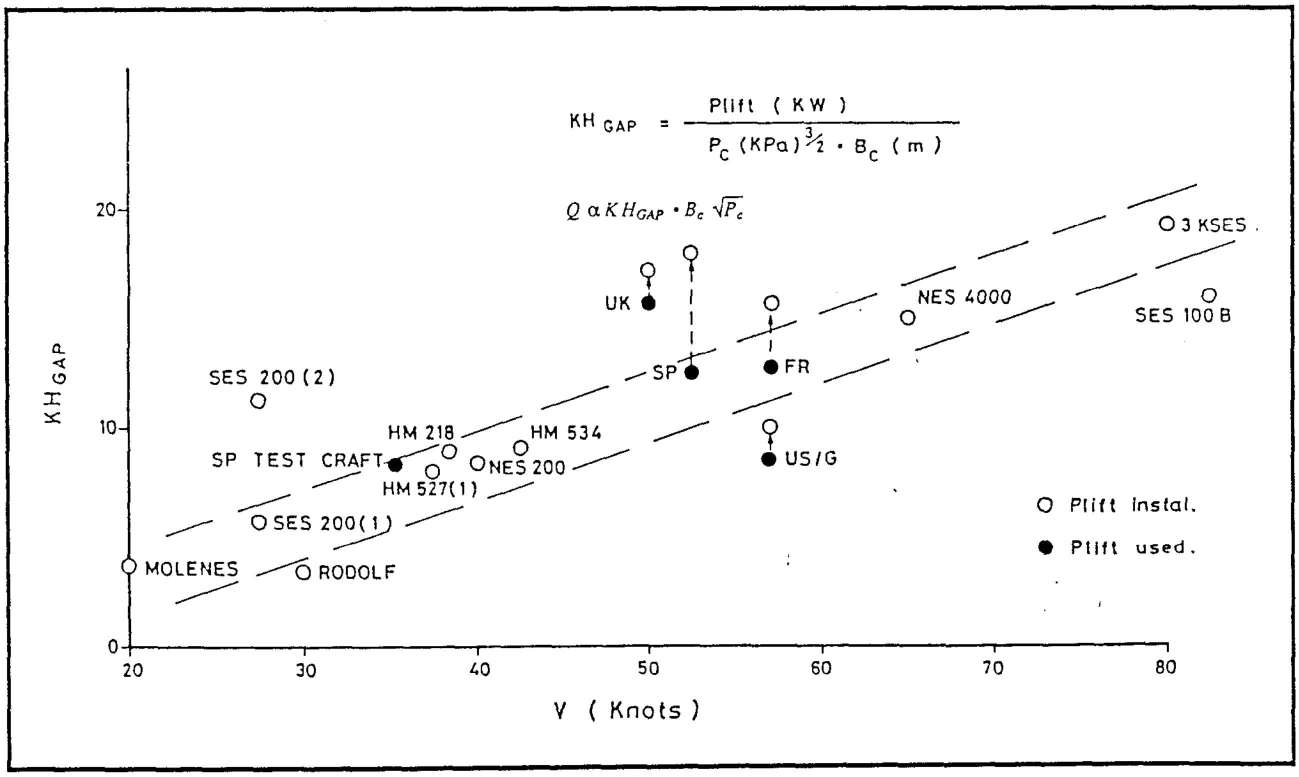


Figure 3.3.7-3. SES Cushion-Air-Flow Seal-Leakage Air Gap Related to Forward Speed

In the U.S., however, DTNSRDC is convinced that the US/G SES has been designed with sufficient cushion-air flow-rate based on their wealth of model and full-scale test-craft experience.

The French Design assumes an immersion of the sidewalls below the skirt hem lines when on cushion and if this is considered together with the "K" factor and power comparison above it would appear that the design capacity is adequate assuming no active control system. However, because of the limited cushion depth of 5.4 meters it is the most likely of the three designs to suffer from wave impacts which could be significant above wave heights of 3.6 meters.

The UK chose a "K" factor of 1.28 for their SES design to allow for the extra deep cushion proportions and a reasonable allowance for the intended heave and pitch active ride-control system.

3.3.7.3 **Lift-Air Distribution**

The arrangements selected to distribute air to the cushion of each SES are illustrated in Figure 3.3.7-4.

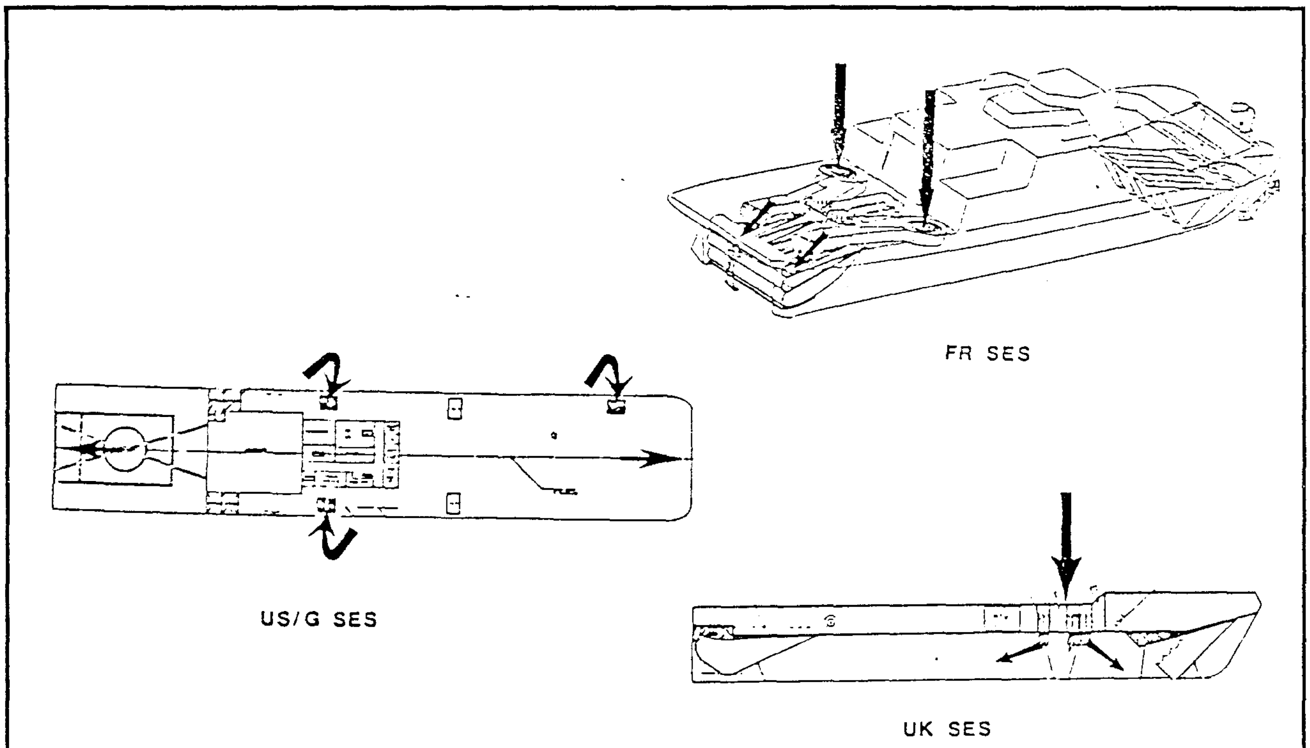


Figure 3.3.7-4. Lift-Air Distribution

The US/G SES point design has a conventional air distribution system (by US standards) which delivers air to the cushion and to both the fore and aft seals, each of which operate at a pressure higher than cushion pressure. The French design has air delivered to the cushion and to the stern seal only while the UK design delivers air only to the cushion and has seals both of which operate at cushion pressure. In all three cases the systems are split between port and starboard sides which operate in parallel and offers the ability to continue operation (albeit at reduced performance) in the event of a failure of one side. The US/G SES has a third diesel-fan unit, on the portside forward, for supplying air to the bow seal.

Relative to the bulk of prior SES experience the UK and French designs are more innovative. The UK design features a newly developed "drag sheet" stern seal which requires no air supply while the French have proposed a new type of bow seal, which also requires no separate air supply, and which was initially developed on the 5.5 MT MOLENES test craft supported by extensive tow-tank model tests. This has permitted the French SES to feature a lift-air supply system which delivers air to the cushion at a convenient location relatively far aft on the ship. This is also a departure from the bulk of prior experience in which it has been generally believed that for operation at high speed in rough weather, a more forward location of the cushion air supply is preferred to ensure that the forward end of the cushion can be rapidly resupplied to maintain cushion and seal pressure forward as large waves divide the cushion when forming a crest amid ships. The UK (Appendix E) have indicated that from past experience they would be apprehensive about feeding the cushion air (and air which finally inflates the bow seal) from an exhaust so far aft. This could aggravate the impact problems in high waves. On previous UK models even when feeding the air only 40% aft of the forward point it was still very necessary to separately feed the bow skirt. The French, however, have successfully tested their air-supply arrangement at model scale and on the Molenes test craft in hgih sea states. On this basis, they have shown that there would be no problem with the FR SES.

3.3.7.4 Lift-Air Supply Fans

All three SES designs use (aerodynamically) conventional, and essentially off-the-shelf, centrifugal fan designs with well-known performance characteristics for supplying air to the cushion and seals. In each case, the rotors are housed within conventional rectangular spiral volutes with unobstructed inlets and ample discharge area. The degree of conservatism in the structural design of the selected rotors is illustrated in each case by the selection of operating tip speeds as illustrated in the structural loading diagram of Figure 3.3.7-5. The French and US/G steel rotors appear to have considerable margin from the standpoint of radial loading. Figure 3.3.7-5 shows that the UK FRP rotors are appropriately designed to operate with the least radial loading. Some development of the structural design of the FRP rotor is expected to be required, although a back-up aluminum alloy design would be expected to have a minimum impact on system weight.

3.3.7.5 Pressure-Flow Slope

It is known that the lift system as a whole has a considerable bearing on craft seakeeping and ride comfort levels experienced. The fan's pressure/flow characteristic has a significant bearing on the response of the cushion system and model and theoretical studies in the UK, U.S. and France have shown that, depending on the frequency of wave encounter, the slope of this characteristic, dP/dQ, is of considerable importance. Model tests in the UK (Appendix E) have shown that there is a considerable attenuation effect in employing low slope characteristics for high frequencies but this has little effect at low frequencies where seasickness is likely to occur. This lack of sensitivity of ship low-frequency motion response to changing dP/dQ is contrary to U.S. and French experience at high frequency the actual fan characteristic about the operating point diverges widely from the static variation, but the resulting effect can still be correlated with the static dP/dQ value.

The lift system P/Q static slope for the US/G SES design at around the normal operating point is -24.75 Pa/m^3/sec which, according to the UK, suggests that the cushion with this P/Q curve may be prone to cobblestoning at high encounter frequencies of about 0.5 - 0.7 Hz unless a different inlet guide vane setting is used or it is attenuated by the active ride-control system. The fan characteristic indicates a peak pressure at about 17% of the design flow which is 16% above the design point pressure.

The French fan characteristic is such that the pressure peaks at about 80% of the design point airflow at which it is only 8% higher than the design point pressure. The lift system P/Q static slope at the normal operating point is -14.5 Pa/m^3/sec. Although some cobblestoning is likely to occur when operating at full flow, reducing the flow slightly should substantially attenuate these high frequency motions. The extra sidewall immersions should also help in this situation.

For the UK design, the slope of the static P/Q curve at the system design point is -8.3 Pa/m^3/sec which should allow for minimal cobblestoning for frequency of encounters above 0.5 Hz. This is the lowest slope of the three designs at their design points.

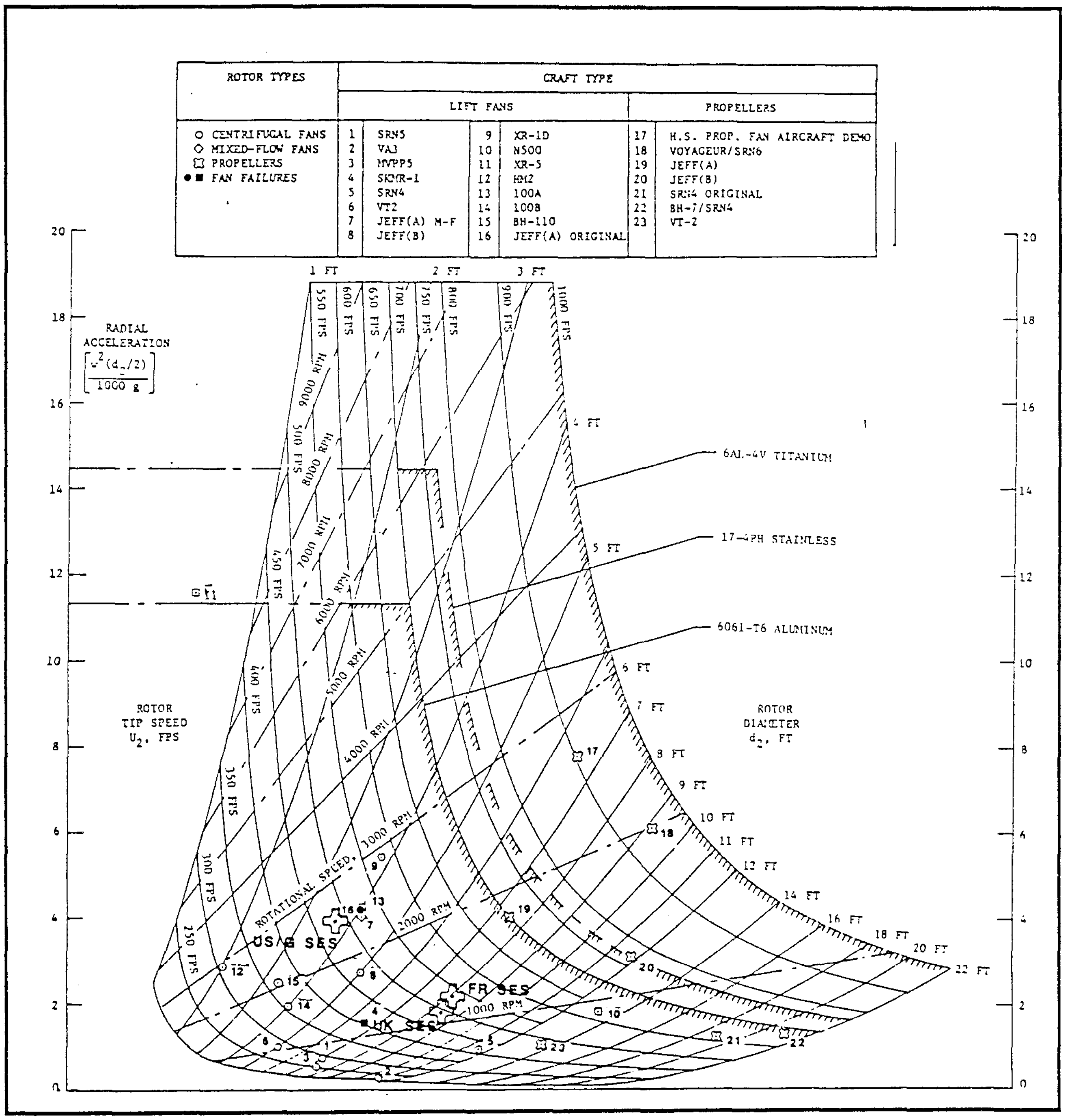


Figure 3.3.7-5. Lift-Fan Rotor Speed Limitations

3.3.7.6 Risk Assessment

The UK (Appendix E) have indicated that, fundamentally, there is little or no technical risk in the efficiency of any of the proposed SES lift systems to elevate the craft to the operational levels stated in calm conditions. They have stated, however, that reservation must be expressed in relation to the US/G design as it appears to be well under capacity for operation in medium to high sea states.

Over and above this, however, remains the final determination of the detail design features which should include:

(i) resolution of fan type.
(ii) the choice of ride-control system for heave and pitch attenuation.
(iii) the optimal distribution of air within the cushion and skirt systems.

In each of these areas there is little or no risk of not being able to determine the most appropriate choice but non-scaling aspects should dictate the inclusion of as large a model as possible in the development program. A half scale model would be a small insurance policy to the final successful derivation of the full-scale craft.

Within the context of this subsystem, most costs according to the UK would be allocated to item (ii) above. Broadly speaking this item, in conjunction with the required seal-system development, could be resolved within an overall program where the availability of the model craft would cost in the order of $17 million within which this system resolution would cost $2.5 to $3.5 million. Such a program could be completed in a five year period.

3.3.8 Prime Movers

All three SES designs use a CODOG propulsion system. This type of system has been an attractive approach for SES designs due to the flexibility of the propulsion plant to provide the most efficient propulsive power in the various operating modes. In the case of these three designs, gas turbines are used to provide propulsive power at high speeds during the cushion-borne mode with diesel engines used to drive the lift fans. During the hullborne mode, when the ship is operating at low speeds, the diesel engines provide the propulsion power and the gas turbines are unclutched from the propulsion drive train. These arrangements allow each engine to be used at, or near, its full power rating with corresponding low SFC value.

The U.S. Hydrofoil design also uses a CODOG propulsion system. This system has a common propulsion drive train that uses gas turbines to provide the high power required for foilborne take-off and cruise, and, efficient, lightweight diesel engines for hullborne cruise power, with foils down. This system is supplemented by hydraulic motor-driven outdrives for hullborne propulsion when the foils are retracted. The advantage of dedicated, hullborne/foilborne prime movers is that each engine can be operated at or near its full power rating with corresponding low SFC values. A CODOG propulsion system, consolidating foilborne and hullborne propulsion requirements in a common drive train, is unique compared with typical Hydrofoil design practice where independent hullborne and foilborne drive systems are employed, using gas turbines to drive strut mounted propellers or hull mounted waterjets for foilborne drive, and diesel engines to drive retractable/trainable outdrive propellers or waterjets for hullborne cruise and maneuvering.

A CODOG propulsion system is also specified for the CA Hydrofoil. Two gas turbines provide the higher power for foilborne operation or higher speed hullborne operation while two diesel engines are available for normal hullborne operations. A common drive system similar to that of the U.S. Hydrofoil is incorporated in the Ca Hydrofoil as well; however, in this case, the nonretractability of the foils facilitates the use of a common propulsor in both hullborne and foilborne modes of operation and a consequent savings in weight.

The SWATH design uses an integrated AC electric propulsion system. This system uses both gas turbines and diesel engines to drive generators, providing electric power for the two propulsion motors and for ship service. During low-speed conditions, the three diesel generators provide the necessary propulsion and ship-service electric power, which are successively brought on line as the load demands. During cruise and high-speed operations, one or both gas turbine generators are brought on line. This system is very flexible; it is possible to have a mixture of diesel and/or gas turbine generators on line at most power demands operating at or near the maximum fuel efficiency of the engines except, when at very low speeds, or at anchor, with one diesel on line at high (synchronous) speed with a very low power demand.

3.3.8.1 Propulsion Gas Turbine

Each of the three SES designs use one gas turbine per shaft to provide propulsion power during on-cushion operation. The US/G SES and FR SES use the General Electric LM-2500 gas turbine. The British design incorporates the Rolls Royce Intercooled (IC) Spey SM1C engine. The US Hydrofoil design uses one Rolls Royce Spey SM3A gas turbine per shaft to provide propulsion power during foilborne operation. The CA Hydrofoil has two Detroit Diesel 570 KB gas turbines that have a projected maximum continuous rating of 7000 SHP and power is taken off from an upper level gearbox. The SWATH design uses two Rolls Royce Intercooled and Regenerated (IC/R) Marine Spey gas turbines with variable geometry power turbines to drive synchronous generators. Table 3.3.8-1 lists the gas turbine rating specified in each design. Also included in this table are the conditions on which the power rating is based. Table 3.3.8-2 lists the gas turbine manufacturers' engine rating at ISO conditions for comparative purposes. In some cases the SWG/6 values are more conservative than the ISO ratings, while in others the SWG/6 values exceed the ISO ratings.

Table 3.3.8-1. Propulsion Plant Prime Mover Ratings (Design Report Values)

Prime Movers	UK SES	FR SES	US/G SES	U.S. Hydrofoil	CA Hydrofoil	Canadian SWATH	SP SES
Gas Turbine	Rolls Royce IC Spey SM1C	General Electric LM 2500	General Electric LM2500	Rolls Royce Spey SM3A	Detroit Diesel 570 KB	Rolls Royce** Spey SM1C ICR Variable	General Electric LM2500-30
MW	18.0	22.4	20.1	11.2	7.5	20	N-A
RPM	5700	3600	3600	5200	11,500	5500	N-A
Ambient Condition	27°C	15°C	20°C	27°C	N-A	N-A	N-A
Intake/Exhaust Losses	0	0	0	1 kPa Inlet 1.5 kPa Exhaust	N-A N-A	N-A N-A	N-A N-A
SFC $\frac{KG}{KW} - hr$	0.220	0.229	0.255	0.239	N-A	N-A	N-A
Diesel	MTU 20 V 1163 TB83	*UNI Diesel 33V20M9 (SACM 195 V20H)	SACM 195 V16 RVR	MTU 16V396 TB83	MTU 12V493	Pielstick 12PA6V280	MTU 20V538 TB 92
MW	5.40	4.42	2.76	1.56	N-A	3.275	3445 kW
RPM	1160	1610	1450	1940	N-A	1000	
SFC $\frac{KG}{KW} - Kr$	0.210	0.217	0.225	0.210	N-A	N-A	

* Formerly SACM
** Variable geometry power turbine
N-A = Not Available

Table 3.3.8-2. Gas Turbine Ratings at ISO Conditions

Gas Turbine	Vessel	MW	Ambient RPM	Duct Losses	Temperature
GE LM 2500 US/G SES, SP SES	FR SES,	23.86	3600	0	15°C
R.R. Spey SM1C		19.50	5500	0	15°C
R.R. Spey SM1C*	UK SES	18.10	5500	0	27°C
R.R. Spey SM3A	US Hyd	12.75	5220	0	15°C
R.R. Spey ICR	SWATH	N-A	N-A	N-A	N-A
D.D.A. 570 KB	CA Hyd	6.35	11,500	N-A	N-A

*Not ISO temperature, included for comparative purposes only
N-A = Not Applicable

3.3.8.2 Propulsion (Lift) Diesel Engines

All three SES designs use diesel engines for hullborne propulsion and lift-fan power. Both the French and British designs use two diesels, one per shaft, to provide propulsion power during the hullborne mode and lift-fan power during the cushionborne mode. The US/G SES uses three diesels for lift-fan power. Two of these diesel engines also provide propulsion power when hullborne. The third diesel is a dedicated lift fan prime mover. This diesel is located forward on the portside, while the remaining diesels are located in the engine rooms, one per shaft. The type of diesel and engine rating used in each design is listed in Table 3.3.8-1. The UK SES design uses the MTU 20V 1163TB83. The FR and US/G SES designs use the SACM V20 and V16 diesel engines, respectively. SACM has combined with another manufacturer to form the UNI Diesel Corporation. The new UNI diesel designation for the SACM 195 V16 RVR used in the US/G SES design is not known.

The US Hydrofoil design uses one diesel engine per shaft to provide propulsion power during hullborne operations. The diesel engine used is the MUT 16V 396TB83. Table 3.3.8-1 lists the diesel rating used in each design. The CA Hydrofoil design report specifies two MTU 12V493 diesels to drive the vessel during low speed hullborne operation.

The SWATH design uses three Pielstick 12 PA6V280 marine diesel engines to drive synchronous generators.

3.3.8.3 Technology Assessment

The French and American gas turbine ratings, for the given conditions, are achievable using the existing LM-2500 gas turbine. As can be seen from Table 3.3.8-2, the ISO rating proposed for the LM-2500 is 23.86 MW or 1.46 MW over the rating proposed for the French design and 3.73 MW over the proposed US/G design rating. If the US/G SES design is using a rating of 20.1 MW at the standard U.S. Navy conditions of 38°C ambient temperature with 1 kPa inlet and 1.5 kPa exhaust duct losses, this rating will then exceed the approved U.S. Navy LM-2500 rating of 19.57 MW. If it is the intention of the US/G SES design to use the current U.S. Navy rating criteria, the engine rating will have to be reduced from 20.1 MW to 19.57 MW. The U.S. Navy rating is a much more conservative rating than that established by ISO and does have to be applied to NATO designs. A primary result of a more conservative rating, i.e., lower power output, is an increase in turbine service life.

The Rolls Royce IC Spey SM1C gas turbine used in the UK SES is an intercooled version of the Spey SM1C. This engine would be a fall-out of the intercooled regenerative gas turbine development program Rolls Royce is involved in using the Spey engine. The engine developed from this program is scheduled for production in the 1992 time frame. The Spey SM1C engine is itself a developmental engine scheduled for production in the 1989 time frame. The ratings of the simple-cycle Spey SM1C engine at ISO conditions and at 27°C are included in Table 3.3.8-2. As can be seen from this table, the rating of the simple-cycle engine at the two temperatures is better than that assumed in the British report for the intercooled version listed in Table 3.3.8-1. Therefore, an intercooled version of the Spey SM1C apparently would provide no advantage over the simple-cycle engine. An exception, however, could be an undetermined reduction in engine SFC using an intercooled model. Once the reduction in SFC has been determined, the fuel saving that would be gained by this reduction would have to be traded off against the increased weight and volume of the intercooled version.

The Rolls Royce Spey SM3A used for the U.S. Hydrofoil design is a lightweight version of the Marine Spey designed for high performance ship applications and identical in performance to the SM1 and 2 variants. The rating for an "A" designated version of this engine, at the design conditions used for the Hydrofoil, is consistent with the ratings at ISO conditions listed in Table 3.3.8-2. A "C" designation of the SM3 engine is currently under developmemt, implying that there is room for growth within the selected plant should there be an increase in foilborne take-off or high-speed requirements.

The Detroit Diesel Allison 570 KB gas turbine, specified for the CA Hydrofoil, is a marine propulsion engine undergoing modification for post-1990 operation at 7000 SHP maximum continuous power. The ISO conditions for this particular variant are not provided; however, ISO data for the 570 K gas turbine is presented in Table 3.3.8-2. The engine has generally good SFC over a wide range of output power and speed and employs a three-stage power turbine.

The Rolls Royce IC/R Marine Spey gas turbine used in the Canadian SWATH design is currently under development and is scheduled for production in the 1992 time frame. No performance data or SFC for ISO conditions was provided, and therefore Table 3.3.8-2 excludes the ISO rating for this gas turbine. It is expected that an intercooled and regenerated gas turbine with a variable geometry power turbine should yield a significantly lower SFC over a large operating range compared with a simple cycle or intercooled gas turbine. If recent developmental estimates for this type of technology hold true for production engines, the reduction in SFC may be on the order of 20 percent, or more, as compared to simple-cycle gas turbines. Any weight savings associated with a reduced quantity of fuel onboard compared with a simple-cycle gas turbine plant, may be significantly offset by the higher weight of the IC/R gas turbines.

3.3.9 Power Transmission

The power transmission systems used in the three SES Point Designs are representative of current SES practice and current world-wide gear train technology. Table 3.3.9-1 outlines the types of gearboxes for both main propulsion and lift fans used in the three SES Point Designs. A schematic of each transmission system is shown in Figure 3.3.9-1. The "k" factor of the individual elements of the US/G SES propulsion gear ranges from 277 to 452. American gear manufacturing capability is currently limited to producing harden and ground gears with a "k" factor of 550. Current U.S. Naval practice is to limit gear "k" factors to 350. Also, several European countries can produce harden and ground gears with "k" factors in the 600 range. Therefore, the technology exists to manufacture a gear with a "k" factor of 452 without affecting the reliability of the gear. The French gear design uses spiral bevel gears to transmit the diesel power to a lift fan or to the main propulsion reduction gear depending on the mode of operation. Spiral bevel gears have been made for use in foreign SWATH ships which use diesel engines as prime movers. Therefore, the technology exists to manufacture bevel gears for use in the horsepower range of the SES. The French gear design, by locating all bevel gear meshes in one gear casing, eliminates the long exposed high-speed shafting runs normally associated with angled gear drives. The US/G and French SES both use epicyclic gears as part of the propulsion reduction gearing. The technology exists and has been used to manufacture epicyclic gears in the horsepower range of the LM2500, which the two designs use as the major propulsion prime mover; however, some development is required.

Table 3.3.9-1. Transmission Description

Main Gearbox	UK SES	FR SES	US/G SES	U.S. Hydrofoil	SWATH	CA Hydrofoil
Type	Double input, double reduction, transfer and combination	Double input combination bevel gear and two stage epicyclic, reversing	Combined double input, single reduction with single stage planetary gear, non-reversing	"Z"-drive - Double input single reduction 90° bevel gear, two strut mounted 90° bevel gears and single reduction epicyclic gear, nonreversing	N/A Generator - Liquid cooled, synchronous (2) 20 MW (3) 3.2 MW Motor - (2) Liquid Cooled, Induction, (2) 22 MW Motor Controller - Unity Displacement Factor, Frequency Controller (2) 22 MW	"Z"-drive - Double input, two 90° bevel gears and double reduction planetary gearbox
*Reduction Ratio	11.4	7.6	15	6.5		19.2
*Output RPM	500	472.5	240	800		600
Idler Gear (Y/N)	Y	N	Y	N		N
K Factor	280-580	Unknown	277-452	500		400
Gear Case	Unknown	Unknown	Steel	Steel		Unknown
Lift Fan Gearbox						
Type	Transfer	Bevel Gear Drive	Conventional	N/A	N/A	N/A
Reduction Ratio	None	1.2	1.5			
Shafting	Unknown	Unknown	High Strength Hollow Steel	High Strength Solid Steel	Composite	Unknown

*Values for cushionborne conditions
N/A - Not Applicable

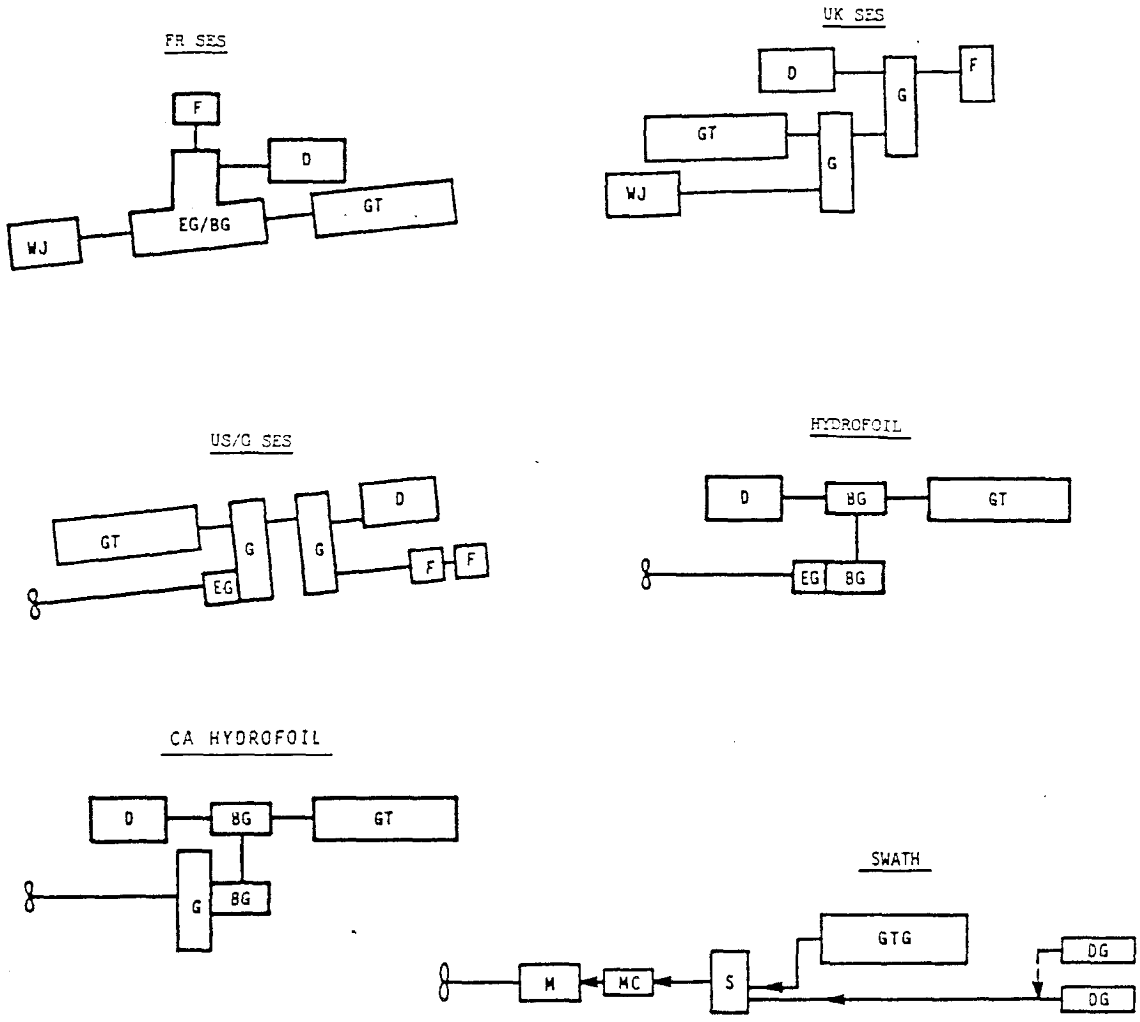
The French gear design appears to be the most complex of the three designs. This increase in complexity will undoubtedly cause additional design problems to arise. However, the technology exists to develop this gear with the use of existing gear-design practices. It is also believed that the effort required for initial testing and evaluation of the prototype gear will not be any greater than the standard for new gear applications. Attention should be given to the diesel/gear interface to insure that minimal diesel vibration is transmitted to the bevel gear, since the diesel will be soft mounted because of shock considerations.

The power transmission system used in the US Hydrofoil design is similar in configuration and power rating to the transmission systems used in the U.S. Navy AEGH-1 Plainview and the Canadian BRAS D'OR. Table 3-3.9-1 outlines the main propulsion transmission system and a schematic of this system is shown in Figure 3.3.9-1. Although recent Hydrofoil experience within the U.S. Navy has concentrated on waterjet based foilborne drive systems, exemplified by the PHM-1 and 3 classes, interest has refocused on propeller Z-drive transmission systems because of the greater propulsion efficiency of transcavitating and supercaviting propellers over the expected speed ranges. A recent example of this technology is the Israeli Navy "Shimrit" class Hydrofoil.

There are major developmental risks associated with a lightweight 15,000 hp per shaft Z-drive transmission. The US Hydrofoil design uses a gear k-factor of 500, which are high compared with typical surface combatants as discussed earlier. There is also limited experience on the long-term reliability of high power Z-drive transmission systems on Hydrofoils. For example, only 198 foilborne hours were logged in the AGEH-1 during its operational life, compared with over 800 foilborne hours logged by the waterjet propelled PHM-3 during the fist two years of operation. Assuming the operational profile of the PHM-3 and a 20-year service life, the US NATO Hydrofoil will experience approximately 8000 foilborne hours and 20,000 hullborne hours on the Z-drive transmission system. This is well outside the experience range of the Z-drive systems tested thus far, so extensive development and testing will have to be performed to validate the transmission.

The transmission system of the CA Hydrofoil is a Z-drive system employing upper and lower level gearboxes that transmits power to a 19.2:1 double-reduction planetary gearbox located in the foil pod. Each of the two transmission systems is independent of the other. The use of a K-factor on the order of 400 is not expected to be a problem.

Only very limited information was presented on the nature of propulsion shafting, in the point designs, but it is believed that with the exception of composite shafting there are no risks in this area. The composite shafting proposed in the SWATH has been tested successfully to a limited degree in the U.S. In the CA SWATH Point Design report, a medium risk is noted for this item.



- BG. BEVEL GEAR
- D: DIESEL
- DG: DIESEL GENERATOR SET
- EG: EPICYCLIC GEAR BOX
- F: LIFT FAN
- G: GEAR BOX
- GT: GAS TURBINE
- GTG: GAS TURBINE GENERATOR SET
- M: DIRECT DRIVE MOTOR
- MC: MOTOR/FREQUENCY CONTROLLER
- S: PROPULSION SWITCHBOARD
- WJ: WATER JET

Figure 3.3.9-1. Transmission Schematics

An electric power transmission system is used in the Canadian SWATH design. The design of this system will require significant development and is unique in many aspects compared with recent technology trends in the U.S. Near-term electric drive options in the U.S. for comparable SWATH applications have focused on geared, high-speed AC synchronous motors with water-cooled stator windings and brushless excitation. The U.S. designs feature variable frequency generator and motor buses, allowing synchronous operation when both gas turbine generators and both motors are on line, and a synchronous operation through a frequency convertor for each motor when one gas turbine is on line to allow flexibility in the selection of an efficient gas turbine operating point and use the full power range of the engine. The Canadian SWATH design uses a liquid cooled direct drive AC induction motor requiring no external excitation. The generator busses appear to be constant frequency (60 Hz); therefore frequency conversion is required over the entire propeller/motor speed range. This results in about twice the frequency conversion electronics as in equivalent U.S. designs, an area which is generally considered as a weak link in the electric drive trains. An additional disadvantage of a constant frequency system is high prime mover SFC at full (synchronous) speed and low load conditions, although the Canadian SWATH design provides for a mix of diesel and gas turbine generators to cover most operating points efficiently. Both the 3.2 MW diesel and 20 MW gas turbine generators employ water cooled stators, a design feature common to U.S. designs and considered state of the art for shipboard applications. Table 3.3.9-1 gives a summary description of the electronic transmission system, and Figure 3.3.9-1 shows a generalized transmission schematic for one shaft.

3.3.10 Electrical Systems

Since each design except the CA SWATH incorporates low risk traditional ship service electric power generators, the primary assessment items are verification of power margin, load prediction, and system weight justification. The FR SES design uses diesel generators with gas turbine emergency generators. The gas turbine emergency generators were selected for weight considerations as well as for their rapid starting characteristics. The mix of prime moves will complicate maintenance requirements and will require additional spare parts to be stowed onboard the ship. It is unclear whether the diesel generators used in all three designs include sound enclosures to reduce radiated noise allowing the machinery space to have a manned watch, or whether the generator space is acoustically treated and unmanned. This issue should be addressed if diesels are chosen for ship-service power generation. Studies have shown that the volume impact of using diesels with work-around enclosures is rather severe and may make gas turbine generators more favorable from a volume standpoint. If enclosures are required, it should be determined if "skin-tight" (instead of walk-around) enclosures can be used to minimize the volume impact.

No information is provided on the distribution systems of the U.S. or CA Hydrofoils.

The number, size and type of ship-service generators are listed for each design in Table 3.3.10-1. Electrical-system arrangements and survivability issues are addressed in Section 3.2.8 and 3.3.2.

Table 3.3.10-1. Electrical System Characteristics

	UK SES	FR SES	US/G SES	U.S. Hydrofoil	CA Hydrofoil	CA SWATH
Generators 60/Hz	(4) 300 kW Diesel Generators One as standby Rolls Royce FD 12 MK7	(2) 320 kW Diesel Generators (2) 320 kW Emergency GT Generator	(3) 500 kW Diesel Generators One as standby DDA 12V92T	(3) 345 kW Diesel Generators One as standby	(2) 350 kW Gas Turbine Generators	Ship Service Power derived from Propulsion System via (2) 3 mW V6300V/440 V Solid Stated Power Converters and and (1) 6300 V/440 V Emergency Power Converter
Sound Enclosure (Y/N)	Unknown	Unknown	N	N	N-A	
Special Frequency Systems	(2) 400 Hz Motor Generator Set	(2) 400 Hz (Converter Unknown)	(2) 400 Hz Solid State Frequency Converter	(2) 400 Hz Solid State Frequency Converter	N-A	(4) 60/400 Hz Solid State Frequency Converters
Switchgear (STD or LTWT)	STD	STD	LTWT	LTWT	N-A	N-A
Cable (STD or LTWT)	STD	STD	LTWT	LTWT	N-A	N-A

N-A = Not Available
STD = Standard
LTWT = Light-Weight

3.3.10.1 Distribution System

The FR and UK SES designs use standard surface-ship electric power distribution systems. The US/G SES design uses "approved-for-production" lightweight cabling and switchgear. These consist of standard ship-service power cable with the armor removed and switchgear cabinet made from aluminum rather than steel. Lightweight no-smoke cable is being used extensively on the DDG 51; lightweight switchgear is not, however.

The CA SWATH has an integrated electric propulsion system; therefore, ship-service power is taken directly from the propulsion electric plant. Electric power is derived from the two 6300 V, 3-phase, 60-Hz main propulsion busses and transformed to 440 V, 3-phase, 60-Hz through solid-state power transformers/line filters. This power is distributed to the ship-service switchboard in each of the four damage control zones via a ring type main.

3.3.10.2 Power Margins

The UK SES Point Design's AC power generation equipment consists of four (4) diesel generators rated at 300 KW each. This provides a 900 KW maximum installed power with one set on standby. The maximum load predicted is 485.3 KW including all margins and growth factors for action (combat) conditions. Although this electrical system design reflects the required 40% growth margin, the report states that a 20% growth margin is more in keeping with traditional UK SES practice.

The US/G SES electrical system design consists of three (3) 500-KW diesel generators. The maximum predicted electrical load for the given ASW mission is 856 KW including the 40% growth margin required. This allows the operation of two generator sets with one on standby to provide full electric service power.

The FR SES electrical system consists of two (2) 320-KW diesel generators plus two additional standby/emergency gas turbine generators each also rated at 320 KW for a total of 1280 KW installed. The maximum predicted electric load is 360 KW without margin. Adding the 40% growth margin will not affect the size or number of generators. Even with the allowance for 40% margin, the electric plant appears to be oversized. The design was developed according to French Navy standards, but with the added goal of providing total redundancy by satisfying total electrical power demand from either side of the ship.

The US Hydrofoil electrical system consists of three (3) 345-KW diesel generator sets for a total installed power of 1035 KW. The maximum predicted electric load is 425 KW without margin, 595 KW with a 40% growth margin. The generators were sized for two generator operation with a 90% parallel load factor, with one generator on standby or in repair. The effective electric-plant margin, based upon the installed power and normal operation, is 46%.

The electric load estimate provided for the US Hydrofoil is based on a simple algorithm predicting total electric load as a function of displacement, and does not provide a detailed load schedule to permit assessment of the individual loads. It is therefore difficult to verify that the estimated electric load is reasonable for this ship except in the most general comparison with similar ships.

No data is provided for the size or number of generators on the CA Hydrofoil; however, based on the output of the ship synthesis model from which this design was developed, it would appear that there are two 350 KW gas turbine generator sets. No information is provided on total predicted electric loads. This is two-thirds that of the U.S. Hydrofoil and, based on a comparison of the size of the two ships and installed systems, this appears reasonable.

The CA SWATH electrical system consists of two (2) 3000-KW Solid-State Power Converters taking power off the main propulsion busses and one (1) 3000-KW Emergency Power Converter which can take power directly off one of the propulsion diesel generators in the event of a complete propulsion electrical-system failure. This results in a total installed ship service power of 6000 KW plus 3000 KW emergency power. This total installed power (including emergency KW) is slightly higher than the DD-963 but compares favorably to other equivalently-sized SWATH designs, in both magnitude and power density. No electric load analysis was available for evaluation of power margin adequacy. One potential problem with the arrangement of the SWATH electric system is a high fuel consumption rate during low demand conditions, particularly at anchor, due to the large size of the propulsion diesels; however, total time spent in this condition is very limited.

Further information is required to perform an assessment of these electrical loads since there is no load schedule of sufficient detail for the US/G SES or FR SES. The predicted electric load for FR SES is approximately one-half of that provided for the US/G SES and UK SES The US/G SES design report states that the 40% growth margin has been included while the French report states the growth margin has not been included. A functional electric-load breakdown for each design is provided in Table 3.3.10-2. A comparison of installed KW for the four NATO designs and other existing ships, and ship designs, is given in Table 3.3.10-3.

Table 3.3.10-2. Functional Electric Load (kW)

	Ship Support	Propulsion	Payload	Total
FR SES	250	45	65	360.0*
UK SES	355.5	54.8	75	485.3
US/G SES	Unknown	Unknown	Unknown	856.0
U.S. Hydrofoil	Unknown	Unknown	Unknown	425.0
SWATH	Unknown	Unknown	Unknown	Unknown
CA Hydrofoil	Unknown	Unknown	Unknown	Unknown

*W.O. Margin

Table 3.3.10-3. Other Ship Comparisons

	Installed KW
US/G SES	1500
FR SES	1280
UK SES	1200
U.S. Hydrofoil	1034
CA Hydrofoil	700
CA SWATH	6000 + Emergency
PXM Mono	1944
PXM Hydro	1005
PXM SES	1500
AMK	2250
3K SES	1530
PCG	1200
PGG	800
PHM	320
FFG-7	3000

3.3.10.3 **Weights**

As discussed in the Weights, Section 3.3.18, SES power generation-system weights, on a unit weight per KW basis, are lower than would be expected based on conventional monohull practice. The US/G SES in particular reports a weight/KW of half that of the UK SES and the FFG-7. However, despite the significantly lower weights, they do not appear to be outside the range of feasibility for small surface combatants, particularly considering the use of lightweight cable and switchgear on the US/G SES design. The PHM and PCG, for example, both report Group 300 weights per KW well below those of the SES Point Designs. The high value of the UK SES design may be explained by:

- Diesel type
- MG converters for 400 Hz

Weight Group 300 for the CA SWATH includes the three propulsion generators and their support systems. The resultant installed weight/kW ratio is comparable to the FFG-7. It is not known whether any weight savings technology such as lightweight cables or switch gear was employed in the design. However, since the diesel generators were sized from a propulsion standpoint and may be oversized for the ship service load requirements, it is likely that the weight of the distribution system would be lower on an installed KW basis than for typical systems.

The U.S. Hydrofoil weight per power value is comparable to the SES values while the CA Hydrofoil has the lowest electrical density of any vessel considered. In general, hydrofoils have lower weights per KW than other vessel types, which reflects emphasis on the use of lightweight systems in these platforms.

3.3.11 Command, Control and Communication

The Command, Control and Communication (C^3) Systems and equipment for each of the SES, Hydrofoil and SWATH Point Designs are outlined in Table 3.3.11-1. This section does not address surveillance type equipment such as sonar, radar and EW equipment. These items are discussed in Sections 3.2.5 and 3.3.16.

Table 3.3.11-1. Command, Control and Communication Systems

ITEM	UK SES	FR SES	US/C SES	U.S. HYDROFOIL	CA-SWATH
I Control	• Sensors & Weapons Systems Integrated w/Action Information Organization (AIO) • Interface between systems via Combat System Hwy (Def. Stan. 0019 digital type) • Systems controlled from tactical pictures (AIO display) via respective equipment control	• Control and Dir of Helo • SAAM, RODEO (SADRAL), Radars for directional and landing assistance of aircraft	• Combat Dir System (CDS) - Includes: 3 UYK-44 computers and 2 consoles Loc. in CIC; and integrated in data base • Tactical Plotting: Hydrofoil collision avoidance and tracking system (HYCATS)	• Combat Dir System (CDS) - Includes: 3 UYK-44 computers and 2 consoles Loc. in CIC; and integrated in data base • Tactical Plotting: Hydrofoil collision avoidance and tracking system (HYCATS)	• Ship Integrated Processing and Display System (SHINPADS)
II Navigation	• Computer-Aided • Interface w/AIO • Automatic/Manual Plotter	• DECCA radar • Other navigational aids	• All-weather • Interface w/ HYCATS • GPS • Inertia Nav • OMEGA	• All-weather • Integrated w/ HYCATS • GPS • Inertial Nav • Omega	• SATNAV • OMEGA • TACAN • Control/Distrib: Fiber-Optic data bus & high speed processor
III Communication	• Comprehensive FIT of MF/HF, VHF, UHF, SHF SATCOM transmitters and receivers • Control/Distrib: Through integrated system w/Fiber Optic Techniques (Reduce EMC problems) • Fully Secure Voice Communications • Automated Message Sys • Full Cryptographic Facilities • Electronics Comp. meet Tempest criteria • Data Links 11,14,16	• Interior Comm • Comm w/Fleet • Info Processing and Command Assistance • Long-range REC and transmitter antenna provided • Small Crypto Facility • Telecommunication by Satellite (Syracuse)	• Interior Switchboard, voice system entertainment system, telephone system, PA, alarm system (Integrated control) • Exterior Comm. System of HF, VHF, UHF & SATCOM with Links 11 & 14	• Interior Switchboard, voice system entertainment system, telephone system, PA, alarm system (Integrated control) • Exterior Comm. System of HF, VHF, UHF & SATCOM with Links 11 & 14	• Coordinated system of HR, VHF, and SHF SATCOM • Integrated interior Com w/1000 channels of information transfer • Fiber-optic technology with communication by hand held terminals using IR and ultrasonic comm, media • Links 11 & 14

Although it is beyond the scope of this assessment to determine the effectiveness of each C^3 suite, it appears that the point designs have adequate C^3 systems for mission performance. Additionally, the weight fraction information presented in Section 3.3.18, Weights, shows that the three designs fall within the range of conventional practice. With the exception of the antenna arrangements discussed in Section 3.2.5, Combat-System Compatibility, the C^3 systems are not significantly impacted by integration into SES or Hydrofoil platforms. The risks associated with installation of C^3 equipment for ANVs appear minimal and are primarily a result of the attempt to incorporate lightweight equipment presently being developed for conventional surface combatants.

As mentioned in Section 3.2.5.1, the US/G SES and the U.S. Hydrofoil include the Hydrofoil Collision Avoidance and Tracking System (HYCATS) for high speed ship control. Neither the FR or UK provide sufficient detail to assess their respective ship-control systems. The CA SWATH employs a Ship Integrated Processing and Display System (SHINPADS) that consists of a large number of similar computers, display consoles and input/output modules connected to three separate data busses. No data is available on the C^3 systems used on the CA Hydrofoil.

3.3.12 Auxiliary Systems

Based on the information provided, the assessment of the auxiliary systems used in the three SES Point Designs did not identify any significant technology differences between SES and conventional monohull design practice. In general, the auxiliary systems outlined in Table 3.3.12-1 required no major system redesign for application to SES's; however, a definition of the arrangement of these systems would be necessary before a detailed assessment could be completed.

The only major exceptions to conventional monohull practice are in the areas of ballasting and anchoring systems. The ballasting systems used in the SES Point Designs require further clarification, with specific information regarding counter flooding, before a complete assessment, particularly regarding weights, can be completed. The use of a combined anchor line of chain and nylon rope and a single lightweight anchor for the US/G SES design is unusual and may pose some performance risk.

The auxiliary systems used in the U.S. Hydrofoil design are based, to a significant extent, on the systems onboard the U.S. Navy PHM. These systems are typically lightweight, with extensive use of GRP piping, titanium valves, lightweight non-MIL-SPEC components, and aircraft-derived components or systems. Experience with the PHM classes has shown that this approach often compromises reliability and maintainability. A significant source of reliability problems on the PHM classes were electrical failures of the 400-Hz integrated motor driven centrifugal pumps in the seawater, chilled water, potable water and other auxiliary systems. The US Hydrofoil design proposes the use of lightweight 60-Hz motors for electrically driven equipment, instead of the 400-Hz motors on the PHM classes, which should improve the reliability and maintainability for these systems.

The hydraulic system proposed for the US Hydrofoil follows typical recent Hydrofoil practice by the use of a highly redundant aircraft-derived system. This approach uses clusters of small aircraft hydraulic pumps and several smaller subsystems instead of single, large pumps and a centralized hydraulic piping system. This results in a more reliable total system, which minimizes the impact of a single component failure. The high degree of redundancy is important, since the US Hydrofoil depends on the hydraulic system for flap control and strut retraction, auxiliary (emergency) fuel and lube oil pump drives, and secondary propulsion and steering. No details are available on the auxiliary system specified for the CA Hydrofoil; however, the non-retractability of the foil system should reduce requirements for onboard hydraulics. The auxiliary systems on the CA SWATH, aside from the unique submarine type anchor handling systems, appears to follow conventional monohull practice.

The weights estimated for the auxiliary systems appear to fall within accepted ranges for surface ships of this size.

Table 3.3.12-1. Auxiliary Systems Description

System	UK SES	FR SES	US/G SES	U.S. Hydrofoil	CA SWATH
HVAC	5 Recirculation Air Conditioning Units w/filtered makeup 7.5 kW Heater 16 kW Cooler	AC in LVG, OPS, and Technical areas. Normal ventilation in Propulsion, Auxiliary, and stores 6 units.	Recirc w/filtered makeup central AC w/some dedicated AC in electrical spaces.	Central recirc and preheating AC units w/dedicated space and/or multizone AC units in LVG, combat, navigation, and control spaces. Normal ventilation in Machinery spaces	(4) 490 kW Chiller, interconnected or isolated when damaged (4) Air distribution plants, electric heat (4) NBC Filtration plants
Fuel	411 tonnes Cap w/service tanks. 47 tonnes Helo cap. 5.1 tonnes service tank Fuel Cleaning System Fuel Transfer System	"Conventional" Fuel Transfer System	Separate ship and Helo Fuel System w/combined storage. Transfer System used for trim	163 tonnes storage tank capacity. Fuel service/transfer systen w/2 day tanks.	DFO - 1040 tonnes/+500 tonnes future margin. Fuel cleaning and transfer system.
Fresh Water	161 liters/day/man (2) RO Distillers 20 cu meters/day (2) Storage Tanks total of 5.79 cu meters reserve	225 liters/day/man (?) distillers 14.8 cu meters/day 12 cu meter reserve	113 liters/day/man (2) Electrically heated, vacuum, 18.2 cu meters/day total for cooling, flushing, washing & drinking	(2) RO Distillers 7.2 cu meter/day 8.2 cu meter storage tanks	RO Distiller plants, 20 tonnes storage tankage
Firemain	(4) 55 cu meters/hr pumps w/ram inlets	Included in Seawater System	Included in Seawater System	Included in Seawater System	Included in Seawater System
Compressed Air	(2) HP Electric Compressors (1) Hand Start Diesel Driven Compressor 4 starts on each GT 5 starts on each diesel 6 starts on each generator set Low Pressure via Reducing Valves - for shops and cleaning	N-A	• Low Pressure: Dry Air, Engine Starting & Service Air High Pressure: MK 32 Torpedo Tubes, N_2 for Helo	(1) Electrically Driven Reciprocating Compressor	(2) 20.6 MPa at 68 m^3/hr Compressors & Air Flasks at GT and Diesels
Hydraulic System	• Individual Hydraulic Power Packs for each of the following: • Waterjet Steering • Anchor Capstans • Skirt Retraction Winches • Ride Control Valves • Helo Handling	N-A	• Cross Connected Sub systems Each Serviced by (2) Pumps	• Individual Hydraulic Power Packs for Each System	• Individual Hydraulic Power Packs & Controls for Each System 100% Redundancy
Refrigeration	N-A	N-A	(2) Independent 60 Hz Systems, Hermetic Compressors, Freon Heat Exchangers	N-A	N-A
Seawater	Separate from Firemain No Ballast	Includes Firemain (2) 50 m Ballast Tanks	Includes Firemain and Auxiliary Cooling (4) Pumps w/2 Seachests Loop Type	Includes Firemain and Auxiliary CLG (4) Pumps w/seachest in hull (2) Pumps with alternative supply from scoops in struts	Includes firemain (4) Pumps (1 per fire zone)
Mooring/ Anchoring	(2) High Holding Power Anchors w/chain 920 kg Bower 325 kg Stream (2) Hydraulic Bow Capstans	(2) Danforth type anchors w/ steel cable and chain (2) Anchor windlasses (4) Mooring Capstans	(1) Stato-Anchor (lightweight) w/nylon rope and chain (4) Mooring Stations w/ Capstans	(2) Lightweight Anchors (5) Mooring Stations	(1) Anchor: submarine type deployment from lower hull
Boats	(2) RIB (Sea Riders) (4) 42 Man Life Rafts	(2) 10 Man Inflatable Boats (6) 20 Man Inflatable Life Rafts	(1) RIB (4 men & 1 litter) (6) 25 Man Inflatable Life Rafts	(1) RIB (1) 25 Man Inflatable Life Rafts	N-A
Steering Gear	Directional Thrust	Directional Thrust	Clevis-Type w/rudders	Foilborne: Swiveling fwd strut & differential flap control hullborne: fwd strut differential thrust Shallow water: directional thrust	(2) FWD Canards for pitch damping (2) AFT stabilizers for heading and pitch damping Differential thrust at low speed
Helo Facility	• Triple Hydraulic Winch Handling Sys. Helicopter Capability, Vertical (supply, fuel, etc.)	• Aviation Fuel - replenishment at sea, helicopter capability vertical (supply, fuel, etc.)	• 900 kg overhead monorail hoist, helicopter capability vertical (supply, fuel, etc.)	N-A	• Helicopter capability vertical (supply, fuel, etc.)
Sewage	• Interconnected vacuum system, Chemical Treatment Overboard Discharge	N-A	N-A	• Interconnected collect-holding, and transfer system using a macerator and evaporator	• Low flush vacuum type interconnected Collection and Treatment including macerators and incinerators
Pollution Control	• Storage tank purification with duplex filter/coalescer to day tank, waste oil storage	• (Fuel) Oil-water separator, 3M/n water tank, 36 hr stockage aviation waste, 500 L tank	N-A	• Collection System	• Centrifugal separators for purification of LO in drain and storage tanks

N-A = Not Available
Note: No data available for CA Hydrofoil.

3.3.13 Struts and Foils

3.3.13.1 Hydrofoils

Table 3.3.13-1 compares the leading particulars of the U.S. Hydrofoil Point Design, the Canadian low-cost option and other designs of somewhat similar displacement. The smaller PHM is included for reference. All of these craft, with the exception of the PHM, were designed for full open-ocean operation.

Table 3.3.13-1. Comparison of Hydrofoil Characteristics

	DBH 1972	NAVSEC 1977	Grumman 1978	PHM 1977	PXM 1986	Canadian 1985	US Hyd 1986
Full Load (MT)	761	702	742	242	620	458	773
LBP (M)	49.7	50.0	56.0	36.0	48.5	57.9	60.0
L/B	4.10	6.02	5.39	4.87	4.88	6.69	5.72
L/D	6.65	6.76	8.23	8.65	8.65	11.76	8.82
C_P	0.70	0.70	0.71	0.68	0.69	0.63	0.69
Δ/L Ratio*	6193	5611	4220	5180	5431	2357	3575
Foil	Canard	Canard	Tandem	Canard	Canard	Canard***	Canard
Foil Loading Fraction	0.33	0.30	0.40	0.35	0.27	0.12	0.30
Payload** Fraction	0.46	0.31	0.25	0.33	0.28	0.38	0.29
Payload (MT)	350	218	186	80	174	174	224

* Δ/L Ratio = (Full-Load Displacement)/(0.01 x LBP)^3; MT/M^3
** Payload = SWBS 400 - (420 + 430) + 700 + Ammo + Fuel
***Fixed Foil System; Foil Loading Fraction = Load at Bow/Load at Sternfoil
C_P = Prismatic Coefficient

By selecting a fixed fully-submerged foil system, the Canadian's were able to design an extreme canard configuration which, in addition to a weight saving, produces a seakeeping advantage.

Also, the low loading on the bow foil achieved with this configuration, at a foil loading fraction of only 12%, is a solution to the problem of designing steerable bow foils on large hydrofoils.

Although the payload plus fuel fraction for the Canadian design is high at 38%, the actual payload is 50 tons less than the payload for the U.S. Hydrofoil. Also of interest is the very low displacement-length ratio for the Canadian design at a value of 2357 MT/m^3 compared to the U.S. Hydrofoil at 3575 MT/m^3 and the PHM at 5180 MT/m^3. This is due, in part, to the lower displacement of the Canadian Hydrofoil and selection of a fixed foil system for the design as discussed below.

The most practical retraction arrangement is to retract the forward foil over the bow and the aft foil over the stern, with the shortest hull (relative to strut length) having an LCB close to amidships, offering the easiest solution. Better hullborne performance, however, is achieved with longer hulls, while good seakeeping results in LCB locations about 7% of the hull length aft of amidships. With these additional requirements the distribution of the lift system will favor loading the aft foils. The simplest means of achieving this is to move the aft foil unit forward towards the LCG which is not conducive to a retractable foil system.

Figure 3.3.13-1 presents the displacement-length ratio for various existing and projected hydrofoils as a function of full-load displacement.

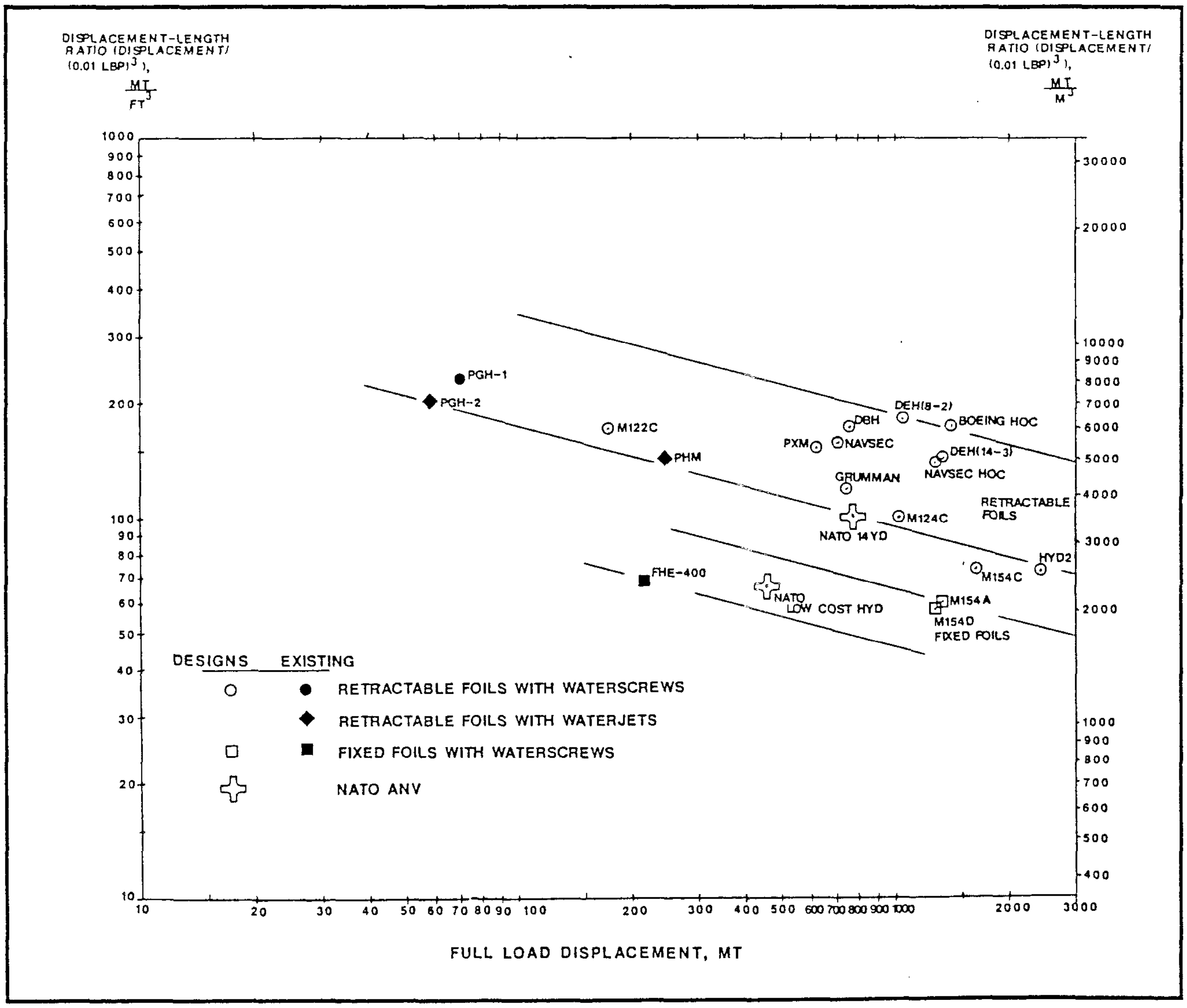


Figure 3.3.13-1. Displacement-Length Ratio for Hydrofoil Craft

With one or two exceptions, the hydrofoils with retractable foil systems employ a canard configuration which retracts the foils over the bow and the stern. Foil loading fractions for these craft are on average approximately 65% aft and 35% forward. The hydrofoils with fixed foils employ either a canard configuration with heavily loaded aft foils (FHE-400 and CA low-cost Hydrofoil) or a tandem foil arrangement with equal foil loading (M154A and M154D). In reviewing Figure 3.3.13-1, it is seen that the displacement-length ratio decreases with increasing displacement for both retractable and fixed foil craft. This is to be expected since craft length generally gets larger as displacement increases. Of more interest in Figure 3.3.13-1 is the fact that the craft with retractable foils group at higher displacement-length ratios (i.e., shorter hull lengths) than the craft with fixed foils. Thus, by abandoning foil retraction the craft length is allowed to increase in order to improve hullborne performance. This explains the reason that the displacement-length ratio for the CA Hydrofoil is much lower than the U.S. Hydrofoil or the PHM. The decision to adopt a fixed foil system with highly loaded aft foils and increased hull length has to be traded-off against the increased difficulty in foil inspection and maintenance.

It should be noted that the hull clearance, when foilborne, for the NATO U.S. Hydrofoil is 46 percent greater than that of the NATO low cost CA Hydrofoil. This is undoubtedly due to the fact that the design sea state for the NATO low cost CA Hydrofoil was sea state 5 rather than sea state 6.

Figure 3.3.13-2 presents a comparison of lift-system weights expressed as a percentage of full-load displacement for existing and projected hydrofoils. This figure illustrates the weight penalty associated with adopting a retractable foil configuration. In reviewing Figure 3.3.13.-2 it is seen that the lift-system weight fraction for the NATO U.S. Hydrofoil is below the trend established by existing and projected hydrofoils employing fully-submerged retractable foil systems. Some of this apparent weight savings could be due to the selection of HY-130 for the struts and foils. Note that HYD-2, which is significantly below the established weight trend for fully submerged retractable foil systems, also selected HY-130 for the strut and foil material.

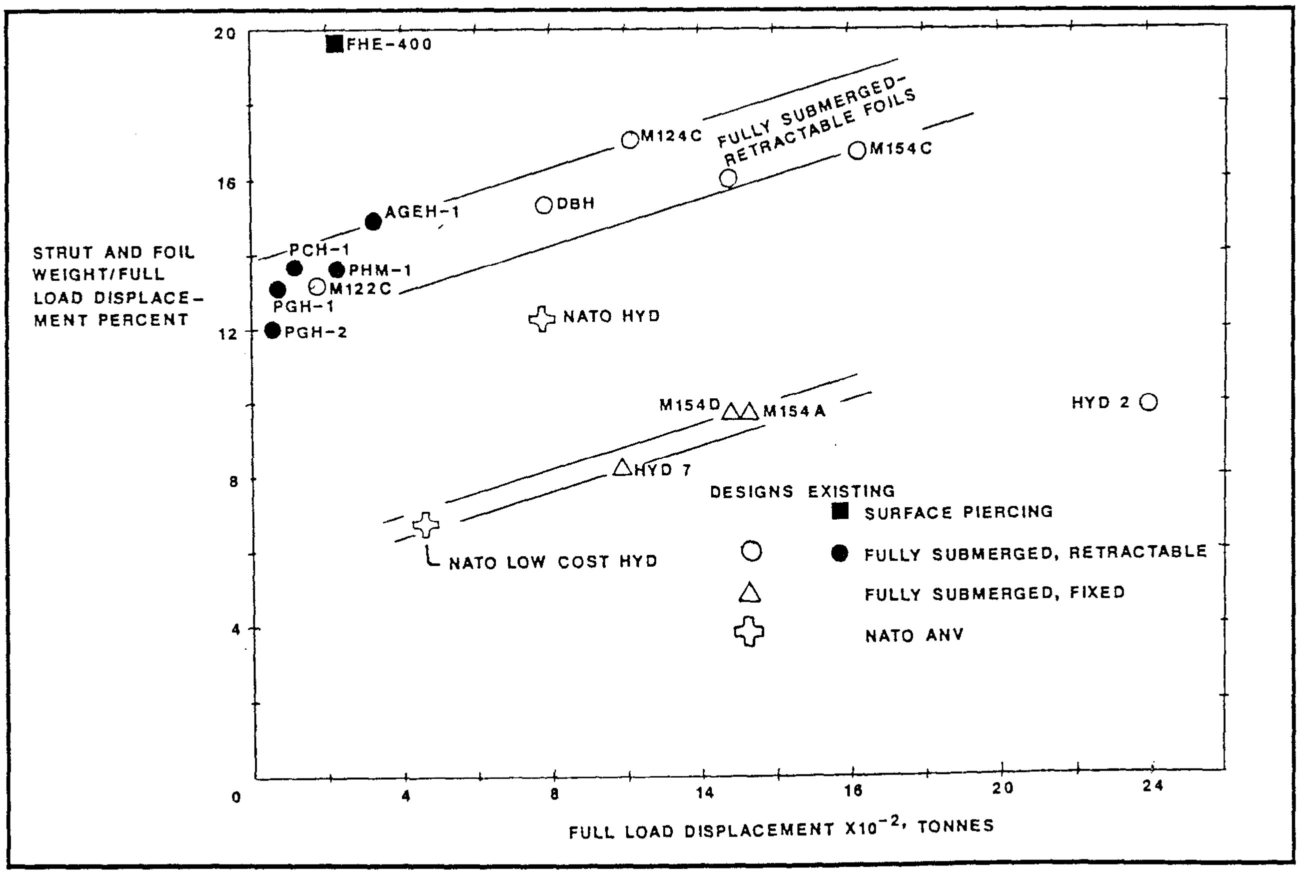


Figure 3.3.13-2. Comparison of Hydrofoil Lift-System Weight

The strut and foil weight fraction for the NATO low-cost CA Hydrofoil is consistent with the apparent trend for projected hydrofoils employing fully submerged fixed foil systems.

3.3.13.2 **SWATH**

The NATO CA SWATH employs short, single struts. The use of short (as opposed to overhanging) struts were selected to make it easier to reduce the distance between LCB and LCF, an important seakeeping consideration. As part of a parametric powering study of SWATH ships conducted by the U.S. Navy, it was seen that the equivalent horsepower (EHP) for dual strut configurations was greater than for single strut configurations at speeds in excess of approximately 20 knots.

A traditional difficulty with using short struts has been in providing a location and internal volume for an effective rudder. The combined stabilizer/rudder ("stabiludder") concept has been adopted in this design to overcome this problem. Another consideration in using short struts is the potential for fouling the props with towed equipment, and increased propeller vulnerability.

The use of the stabilizer/rudder concept for maneuvering will provide good low-speed performance. However, the high-speed performance may not be as good as can be achieved with a conventional rudder which could adversely effect the station-keeping capabilities of the ship during high-speed UNREP. The stabilizer/rudder concept should, however, result in a weight saving because of the reduced number of control surfaces relative to a conventional rudder.

The aft location of the propulsion motors places the motors under strut sections that are extremely thin and removal of the motor components is a consideration. Also, the strut spaces above the motor rooms, stabiludder actuator rooms, and canard machinery rooms are foam filled and access needs to be considered. The roll period of the NATO SWATH is approximately double the heave period, which is likely to result in adverse hull motions. An increase in strut thickness could be one method to decouple heave and roll.

The stabilizers and canards in the NATO CA SWATH are proposed to control ships heading and pitch attitude. However, the seakeeping calculations were based on the assumption that the fins were fixed. Further development of the CA SWATH design would benefit from additional study as to the benefits of an active fin ride-control system on CA seakeeping performance.

3.3.14 **Ride-Control System**

Generally accepted U.S. Navy criteria for an acceptable ride is a significant single-amplitude vertical acceleration of 0.4 g (0.2 g rms) and a corresponding lateral acceleration of 0.2 g (0.1 g rms) A number of methods have been introduced at different times to improve the quality of the "ride":

- **Size** - as ship sizes increase, they are less affected by the waves, but even the largest of modern passenger liners still employ fin stabilizers for roll-motion reduction

- **Hydrofoil Systems** - by lifting the main hull clear of the waves and running on submerged hydrofoils, a great deal of the effect of the waves is avoided

- **Small Waterplane Area Twin Hull (SWATH) hullform** - by adopting a twin-hull configuration and concentrating the buoyancy in two submerged, torpedo-like bodies, the SWATH is able to support the main hull, well above the water surface, on two (or more) slender struts. In this way the SWATH, like the Hydrofoil, is relatively free of the influence of the water surface and provides a very smooth ride.

- **Roll-reduction systems** - numerous roll-reduction systems have been employed on ships of all sizes. These systems have included passive bilge keels, active fin stabilizers, cross-connected anti rolling tanks and even massive gyroscopes. The most commonly used of these systems is the fin stabilizer, now fitted to many naval ships and commercial passenger ships. Active rudder control is sometimes used for the same purpose.

- **Air cushions** - the air cushion, which supports most of the weight of surface-effect ships and air-cushion vehicles, serves, to some extent, to insulate the hull from the irregularities of the water surface but the pressure changes in the air cushion itself, due to passage over waves, can cause undesirable accelerations in the ship. Ride control systems (RCS) have been introduced on some SES (such as the SES-100A, SES-100B, XR1-E, SES-200 and NORCAT) in an attempt to reduce the extent of the fluctuations in cushion pressure. This can be achieved in two ways: by venting the cushion, through controlled louvers, to the atmosphere or by controlling the air intake to the fans. Sometimes a combination of both methods has been proposed, as for the 3KSES.

An active form of RCS, whereby cushion venting is controlled by accelerometers and/or pressure transducers, was introduced in the USA in the late 1960s. Such systems were successfully fitted to the SES 100A, SES 100B, XR-1D and more recently to the SES 200. These systems have been shown to give substantial reductions in heave accelerations in moderate wave conditions (wave heights up to about half cushion depth). A similar system has also been fitted to the NORCAT with, it is understood, an equal degree of success. However, in rougher seas with wave heights approaching cushion depth, the performance of this form of RCS decreases rapidly, and tests in the UK and US on the SES 200, indicated that the RCS had negligible effect on motions in extreme rough-water.

In the US, the development of improved ride-control systems is continuing while in the UK, VHL had planned to carry out further research in this field and had provisionally arranged for project funding from UK Government sources before the Company's failure. The proposal was based on the concept of sub-division of the cushion by a lateral flexible seal divider. Cushion air feed would then be controlled between the two compartments and active vent valves were to be fitted forward and probably also aft. This system would in theory have effective and rapid control of both pitch and heave motion, and with the appropriate tuning and regulation, held promise of providing a solution to the rough-water ride-control requirement. Estimates of the power, air flow and control requirements were made for such a system, but no testing was carried out.

Other systems for controlling pitch were also considered by VHL. Small actively controlled fins fitted beneath the forward edge of the sidehulls were considered to be a promising means of control. Model tests were carried out with fixed fins but these were found to give insufficient control.

A successful roll damping system was devised by VHL in conjunction with GEC Avionics based on active modulation of the craft's rudders. This system was fitted to an HM2 and HM5 craft and proved to be effective in beam sea operations. In moderate to rough seas the reduction in roll amplitudes was about 50%. It was also shown that it was possible to obtain some control of pitch motion by rudder angle modulation, but this concept was not pursued further.

There would therefore seem to be good reason for continuing with this line of development in roll control. A proposal was made for the UK SES Point Design to actively modulate the waterjets, suitably angled, in a similar way. This system was, of course, to be incorporated in addition to the system for controlling pitch and heave.

The approach of the NATO SWG/6 designers to the subject of ride control varies widely from one point design to another. The RCS proposed for the SES, Hydrofoil and SWATH point designs and for the NFR 90 are summarized in Table 3.3.14-1. They are described in more detail in the following paragraphs.

3.3.14.1 UK SES

The UK SES design includes a comprehensive and innovative ride-control system. It is planned to control heave acceleration by using vent valves and to control pitch by installing an inflated, transverse, flexible seal located just forward of amidships and by controlling the air flow into the forward and aft sections of the cushion. The transverse seal extends from the wet deck to within about one meter of the calm-water, cushion-borne water line so that it is not expected to increase calm-water drag. In rough water, the transverse seal is expected to make contact with the waves and will allow pitch accelerations to be controlled to some extent. This is an innovative approach but has not yet been subjected to experimental verification.

Table 3.3.14-1. Ride-Control Systems.

	UK/SES	FR SES	US/G SES	SP SES	Hydrofoil	SWATH	NFR 90
Heave	MTS + VV + DC	Passive	VV (SES-200)*	VV		FS	None
Pitch		None	None	None	ACS (PHM)*	FS	None
Roll	WJ (HM-2, HM-5)	None	None	None		None	FS (FFG-7)*

* *Prior, Similar Systems are quoted in parentheses*

Abbreviations: ACS Automatic Fully-Submerged Hydrofoil Control System
DC Lift-Air Distribution Control
FS Fin Stabilizers
MTS Midship Transverse Seal
VV Active Cushion Vent-Valve System

It is proposed to control roll on the UK SES by using active steering control of the main propulsion water jets. A similar system has been successfully used by Vosper Hovermarine for the rudders on the HM series of SES. The Vosper Hovermarine system uses actively controlled twin rudders to achieve roll reduction.

3.3.14.2 FR SES

The designers of the FR SES state that their SES will perform satisfactorily without the need for an active cushion-air control system. While this point of view differs from that of the other NATO SES point designers, it should be pointed out that only a very few of the several hundred SESs and ACVs operating today have any ride-control system and those ride-control systems that are in use provide, in any case, a rather marginal improvement in ride, particularly in heavy seas. There is no prior experience of the behavior of a large SES in a seaway. It may, in fact, prove to be possible to achieve a satisfactory ride in rough conditions by the traditional method of making slight changes in speed or heading.

The French SES point design does, however, feature an innovative bow-seal concept which, it is claimed, will "automatically" track the surface of waves by responding to changes in pressure between the lower leading and trailing elements of the seal which cause corresponding changes in the inflated equilibrium of the upper support loops and therefore a favorable dynamic change in the operating height of the seal. This seal has been shown to work in the towing tank, in experimental bench tests on the Molenes test craft. It is the use of this seal that the French believe can eliminate the need for an active cushion-control system.

3.3.14.3 US/G SES

The US/G team have selected a ride-control system for their point design based on that of the SES-200. This system makes use of controlled fan-inlet guide vanes and valves which vent the main cushion as required to reduce vertical (heave) accelerations. No attempt is made to actively control roll or pitch. This system has the advantage of having undergone extensive trials, on the XR-1E, on the SES-200 and on the NORCAT. It is similar to the systems which were very extensively evaluated on the SES 100A and SES 100B for application to the US 2K and 3K SES programs in the late 1970s. Its use on the NORCAT eleviated the broaching of the water-jet inlets and its use on the SES-200 has, reportedly, had the unexpected effect of slightly increasing ship speed under some circumstances in low sea states, presumably caused by a reduction in drag due to reduced motions.

3.3.14.4 **SP SES**

To attenuate vertical motions, when operating in rough seas the Spanish have selected for their SES a passive vent-valve system to bleed air from the cushion to the atmosphere. The vent-valve system will be driven by the cushion pressure variations. During the planned Spanish program on SES technologies, other systems are to be evaluated.

3.3.14.5 **U.S. Hydrofoil**

The Automatic Control System (ACS) which controls the ship's foils is an essential part of fully-submerged hydrofoil operation and is, in itself, a ride-control system and no further measures are necessary. The smooth ride achieved by a fully-submerged foil system has been demonstrated by the PHM, by prior U.S. Navy hydrofoils and by the Boeing Jetfoil. Even when operating hullborne, it is claimed that active control of the foils can be used to achieve substantial improvement in the ride. Although this is a procedure not often practiced in order to maximum system-hardware reliability.

The ACS also provides continuous dynamic control of the ship during take-off and landing. In addition to providing ship roll stability, the ACS controls the height of the hull above the water surface and initiates and holds coordinated turns. The combination of the ACS and fully-submerged foils permits the ship to operate in seas up through sea state 6. Although the system is similar to the ACS presently in use on the PHM, the addition of a forward-looking radar is expected to provide smoother ride conditions than achieved by previous hydrofoils.

3.3.14.6 **SWATH**

The very nature of the SWATH's low water-plane area provides for exceptionally good seakeeping, however, an active-control system and control surfaces are incorporated into the design primarily for steering and for enhanced pitch stabilization.

The control surface design consists of a set of canted stabilizers placed forward of the trailing edge of each strut and a set of canards placed aft of the leading edge of each strut. These stabilizers and canards can be used to control ship's heading and pitch attitudes but an active fin ride-control system has not been considered in the NATO SWATH seakeeping predictions. The control-surface design also has limited authority to control ship heave motion. The use of stabilizing control surfaces on the SSP Kaimalino was shown to be very effective in reducing craft motions.

Using the stabilizer to steer the ship and to control heading is a fairly new concept that is being studied extensively at the David Taylor Naval Ship Research and Development Center (DTNSRDC) in Bethesda, Maryland and at the Naval Sea Systems Command in Washington, DC. Model tests at DTNSRDC have shown the viability of the concept to the point where it will be employed on the current 3400 ton U.S. SWATH T-AGOS 19 design.

3.3.14.7 **NFR 90**

The designers of the NFR 90 plan to use a roll reduction system which may consist of active fins or active control of the twin rudders or, possibly, a combination of the two. Final selection will be based on system effectiveness and on the noise level generated by the different arrangements.

3.3.15 Outfit and Furnishings

Outfit and furnishings consist of ship fittings, hull compartmentation, paint and preservation coverings, living spaces, service spaces, and working and stowage spaces. The Point Designs have all specified adherence to standard design practice, implying little deviation, and thus minimal risk, from conventional experience. Although no significant differences were expected, each design does exhibit distinctive features worthy of note. The UK SES design specified the use of standard lightweight nonstructural bulkheads and includes no requirement for painting above the hullborne waterline due to the use of pigmented resin in the GRP fabrication process. The FR SES design also specified the use of conventional lightweight existing technology, as did the US/G SES design. The U.S. Hydrofoil report specifies lightweight aluminum or composite components to be used wherever possible. It also specifies thermal insulation for all living and working spaces. This attention to weight savings has resulted in a lower weight per accommodation for SWBS Group 640, for the SES's and U.S. Hydrofoil than an equivalent monohull, Table 3.3.15-1. Although the FR SES weight per accommodation appears slightly higher than that of the other three SES Point Designs, the FR SES weight per accommodation was developed using the required number of accommodations (104) and not the maximum complement (120). The weight per accommodation for the maximum complement would bring the FR SES fraction into line with the UK and US/G SES designs. The U.S. Hydrofoil weight per accommodation, while marginally higher than the SES Point Designs, is still within range and significantly lower than the weights for a high speed monohull of similar size and mission requirements. It is not clear whether margins are included in the CA Hydrofoil accommodations number; however, the range of this parameter (0.8 to 8.5) is consistent with the other designs. The SWATH weight per accommodation is slightly more than the monohull but is not unreasonable in a vessel with over twice the total displacement.

Table 3.3.15-1. Living Space/Weight Per Accommodation

	UK SES	FR SES	US/G SES	SP SES	FFG-7	U.S. Hydrofoil	CA SWATH	DD 963
$\frac{SWBS\ 640\ WT}{ACCOM}\ \frac{(MT)}{(ACCOM)}$	0.12	0.15	0.13	0.13	0.17	0.15	0.19	0.18
$\frac{ACCOM\ VOL}{ACCOM}\ \frac{(M^3)}{(ACCOM)}$	19.9	25.4	16.2	16.5	14.0	14.9	21.3	16.5
$\frac{SWBS\ 640\ WT}{ACCOM\ VOL}\ \left(\frac{KG}{M^3}\right)$	6.0	5.9	8.0	7.9	12.1	10.1	8.9	10.9

The accommodation volumes per accommodation for the Point Designs are given in Table 3.3.15-1. Once again, although volume per man for the FR SES design appears high, it has been calculated using the required accommodations. The U.S. Hydrofoil has the lowest values, reflecting the very limited volume available and the resulting tight arrangements on the hydrofoil. The SWATH has the next to highest value of accommodation volumes per accommodation, exceeding all but the FR SES.

In terms of accommodation density, as shown in Table 3.3.15-1, the monohull is higher than some of the ANVs. However, the difference in weight per accommodation values is only about 30 percent. This indicates a reliance upon the use of lightweight furnishings in some of the ANVs.

The total SWBS Group 600 weights per accommodation for several Hydrofoils, Monohulls, SES's and SWATH's are shown in Figure 3.3.15-1. This appears to show that the estimated SES weights for Group 600 tend to fall at the low end of the spectrum for monohulls and some other SES designs, but when Hydrofoils are included they are within an expected range for ANV's. This indicates extensive use of lightweight compartments or austere standards with respect to equipment. The CA SWATH also has a value somewhat less than would be expected of a comparable monohull.

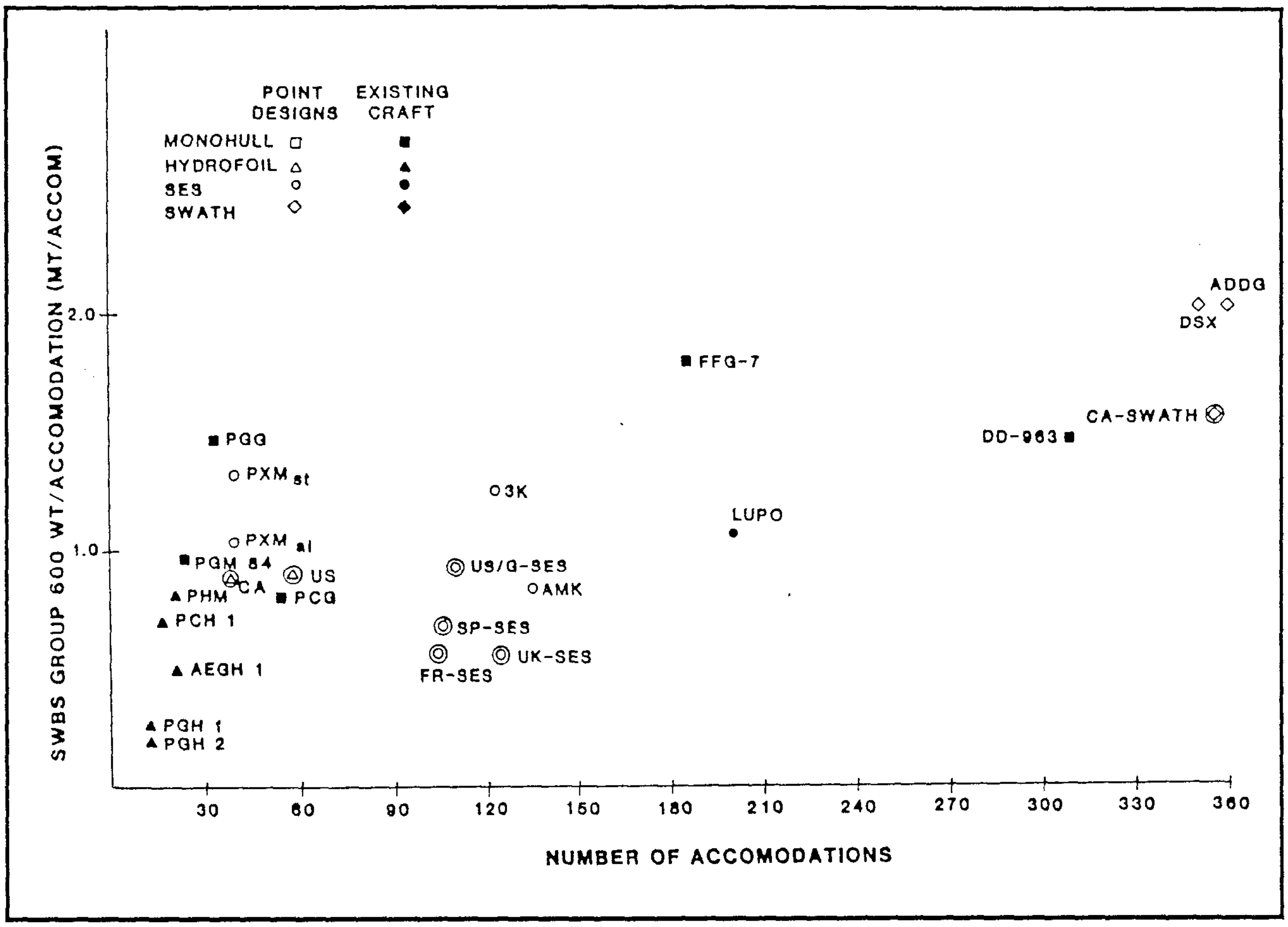


Figure 3.3.15-1. Group 600 Weight Per Accommodation

It is apparent from the level of detail of these Point Designs that the weights for outfit and furnishings were estimated parametrically. Using weight algorithms presumably modified for advanced naval vehicles, these lighter weights, although achievable, may change as the design process continues and weight relationships are better defined.

3.3.16 Combat System

With few exceptions, all of the Point Designs meet the intent of their respective ONST's. Differences between the Point Designs arise because of differing ONST requirements between the platform types, differing design practices and philosophies between participating countries, and differing component availabilities and capabilities in the different countries.

At this stage of design, none of the systems have been integrated together into a functional optimized combat system. Therefore, any assessment at this point is necessarily an analysis of individual components only and it will be assumed that all of them can be made to work together in a coordinated fashion.

The combat systems for the various Point Designs are summarized in Table 3.3.16-1 and discussed in detail in the following sections.

3.3.16.1 **Antiair Warfare (AAW)**

The ONST requirements for SES's state that:

1. Missiles and aircraft are to be detected, acquired, and tracked by active and passive sensors.
2. An accurate local and general air picture is to be maintained.
3. Destruction of targets must be limited to self defense at close range.
4. A gun/short-range missile/counter measures combination should be studied.

All of the SES Point Designs are configured with the systems necessary to perform the missions stated above. The UK SES employs an ASWS 6 air and surface surveillance radar with IFF to actively detect, acquire, identify, and track both local and general targets. The (2) SEA ARCHER optronic trackers can be used to passively or actively track targets and direct the guns. On-mount trackers provide guidance for the surface to air missiles. Passive surveillance is also provided by the CUTLASS ESM System. Destruction of the target will be by the (2) 30 mm guns or by the (50) short range JAVELIN missiles fired from (2) 5 round launchers. General purpose machine guns have also been provided for both air and surface targets. An optional phased array radar system is proposed to replace all of the above radars and trackers. (100) Chaff and IR decoys of the shield system can be deployed along with (4) inflatable (RUBBER DUCK) floating radar decoys.

The FR SES uses a V15 long range air- and surface-search radar to actively detect and acquire targets. The SAAM and SADRAL fire control system (RODEO) also actively detect and track targets. Passive detection is provided by the ARBB 17 or DR 4000 radar detector and the TELEGAN II VHF/UHF interceptor. The radar and optical sensors belonging to the helicopters may also be used for active and passive detection and tracking. Destruction of the airborne targets is accomplished by the (12) Close-In SADRAL missiles in (2) launchers and by the (16) longer range VLS launched SAAM missiles. The SAAM missiles may exceed the requirement for limiting target destruction to close ranges.

Two (2) integrated Goalkeeper 30 mm gun, detection, and tracking systems are proposed as an option and would replace the lighter SADRAL missile systems. Two (2) SAGAIE launchers with both IR and radar decoys operate in conjunction with the (2) ARBB radar jammers to provide both active and passive countermeasures.

The US/G SES has a SEA GIRAFFE air and surface surveillance radar, with a MK XV IFF installed, to provide active detection, acquisition, and tracking of general and local targets and to provide fire control data to the various weapons. An electro-optical sensor is provided for additional active and passive tracking and directing. The SLQ-32 EW system will also provide a passive detection and acquisition capability. Destruction of short-range targets will be by the integrated 30-mm Goalkeeper gun with its detection, acquisition and tracking system, which is combined with (2) triple JAVELIN launchers. Because these are all on the same mount, engagement of multiple targets simultaneously will be difficult. Medium range targets will be prosecuted by the (4) VLS launched SM1 missiles. Again, like the French SAAM missiles, these do not qualify as "Limited Close Range" missiles. The (2) VLS modules on the US/G SES contain a mix of AAW, ASW and ASUW missiles, which can be varied to suit a particular mission. The modified MK 34 Decoy Launch System, along with the SLQ 32, will provide active and passive countermeasures against IR and radar threats.

The primary difference between the SES and Hydrofoil ONST's is elimination of the need to study an integrated gun/short-range missile countermeasures system. Like the US/G SES, the U.S. Hydrofoil also uses the SEA GIRAFFE Search Radar with IFF, and electro-optical sensor to provide active and passive detection, acquisition, tracking, and fire control data. The integrated ESM/ECM system will also provide a passive capability. Even though it is not required, the U.S. Hydrofoil has an integrated 30-mm Goalkeeper gun and radar with (2) triple JAVELIN launchers. For longer range point defense, (21) RAM missiles have been provided. The ESM/ECM System along with the lightweight decoy launch system, will provide an active and passive countermeasure from IR and radar threats.

The combat systems for the CA Hydrofoil are less well-defined than on the other point designs. Based on the information available, it appears that AAW capabilities are centered on an AN/SPS-58 air-search radar, an RCA R-76

Table 3.3.16-1. Combat System Summary

	CA Hydrofoil	UK SES	FR SES	US/G SES	SP SES	Hydrofoil	SWATH
Guns	(1) 30 mm CIWS (Goal-keeper)	(4) General Purpose Machine Guns (2) 30 mm Guns (LS 30 B)	(2) 30 mm CIWS (Goalkeeper) (Optional)	(1) 30 mm CIWS (Goal-keeper)	(1) 76/62 76 mm (Oto Melara) (1) 20 mm CIWS (Meroka)	(1) 30 mm CIWS (Goal-keeper)	(1) 57 mm DP (BOFORS) (2) 30 mm CIWS (Phalanx)
Missiles	(8) Antiship Missiles (Harpoon)	(50) AAW Close In (JAVELIN) W/2 5 Round Launchers or High Velocity Missiles (HVM) (4) Antiship (Harpoon) Canister Launched (16) Antiship Medium Range (Sea Skua) Helo Launched (?) ASW Missile Carried Torpedoes (MCT) Can-ister Launched (Optional)	(12) AAW Close In (SADRAL) W/2 Launchers (Not on CIWS Equipped Options) (16) AASW (SAAM) VLS Launched (4) Antiship (MM40 or ANS) W/Canister Launchers In Bow (4) ASW Missile Launched Torpe-does (NTL 90) W/ Canister Launcher	(50) AAW Close In (JAVELIN) W/2 Triple Launchers (4) AAW Medium Range (SM1) VLS Launched (6) Antiship (Harpoon) VLS Launched (6) ASW Standoff (ASROC) VLS Launched	(65) AAW Close In (JAVELIN) W/3 5 Round Launchers (6) Antiship Missiles (Harpoon) VLS Launched (4) AAW Medium Range (SM-2) VLS Launched (6) ASW Missiles VLS Launched	(18) AAW Close In (JAVELIN) W/2 3-Round Launchers (21) AAW Medium Range Box Launcher (4) ASW (ASROC) VLS Launched (4) Antiship (Harpoon) VLS Launched	(56) AAW Close In (Sea Amraam) VLS Launched (8) Antiship (Harpoon) Canister Launched (4) ASW Standoff (ASROC) VLS Launched *VLS Has a Strike-down Capability
Torpedoes	(12) Lightweight (A LWT) W/2 (MK 32 Mod 9) Triple Tubes	(24) Lightweight (Stingray) Helo and Tube Launched W/4 Tubes In Magazine	(16) Lightweight (NTL 90) Helo Launched	(24) Lightweight (MK 50) Helo and Tube Launched W/2 (MK 32) Triple Tubes	(18) Lightweight (MK 50) Helo and Tube Launched W/2 SLTT Tubes	(6) Lightweight (MK 50) W/2 (MK 32) Triple Tubes	(48) Lightweight (ALWT) W/2 (MK 32) Double Tubes
Sonar	(1) Towed Array (HITAS) (1) VDS (HITOW)	(1) Twin Passive Towed Array (1) Or Single Passive Towed Array (Optional) (1) Or VDS Active/Passive (Optional) (Shorter Range) (1) Flank Array Active/ Passive (1) Or Circular Active/Passive Array (Optional) *Sonar on Helo *Sonobuoys on Ship and Helo	(1) High/Low Freq Active/Passive Depressor Towed Array (ETBF) (1) Dipping Active Sonar *Sonobuoys on Helos	(2) High/Low Freq Active/ Passive Depressor Towed Array (LASS) W/Hull Mounted Active Adjunct (1) Lamps Processor (SQQ 28) *Sonar and Sonobuoys on Helos	(1) VDS (1) Towed Array	(1) VDS (HYTOW) W/ (MK 116) ASW FCS	(1) Conformal Mounted Hull Array (1) VDS (AN/SQS-510) (1) Towed Array (AN/ SQR-19 TACTAS) *Sonar and Sono-buoys on Helos

Table 3.3.16-1. Combat System Summary (Continued)

	CA Hydrofoil	UK SES	FR SES	US/G SES	SP SES	Hydrofoil	SWATH
Radar	(1) Surveillance Air Search (AN/SPS-58) (1) Surface Search (AN/SPS-67) (1) Fire Control (RCA R-76)	(1) Surveillance (ASWS 6) W/IFF (1) Navigation (1007) (2) Optronic Trackers (Sea Archer) (1) Phased Array (Optional)	(1) Surveillance (V15) (1) Navigation (DECCA) (1) FCS (SAAM) (1) FCS (Rodeo)	(1) Surveillance (Sea Giraffe (1) Navigation (SPS-64(V)9) (1) IFF (1) E/O Sensor	(1) Surveillance, Air-Surface Search (1) Fire Control Radar	(1) Surveillance (Sea Giraffe) (1) Navigation (DECCA) 'SS (1) IFF (1) E/O Sensor	(1) Surveillance 2-D (AN/SPS-49) W/IFF (1) 3D Air Defense (GE Fast) W/IFF (1) Guns FCS Radar & Optical (HSA LIROD) (1) E/O Surveillance Sensor (AN/SAR 8)
Counter-Measures	UNKNOWN	(1) ESM System (Cutlass) (100) Radar/IR Decoys (Shield) W/2 Launchers (4) Inflatable Decoys (Rubber Duck)	(1) ESM System (ARBB 17) (1) Torpedo Decoy (Nixie) (2) Decoy Launcher (Sagaie) (1) Anti Torpedo Defense (Slat) (Optional) (2) Jammers (ARBB 33)	(1) EW System (SLQ-32) (2) Decoy Launchers (Modified MK 34 W/4 Tubes Each) (1) Torpedo Decoy (SSTD) (1) Degaussing System	(2) Decoy Launchers (1) Integrated ESM/ECM System	(1) Integrated ECM/ESM System (2) Lightweight Decoy Launch System (1) Torpedo Decoy (SSTD)	(1) Integrated EDM/ESM System (Canews Ranses) W/Passive Chaff & IR Decoys & Decoys & Active Jamming (1) Torpedo Decoy (AN/SLQ 25 Nixie) (1) Degaussing System
Embarked Aircraft	(3) RPH Vehicles	(1) EM 101	(2) 8 to 9 Tonne Helos	(2) Lamps MK III	(1) Lamps MK III	(?) RPV's (Optional)	(4) Med Helos (Sea King or Equiv) (10) VTOL RPV's (Canadair CL 227)

tracking radar, and a single 30-mm Goalkeeper gun. Three RPVs are also available for surveillance, ECM/ESM and a decoy role.

The ONST requirements for the SWATH include:

I. Detection of small air targets at long range (up to 200 nm) with a secure identification feature.

2. Passive measurement of bearing and elevation in ECM environments of all targets to 40 nm. An electrical/optical (E/O) system using TV, IR and lasers for surveillance, tracking, and target designation to 10 nm.

3. Direction of fighter aircraft at ranges of 200 nm.

4. Active multiple acquisition tracking and weapon control to 40 nm.

5. An effective point defense system to defend escorted units within 5 nm.

6. An automated CIWS.

The SWATH uses an AN/SPS 49 2-D Radar with an IFF System for long range surveillance, detection and tracking. It can also be used to direct fighter aircraft and for initial target designation for the Sea AMRAAM Missiles, a proposed development of the Advanced Medium Range Air to Air Missile. The GE Fast 3-D Air Defense Radar, a proposed rotating dual phased-array radar with an IFF System, is also available for surveillance, detection and tracking of air targets as well as primary target designation for the Sea AMRAAM Missiles. The AN/SAR 8 Electro-optical Surveillance Sensor provides passive surveillance, detection and tracking of air targets by TV, IR, and laser in severe ECM environments, and can provide director capabilities for the Sea AMRAAM Missiles. There are 56 Sea AMRAAM Missiles for point defense and medium range air targets. Although space has been made for 56, some can be exchanged for ASROC's if desired. Additionally, the VLS on SWATH has a strikedown capability for underway replenishment. A BOFORS 57 mm Multi-Purpose Gun is also provided, primarily for air targets, and is directed by an HSA LIROD Fire-Control Radar with both radar and optical direction. Two PHALANX CIWS are provided for automatic close-in engagement of air targets. Both active and passive CANEWS/RAMSES are fitted for ECM and ESM, which includes CHAFF, IR decoys, active deception and jamming. The 10 CANADAIR RPV's can also be used for surveillance, ECM/ESM, and in a decoy role.

All of the primary Point Designs are similar in their AAW roles. All provide long range search radar and an ESM system for active and passive general and local detection, acquisition, and tracking. All designs except for the FR SES and perhaps the CA Hydrofoil provide some sort of electro-optical sensor for tracking and directing. The FR SES employs separate fire-control radars for this purpose. A 30 mm gun is specified for each design except for the FR SES where it is optional. The UK and FR SES's, as well as the SWATH have two guns, one port and one starboard for full 360° coverage. The US/G SES and the U.S. and CA Hydrofoils each have one gun located on the fore deck. All of the designs, except the UK SES, and the SWATH, use the Goalkeeper Integrated Automatic-Control System for automatic control of the gun from target detection through target destruction. It is unclear if the UK SES and the CA Hydrofoil have automatic gun control. All of the designs except the CA Hydrofoil mount close in missiles; SADRAL on the FR SES and JAVELIN on the others. In addition, the U.S. Hydrofoil has (21) RAM missiles for further protection. The FR and US/G SES's employ medium range missiles, SAAM's and SM 1's, respectively, to enhance their AAW suite. These seem to go beyond the ONST requirement to limit AAW capabilities to close-range self-defense only. All the ships except perhaps the CA Hydrofoil employ both active and passive IR and radar decoys for countermeasures. The SWATH, because of its large size, differs from the other Point Designs in the extensive radar systems required and the ability to defend other ships as well as itself from air attack. It also employs a more potent gun in addition to its two (2) CIWS. Like the FR and US/G SES it employs medium range missiles.

3.3.16.2 **Antisubmarine Warfare (ASW)**

The ONST requirements for the SES's in ASW are summarized as follows:

1. Active and passive sensors to work at up to 18 knots and be quickly retractable or capable of being towed at high speeds.

2. Consideration of:

   a. Low frequency arrays
   b. Acoustic buoys
   c. Light to medium or heavy helos
   d. Active arrays
   e. Magnetic anomaly detection

3. Consideration of destruction of the target by the following:

   a. Medium range torpedo-carrying missiles
   b. Light helo or ship launched torpedoes
   c. Quick reaction shipboard ASW weapons
   d. Smart depth charges

4. (1) or (2) ASW helicopters

5. Employ torpedo warning and countermeasures

The UK SES was designed to carry a twin, passive towed-array sonar system and an active, hull-flank sonar array, the combined weight of which is the same as that installed on the FFG-7. Passive detection on the UK SES is provided by twin 500 m low frequency towed arrays. They will operate up to 20 knots and are capable of being towed at full speed, although it is intended that they be recovered before going into sprint mode. The twin configuration gives unambiguous target direction and also reduces recovery time. Hull mounted flank arrays containing both active and passive elements are provided to obtain a fire control solution once the target is located. They can also operate at all displacement speeds up to 20 knots. These sonars are augmented by the dipping sonar on the helicopter and by the ship and helicopter deployed sonobuoys. Prosecution of the target will be by lightweight Stingray torpedoes, which can be either helo launched or ship launched from the magazine. Canister launched missile carried torpedoes were considered as options as were several sonar variations. One (1) EH 101 ASW helicopter is provided. No dedicated torpedo decoy system has been provided; however, active elements in the towed array can be used for decoy purposes.

The FR SES meets the ONST requirements with a 300 m very low frequency linear towed array. It is designed to function up to 18 knots, and will be recovered before going into sprint mode. An emitter, located in the depressor, provides an active capability. A dipping sonar provides listening and localization during drift periods. The operation of the vessel and dipping sonar would be expected to be analogous to that of a helicopter with a dipping sonar. The two (2) embarked 8 to 9 tonne medium weight ASW helicopters are equipped with a sonar, sonobuoys, and MAD. Each helicopter can carry (4) NTL 90 torpedoes. The ship is also equipped with (4) box-launched missile carried torpedoes. A Nixie electro-acoustic decoy is employed along with SLAT, a system still under development consisting of a passive linear array and a decoy launcher of the SAGAIE system.

The US/G SES deploys a high/low frequency, active/passive depressor towed array with a hull mounted active adjunct. A spare array is carried for redundancy. The array can be quickly recovered or towed (in a non-active mode) at high speeds. Two (2) Lamps MK III helicopters are provided which carry a full array of sensors and lightweight MK 50 torpedoes. The torpedoes can also be launched from the MK 32 tubes on the ship. Six (6) ASW standoff VLS launched ASROC missiles are also embarked; however, like the VLS's on the US/G SES, the VLS on the Hydrofoil can supplement or reduce its ASW loadout to allow for different levels of ASU loadout, depending upon the mission requirements. The developmental surface ship torpedo decoy (SSTD), which is an automatic system that senses a torpedo and fires a decoy, has been installed to counter the torpedo threat.

The ONST for the Hydrofoil is similar to that of the SES's, except that the ship is only required to control and not support a helicopter and the sonar system can be anything which can detect, localize and track a submarine in deep or shallow water.

HYTOW, a Hydrofoil VDS currently under development and capable of being towed and recovered at high speed, was specified to meet the sonar requirement on both hydrofoil designs. HYTOW information is used primarily to estimate space and weight impacts and no performance figures were given in the report. The CA Hydrofoil uses a HITAS towed array system. Six (6) advanced lightweight MK 50 torpedoes carried in tubes and four (4) ASROC missiles in the VLS are carried to attack targets on the U.S. Hydrofoil. Twelve (12) ALWT torpedoes are specified for the CA Hydrofoil design. SSTD on the U.S. Hydrofoil is installed to decoy enemy torpedoes. Optional, as yet to be defined, RPV's were suggested for the U.S. Hydrofoil; however, it is not known what role, if any, they might play in ASW.

To detect, classify, localize and track submarine targets the ONST for the SWATH requires the following:

1. Use of a combination of a hull mounted sonar, deep VDS, recoverable or expendable arrays, aircraft, and sonobouys. The vessel should be able to coordinate ASW activities of consorts, embarked aircraft, and their sub-surveillance systems within a radius of 150 nm. Ideally, the above systems should provide a capability to detect, track and destroy targets to the third convergence zone, concurrent with the SWATH going at least 20 knots in both deep or shallow water.

2. Engagement of at least 18 targets will be by ASW standoff weapons and HELO launched torpedoes, without replenishment.

3. Conduct airborne ASW operations by supporting the storage, first-line maintenance, and operation of at least (4) medium weight helicopters and RPV's.

4. Employment of some form of torpedo warning system and torpedo countermeasures system.

5. An all weather stand-off ASW weapon capable of ranges to 15,000 miles and sharing a common launching and magazine system with the surface-to-air missiles.

While no performance figures are available, the SWATH has a conformal bow mounted sonar, an AN/SQS 510 VDS with a 600 M cable for use in the first convergence zone, and an AN/SQR 19 towed array sonar with a 250 M tail on an 1800 M cable for longer range detection. Four Sea King Helicopters are employed for long range localization and prosecution. Sonobuoys deployed by the helicopters can relay submarine contact information via launched RPV's or the helicopters. Forty-eight Advanced Lightweight Torpedoes can be launched from either of the 2 MK 32 MOD 9 Twin Torpedo tubes or from the Sea King Helicopters. Four ASROC Torpedoes are carried in one of the 8 cell MK 41 VLS. They can be exchanged with the Sea AMRAAM Missile on a 1 to 4 basis if desired, as (4) AMRAAM Missiles can be loaded in a single cell. The AN/SLQ 25 NIXIE Torpedo Decoy is also used to provide an active counter-measures capability.

While all the Point Designs have equipment systems that are capable of satisfying the mission requirements of their respective ONST's, differences exist between them. In general, both Hydrofoils are less capable than any of the SES's due to their severe weight sensitivity. Not enough information is given to evaluate performance differences between systems in most cases; however, some conclusions can be drawn:

1. The Hydrofoil VDS will not be as effective as the much more extensive Sonar installations on the SES's and SWATH. In this regard, the system on the UK SES is as extensive as that on the FFG-7, while the SWATH, because of its large size, carries a system which is nearly three times heavier than that on the FFG-7.

2. All ships carry lightweight torpedoes, but the FR SES has 16 as opposed to 24 on the UK and US/G SES and they can only be helo launched (unlike the other Point Designs). The U.S. and CA Hydrofoils will be even less flexible with 6 and 12 torpedoes, respectively, that can only be ship launched. The SWATH with 48 will be able to engage many more targets than the other Point Designs.

3. All ships have missile carried torpedoes except the UK SES and the CA Hydrofoil which can carry them as an option. They will add an important dimension of flexibility, especially to the UK SES which has only one helo and to the Hydrofoil which has no helo capability.

4. All the torpedo decoy systems are comparable, except for the UK SES and the CA Hydrofoil which do not have dedicated systems but must rely on elements contained on the towed arrays.

5. The helicopters will greatly extend the range and shorten the times for detection, localization, and attack of underwater targets. The UK SES may be at some disadvantage with only one; however, this is offset by the increased capability of a medium helicopter compared to the light helicopters carried on the other SES's. The Hydrofoils suffer the greatest disadvantage in this area due to the lack of helo capability. The SWATH with 4 medium helos will be able to patrol a much larger area than any of the other ANV Point Designs.

3.3.16.3 Antisurface Warfare (ASUW)

The ONST in the area of ASUW for both the SES's and the Hydrofoil requires:

1. Over The Horizon (OTH) detection and tracking by third parties and ownship vehicles.
2. OTH destruction capability with anti-ship missiles.
3. Ability to deploy countermeasures against anti-ship missiles.

In general, the same systems used for AAW detection and tracking will be used for ASUW within the visible and radar horizons. Also, countermeasures effective against air launched missiles will be effective against ship launched missiles. Sonars, which are primarily used for ASW, have some capability to detect surface ships. The guns used for airborne targets can be employed as well for surface targets.

To meet the ONST, the following systems were specified. The UK SES uses its EH 101 helo for OTH detection and tracking. Four (4) anti-ship canister launched HARPOON missiles are provided for target destruction. In addition, (16) SEA SKUA air-to-surface missiles can be fired from the helicopter. The FR SES uses detection and tracking information from its (2) helicopters and carries (4) MM40 or ANS anti-ship missiles with OTH capabilities. The US/G SES uses OTH tracking and detection information from its (2) LAMPS MK III helicopters and can fire (6) VLS launched HARPOON anti-ship missiles. The U.S. Hydrofoil carries (4) VLS launched HARPOON anti-ship missiles, which can be targeted by on board systems or optional RPV's. Eight (8) HARPOON missiles, are carried by the CA Hydrofoil in armored box launchers.

The ONST for the SWATH is similar to that of the other Point Designs except that it specifies 8 anti-ship missiles and a gun capable of disabling a surface target.

The CA SWATH employs its helos and RPVs for over the horizon surveillance and can fire 8 Harpoon Anti-ship Missiles. The BOFORS 57 mm Gun, targeted by the HSW LIROD Radar, can be used against surface targets as well as airborne ones.

All of the ships will be able to use detection and tracking information from third parties. The helicopters on the SES's are undoubtedly more effective than the RPV's on the Hydrofoil; Having two helicopters on the FR and US/G SES will improve their detection capabilities over those of the UK SES although the EH101 helo, to be used on the UK SES, is significantly more capable than each of the helos used on the other SES. Air to surface missiles on the UK SES's helicopter will provide a quicker response to the identified threat. It is also possible to replace four of the lightweight torpedoes on the FR SES with four air to surface AA39 missiles that can be carried by one of the two helicopters. The US/G SES has two more anti-ship missiles than any of the other SES designs. The SWATH, because of its much larger size, has more helicopters, RPV's and (with the exception of the UK SES) anti-ship missiles than any of the other ANV's and hence should have a stronger capability in the ASUW area than the other ANV's.

3.3.16.4 Other Warfare Areas

Strike and amphibious warfare capabilities were not required and not addressed in the reports. Mine warfare was an optional requirement and was also not addressed.

3.3.16.5 Summary

The following observations can be made with respect to ANV combat systems as specified in the Point Designs:

- A wide range of weapons and sonar types can be accommodated.

- Total weapons load-out of Hydrofoils and, in some cases SES's, are limited because of their small size.

- Helicopter capabilities can be quite extensive on SES and SWATH designs because of topside space availability.

- There is a need for development of an optimized sonar system and operational doctrine for high speed operation, and twin hull platforms.

- Improved motions characteristics on all the ANVs, particularly on the very large SWATH, can enhance combat-system performance.

3.3.17 Ship Interfaces

The functional and physical interfaces of SES, SWATH and Hydrofoil platforms, as represented by the point designs, with other NATO ships, craft, shore commands, and aircraft exhibit a perceptible advantage over normal monohulls in HIFR, UNREP and RAS due to improved seakeeping and ship motions. This advantage is coupled with the SES, SWATH and Hydrofoil platforms' ability to accept conventional ship interface equipment. The following interfaces were investigated with respect to ANV platform impacts on operational effectiveness and were found to require no new technology developments.

- Vertical underway replenishment with the capability for rapid strike down.
- Underway replenishment of fuel and stores.
- Fuel and lubricant replenishment of aircraft.
- In flight refueling of helicopters (not investigated for the Hydrofoil)
- Towed/towing operations
- Reception of shore "hotel" services including power and water.

While the issue of drydock width requirements may constrain the repair of SES's at non-major dockyards, the hullform should require no new blocking technology. The US/G SES and UK Point Designs have keel flats which greatly facilitate drydock blocking arrangements. The FR SES keels have been specifically designed for drydocking loads; however, the edge geometry of the keels may necessitate use of unique notched blocking. The U.S. Hydrofoil has a 0.3 m keel flat as well as longitudinal and keel girders for docking. Its small size and monohull like configuration should enable it to be docked in any moderately sized dockyard. Docking and coastal navigation of the CA Hydrofoil will be more restricted because of the inability to retract foils. Other interface parameters of the CA Hydrofoil are unknown. The large dimensions of the CA SWATH will restrict drydocking in small facilities. Additionally, the relatively large sail area may hinder mooring operations during high winds, as compared to the other ANV concepts or a monohull.

Table 3.3.17-1 provides a summary of ship interfaces described in the Point Design reports.

Table 3.3.17-1. Ship Interfaces

UK SES	FR SES	US/G SES	U.S. Hydrofoil	SWATH
• VERTREP • RAS • Mooring • Anchoring • HIFR • Shore Services	• VERTREP • RAS • Mooring • Anchoring (80 m, 55 kt Wind, 3 kt Current) • HIFR • Drydocking-Reinforced Keels	• VERTREP • RAS • Mooring • Anchoring • HIFR • Shore Services	• VERTREP • RAS • Mooring • Anchoring • Shore Services • Towing	• VERTREP • RAS • Mooring • Anchoring • HIFR • Shore Services • Towing • Missile Strikedown

3.3.18 Weights

The analysis of weights, weight fractions and parametric ratios provides an overview of each subsystem area in the attempt to identify gross deviations from platform trends and conventional practice. The assessment of subsystem weights and parametric weight fractions involves a comparison of the weights estimated for a given ship to known weights or weights estimated for other ships. Due to the weight prediction methods and, in many cases, lack of traceability of subsystem component weights, detailed analyses of anomalies between the point designs are restricted. The basic parametric weight data is presented in an attempt to develop some general trends for ANV designs. However, the scarcity of additional parametric data and the variation in design practices that could be used in arriving at optimum designs dictates the need for caution in the interpretation of these analyses.

3.3.18.1 Methods of Weight Prediction

The ANV Point Designs employ various methods of weight prediction and estimation including actual weights of primary subsystems, as well as estimations and extrapolations based on previous experience.

The weight estimate developed for the UK SES was primarily based on the corporate experience of Vosper Hovermarine LTD. The actual weights of equipment were based on manufacturer's data. The FR SES weights were developed analytically for load items, propulsion, weapons and lift subsystems. Other subsystems were developed using parametric comparisons to weights of conventional ships. The structural weight estimate was made from the initial development of scantlings. The weight estimate was developed according to STCN standard methods, with advanced vehicle impacts added to each subsystem. These appear to be separate from the margins specified in the Study Guidance Document. It should be noted that for comparison purposes the margin of 12.5% has been removed from each weight group and added as a separate line item for the FR SES.

The US/G SES weights were primarily developed using the SESDOC computer aided design tool. This program estimates weights using algorithms based on ship characteristics such as SHP and volume. Weights were calculated for the structure, propulsion and power generation subsystems based on identified characteristics of these subsystems.

The U.S. and CA Hydrofoil weights were estimated using the Hydrofoil Analysis and Design Program (HANDE) developed for use in the feasibility and early preliminary design of hydrofoils. As in SESDOC, the weights were estimated using weight algorithms. Weights for the Canadian SWATH design were both calculated and estimated using weight algorithms based on previous ship designs. The method used for each group was dependent on the degree of information developed in the various applicable subsystem designs.

3.3.18.2 <u>Weight Analysis</u>

The following is an analysis of the weights, by major SWBS group of the ANV designs. Each weight group is investigated in an attempt to isolate significant weight differences between ANV practice and conventional ship practice and identify anomalies among the designs. A summary weight breakdown with weight fractions is presented in Table 3.3.18-1.

Table 3.3.18-1. Weight Summary (MT)

		UK SES		FR SES		US/G SES		SP SES		FFG-7		DD 963		U.S. Hydrofoil		CA Hydrofoil		SWATH	
	SWBS Group	WT	%*	WT	%	WT	%	WT	%	WT	%	WT	%	WT	%	WT	%	WT	%
100	Structure	368	39.7	339	42.5	740	55.0	675	57.2	1462	47.0	3124	52.6	152	29.5	84	29.7	3984	60.6
200	Propulsion	301	32.4	176	22.1	242	18.0	217	18.4	297	9.6	774	13.0	69	13.3	38	13.4	610	9.3
300	Electric Plant	48	5.1	50	6.2	50	3.7	52	4.4	218	7.0	289	4.9	35	6.9	14	5.0	325	4.9
400	Communications/Control	48	5.1	56	7.0	68	5.0	46	3.9	145	4.7	361	6.1	25	4.9	28	9.9	203	3.1
500	Auxiliary Systems	80	8.7	83	11.9	118	8.8	83	7.0	544	17.5	748	12.6	158	30.6	73	25.8	813	12.4
600	Outfit/Furnishings	69	7.5	62	7.7	102	7.6	72	6.1	342	11.0	486	8.2	54	10.4	36	12.7	559	8.5
700	Armament	11	1.2	33	4.0	26	2.0	35	3.0	101	3.2	156	2.6	22	4.3	10	3.5	76	1.2
	Margin*	116	12.5	101	12.5	168	12.5	148	12.5	103	2.5	85		65	12.5	28	9.9†	1523	23.2‡
	Light Ship	1041		911		1513		1328		3212		6023		572		311		8093	
	Loads**	560	34.9	488	34.9	423	21.8	414	23.8	855	21.0	2007	25.0	197	25.3	147	32.1	1455	15.2
	Full Load	1601		1399		1934		1742		4067		8030		779		458		9548	

* % of LS W/O Margins
** % is Expressed as Part of FL
† CA Hydrofoil designed to 9.9% margin rather than the required 12.5% margin
‡ 12.5% designed build margin + 10% service life applied to full load which must be carried by SWATH at beginning of service life

Figure 3.3.18-1, a comparison of total ship densities (lightship displacement divided by total enclosed volume), shows that the FR and UK SES Point Designs obviously fall well below conventional monohull densities and also appear low with respect to other high performance ships. A portion of this difference is a result of different hull materials and structural design approaches, but it is also indicative of the use of weight saving initiatives in many other areas. Also in the case of the UK and FR SES designs, larger enclosed volumes result from a shorter and wider hullform, while the US/G SES design is more slender, contributing to a higher structural density assuming equivalent materials and design methods. The U.S. Hydrofoil's density is consistent with the trend for US practice in ANV design, although slightly lower than the PHM class hydrofoils. This difference does not appear to be alarmingly significant considering the range of densities covered by existing Hydrofoils. The CA Hydrofoil density is slightly lower, possibly due to the reported weight advantages gained by doing away with foil retraction systems and foil location. The SWATH density is greater than for both monohull and other SWATH values, although the design itself appears consistent with typical SWATH practice.

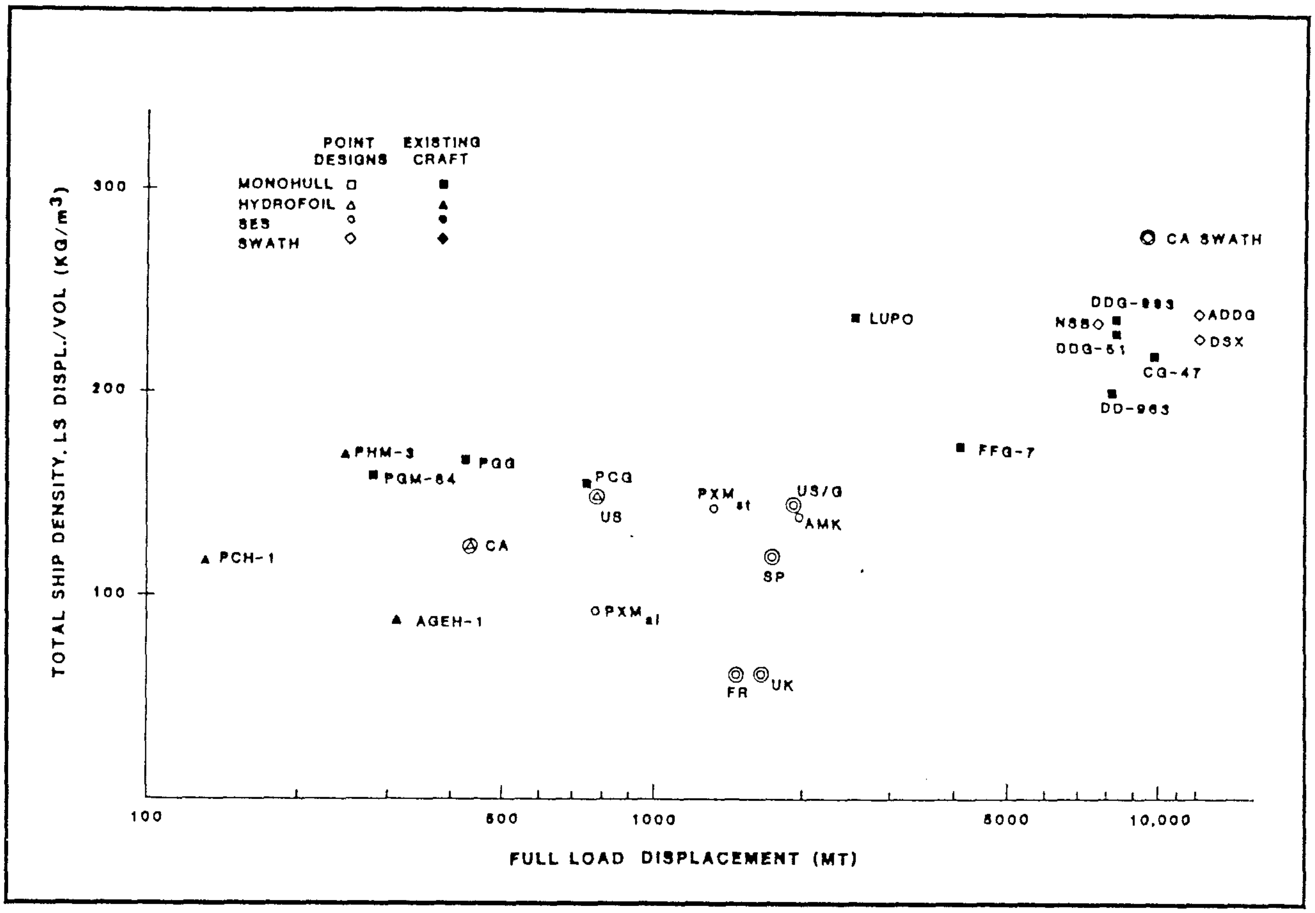


Figure 3.3.18-1. Total Ship Density

Group 100-Structural Weights

The structural weights for the NATO ANV Point Designs and several monohulls are summarized in Table 3.3.18-2 at the two digit SWBS level. In general, the point designs fall within or below the expected bounds of previous designs as shown in Figures 3.3.18-2 and 3.3.18-3. The major deviations are the UK, FR and US/G SES's light structural densities which result from their excess volume and hull materials as compared to conventional monohulls.

For group 110, the weight fractions for the UK and FR SES's are very close at 56% and 55% respectively. The US/G SES fraction is much smaller, but this can be explained by the US/G SES practice of including the wet deck weight in group 130 instead of 110. When the US/G SES wet deck is added to the 110 weight the weight fraction becomes 55%. It would be expected that the SES weight fraction for group 110 would be higher than that of the FFG-7 due to the greater surface area required to enclose a given volume and to the inclusion of the seals in this group. The hydrofoil weight fractions are close to the FFG-7 due to its monohull type configuration. The SWATH structural weight fraction falls between the SES Point Designs and the Hydrofoil and FFG-7 values. Compared to the monohulls this is a result of a greater shell surface area and different loading mechanisms.

The bulkhead weight fractions, group 120, of all the ships are similar. The SES's have fewer transverse bulkheads than the FFG-7 but they also have extensive longitudinal bulkheads. The U.S. Hydrofoil has fewer bulkheads than the FFG-7 and thus a lower weight fraction. The SWATH bulkhead fraction is essentially the same as the FFG-7. Major differences in this value between monohulls and SWATH's should not be expected although the SWATH number could be higher depending upon subdivision and ship principal dimensions.

Table 3.3.18-2. Structural Weight Comparison (MT)

		UK SES		FR SES		US/G SES		SP SES		FFG-7		DD 963		U.S. Hydrofoil		CA Hydrofoil		SWATH	
SWBS	Item	WT	%*	WT	%**	WT	%	WT	%	WT	%	WT	%	WT	%	WT	%	WT	%
110	Shell	205.9	56.0	188.3	55.6	275.1	37.2	279.3	41.4	460.7	31.5	1080.9	34.6	56.6	37.0	33.4	40.0	1611	40.4
120	Bulkhead	34.0	9.2	34.3	10.1	61.5	8.3	90.9	13.5	182.5	12.5	372.3	11.9	8.6	5.6	3.4	4.1	484	12.1
130	Deck	64.0	17.4	52.3	15.4	304.5	41.2	198.1	29.4	290.7	19.9	504.2	16.1	36.2	23.7	18.3	21.9	764	19.2
140	Platform	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	66.3	4.5	281.9	9.0	0.0	0.0	0.0	0.0	73	1.8
150	Deckhouse	33.0	9.0	48.0	14.2	31.7	4.3	43.5	6.5	113.8	7.8	197.9	6.3	7.8	5.1	8.2	9.8	266	6.7
160	Special Struc.	13.0	3.5	2.7	0.8	18.0	2.5	0.0	0.0	72.8	5.0	259.3	8.3	9.2	6.1	5.2	6.2	31	0.8
170	Masts	2.0	0.5	4.4	1.3	8.5	1.1	1.3	0.2	7.4	0.5	26.8	1.0	1.3	0.9	0.8	1.0	66	0.2
180	Foundations	11.0	3.0	8.9	2.6	26.2	3.5	32.4	4.8	180.7	12.4	301.5	9.6	27.8	18.2	11.3	13.4	443	11.1
190	Special Purp.	5.1	1.4	0.0	0.0	14.2	1.9	28.5	4.2	87.5	6.0	98.9	3.2	5.2	3.4	3.0	3.6	306	7.7
100	TOTAL	368		338.9		739.7		674.3		1462.4		3123.7		152.7		83.6		3984	

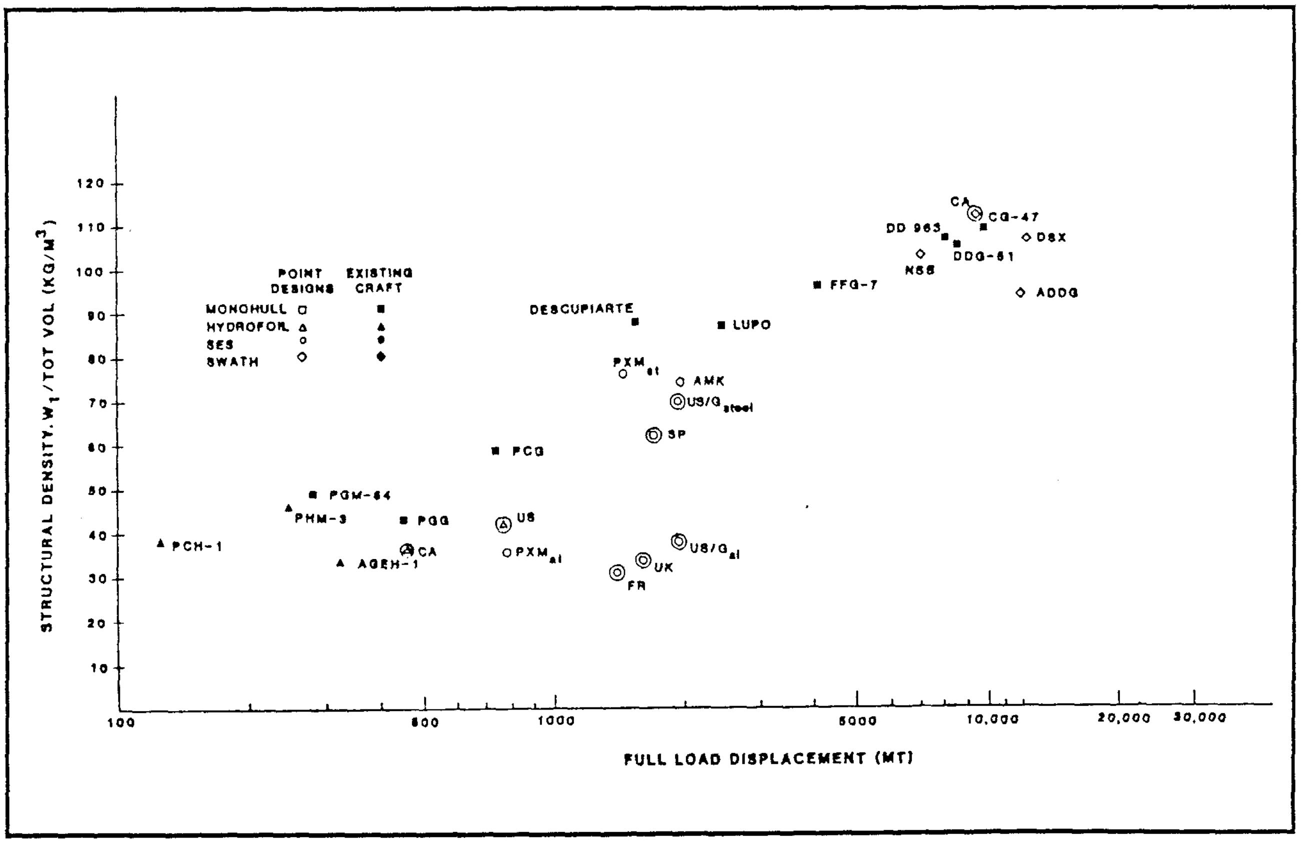


Figure 3.3.18-2. Structural Density

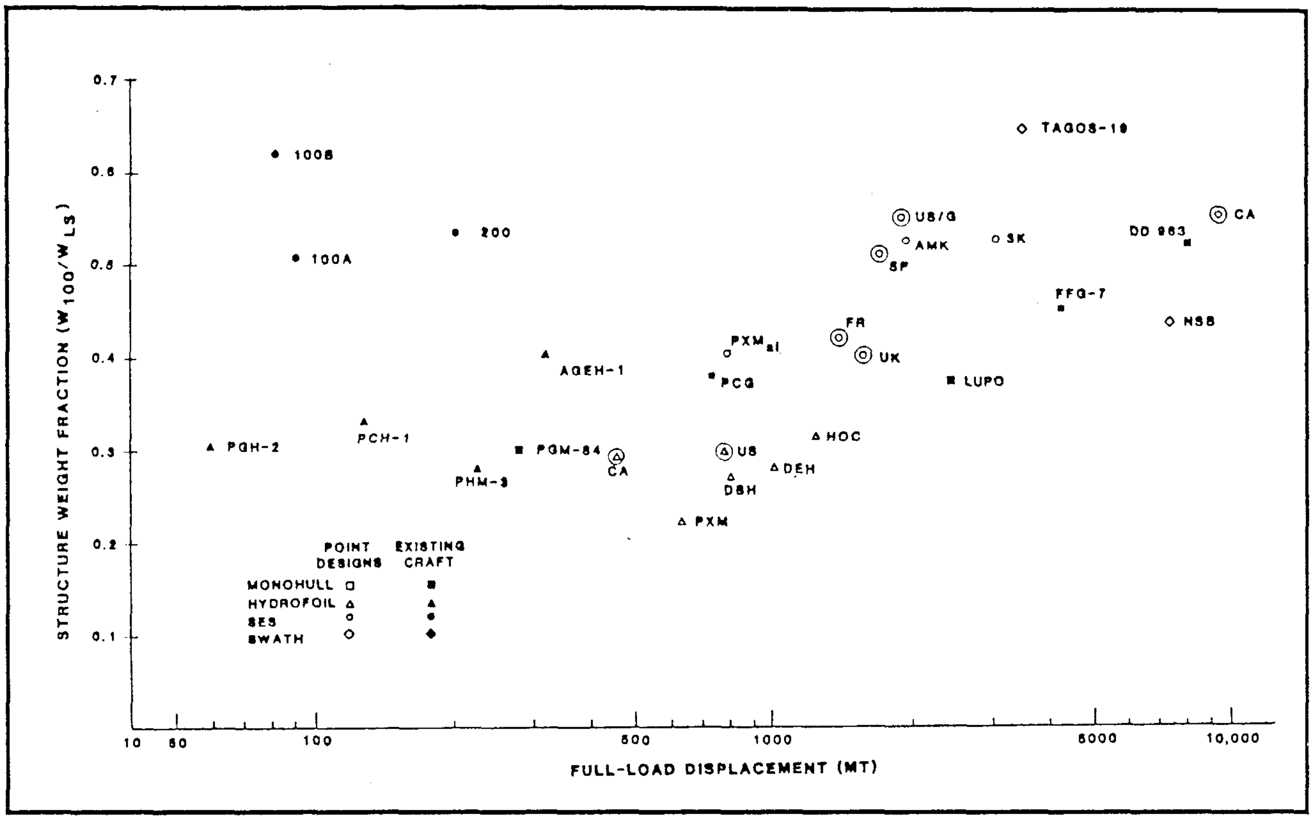


Figure 3.3.18-3. Structure Weight Fraction

None of the SES or Hydrofoil Point Designs differentiate between hull decks and platforms. All group 130 and 140 weights were condensed to group 130. Initially the US/G SES weight fraction looks very high; however, when the weight of the wet deck is subtracted from group 130 and added to the shell structure the resulting group 130 weight fraction is more consistent with the other ships. Even with this adjustment the UK and FR SES's would still have smaller weight fractions than the US/G SES, probably due in part to the additional sidehull platform in the US/G SES. Another contribution to the smaller fraction is the use of lighter deck scantlings on the FR SES. The SWATH design does differentiate between hull decks and hull platforms. It can only be assumed that the hull platforms are located in the lower hulls of the SWATH design. The group 130 weight fraction of the SWATH is in line with the rest of the point designs, but tends towards the FFG-7 fraction, indicating scantlings of conventional size. The hull platform (Group 140) fraction of the SWATH design is lower than the FFG-7 fraction. This is a result of the platform being located only in way of ballast tankage within the lower hull.

Group 150, superstructure, shows a wide variation, which is due to the large size differences in superstructures among the point designs. Also the FR SES, the Hydrofoils, and FFG-7 have aluminum deckhouses while the US/G SES superstructure is steel and the UK SES superstructure is fiberglass. An examination of group 150 weight per superstructure volume for the point designs shows that the UK SES and the U.S. Hydrofoil are very close at 9.6 kg/m^3 with the CA Hydrofoil also close at 12.2 kg/m^3, the US/G SES and FFG-7 are close at 27.1 and 25.6 kg/m^3, respectively and the FR SES and DD 963 fall in between these extremes at about 20.7 kg/m^3 and 22.3 kg/m^3. The SWATH superstructure density is 42.9 kg/m^3, which is greater than all of the other ANV designs. The FR SES superstructure weight per volume is expected to be similar to the Hydrofoil.

One would expect the UK SES, FR SES, US Hydrofoil, and CA Hydrofoil to be within the some range taking into account general similarities in size, complexity and material properties. The FFG-7 superstructure, although constructed of aluminum, is larger, more complex and supports additional equipment; therefore, it could be expected to be relatively heavier, although the factor of three difference is surprising. Part of this disparity could perhaps be explained by the equipment contained within and supported by the deckhouse. The FR SES density, given the European use of lighter scantlings and its relative simplicity, is less than that of FFG-7 and DD 963 which is not unexpected. The US SES with it's simple steel superstructure, much of which is comprised of the hangar, may not be that out of line with the FFG-7 or DD 963 from a density viewpoint even considering the material differences. The SWATH is approximately twice as dense as the DD 963, which would be expected with a steel versus aluminum comparison, although the large relative hangar volume on the SWATH should tend to reduce this effect.

In conclusion the UK SES, US Hydrofoil and CA Hydrofoil and US SES densities are low compared to the conventional practice embodied by the FFG-7 and DD 963. Non-conventional structural design practices which may be more appropriate to ANV's may justify much of this difference.

Special structures, group 160, shows some variation but few details are available. Reasons for these variations cannot be deduced with the available data.

All of the point designs have similar masts which support similar equipment. The weights for group 170 are all similar as expected except for the US/G SES. This appears to be an anomaly as the equipment supported by the mast on the US/G SES and the U.S. Hydrofoil is identical. Additionally, the US/G SES Group 170 weight is also greater than the FFG-7's, which has two masts and much heavier equipment.

Group 180, foundations, also shows some disparities. When the foundation weight ratios (group 180 divided by the total of groups 300, 400, 500 and 700, the groups which require the majority of the foundations) are compared, the UK and FR SES at 0.059 and 0.038 respectively, are lighter than the US/G SES (0.1) which is undoubtedly a result of the extensive use of GRP and aluminum in their foundations. All of the SES's are lighter than the FFG-7 (0.179) and DD 963 (0.194). While the SES's will experience some shock attenuation from the cushion, the weights still appear light compared to conventional practice. In the case of the U.S. Hydrofoil some shock attenuation will also be experienced from the foils but it must be designed to the limiting hullborne case. Its foundation weight ratio (0.116) and that of the CA Hydrofoil (0.09) are also less than the FFG-7 but may be within the correct range. It is interesting to note that the group 180 fraction for both Hydrofoils is larger than for any of the SES's. A more detailed analysis will be required to resolve these differences; however, one explanation may be the algorithm used to estimate weights in the Hydrofoil Synthesis Model. The SWATH foundation weight is the largest of all the point designs compared. Its fraction of group 100 is in keeping with the FFG-7 and the Hydrofoil, but when calculating the foundation weight fraction as described above, the value (0.313) is quite a bit higher than all the other designs. US Navy SWATH foundation weight estimating algorithms are based on groups 200, 300, 400, 500 and 700 weights. It is unclear if the CA SWATH design used a different algorithm.

Group 200 - Propulsion System Weights

Table 3.3.18-1 lists the Group 200 weight totals as a percentage of lightship displacement without margin. This comparison reflects the general trend for surface combatants; for a given speed, as ship displacement increases, the propulsion plant weight fraction decreases. The variation among the SES Point Designs lies primarily between the UK SES (32.4%) and the relatively similar US/G SES and FR SES (18% and 22.1% respectively). This difference is the result of a propulsion unit weight more than 100 LT greater. This additional weight appears justifiable, since the UK SES uses Rolls Royce IC Spey SM1C gas turbines that are designed to withstand higher shock loading and have integrated support systems including intercoolers within the heavy subbase frames. Also the UK SES design appears to use relatively larger conventional reduction gears. The acoustic enclosures used in the UK SES add an additional 10 LT each over the unenclosed GE LM-2500 power plants. The small variation between the US/G SES and FR SES propulsion weight fractions is chiefly a result of the stated transmission system weights for the two designs. The complexity and developmental requirements of the weight reduction efforts of using aluminum gear casings in the US/G SES and the epicyclic reduction gear in the FR SES design may make the low weight estimates optimistic. The U.S. and CA Hydrofoil group 200 weight fractions closely follows the existing PHM class hydrofoil data. The propulsion unit weights (SWBS Group 230) reflect the general trends and standard hydrofoil practice.

The weight differences found to exist between the three SES designs in the area of propulsion support (Group 250) are presumably due to the inclusion of propulsion support weight within other propulsion SWBS groups. The weights for fuel and lube oil systems are in close agreement between the UK and FR SES design; however, the US/G SES weights are more than double. The reason for this anomaly is not apparent from the material presented in the design reports. The weights for special purpose systems (Group 290) are substantially larger on the FR and UK SES's due to the weight of the water in the waterjets.

The propulsion system weight per shaft horsepower for the US/G and UK SES designs appear to follow the trend for SES's and other high performance monohulls with similar propulsion plants and are heavier than most hydrofoil concepts, as shown in Figure 3.3.18-4 which would normally be expected because of the inclusion of lift fans on the SES's. The FR SES weight/SHP is noticeably lower chiefly because of the higher gas turbine rating applied to the LM-2500's. Note that the US 3K SES, an all gas turbine design, defines a lower boundary for SES practice.

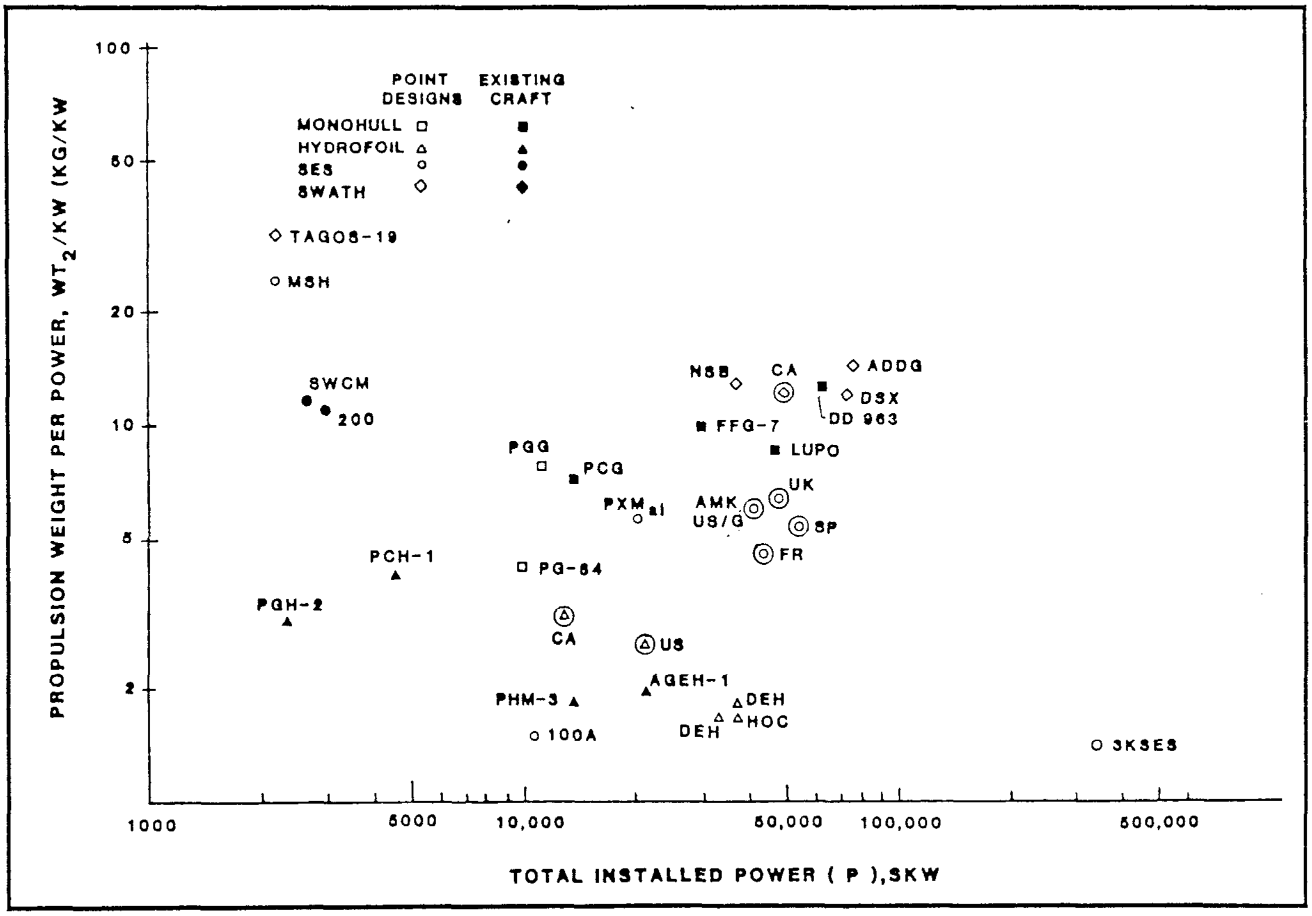


Figure 3.3.18-4. Propulsion System Weight Per Installed Horsepower

The propulsion system densities for the U.S. and CA Hydrofoils are comparable to the densities of the PHM, PCH and PGH Hydrofoils, indicating conformance to hydrofoil trends.

The Canadian SWATH Design was evaluated against four other SWATH designs as well as the other Point Designs. As shown in Table 3.3.18-1, the SWATH's group 200 weight percentage is much lower than the SES Point Designs, because of a much lower speed requirement and the use of heavier conventional design practices in other system areas, but it is in line with the four other SWATH designs, all of which are around 10% as well as the DD 963.

The propulsion system weight per shaft horsepower for the SWATH design is higher than the SES Point Designs, but is in keeping with the more conventional nature of current SWATH and monohull design practices as indicated by the four other SWATHs and DD 963 shown on Figure 3.3.18-4. The specific weight is comparable to the FFG-7 and other SWATHs but might be expected to be higher because of the use of an electric drive transmission and the use of an intercooled/regenerative gas turbine scheme in the SWATH design.

Group 300 - Electric Plant Weights

Figure 3.3.18-5 presents the group 300 weights per installed KW for the Point Designs. While the point design values are generally lower than for the frigate-sized ship (FFG-7) they are relatively consistent with other ANV and high-performance monohulls. The US/G SES design tends toward the low end of the band while the UK SES design is somewhat high. The CA Hydrofoil has the smallest power density; however, no back-up information is available to determine why the value is so much lower than the others. These differences are obviously driven by design practices or technology differences in the power generation and distribution systems and methods of accounting for installation of components. The CA SWATH falls within the range of these combatants (SWATH and monohull).

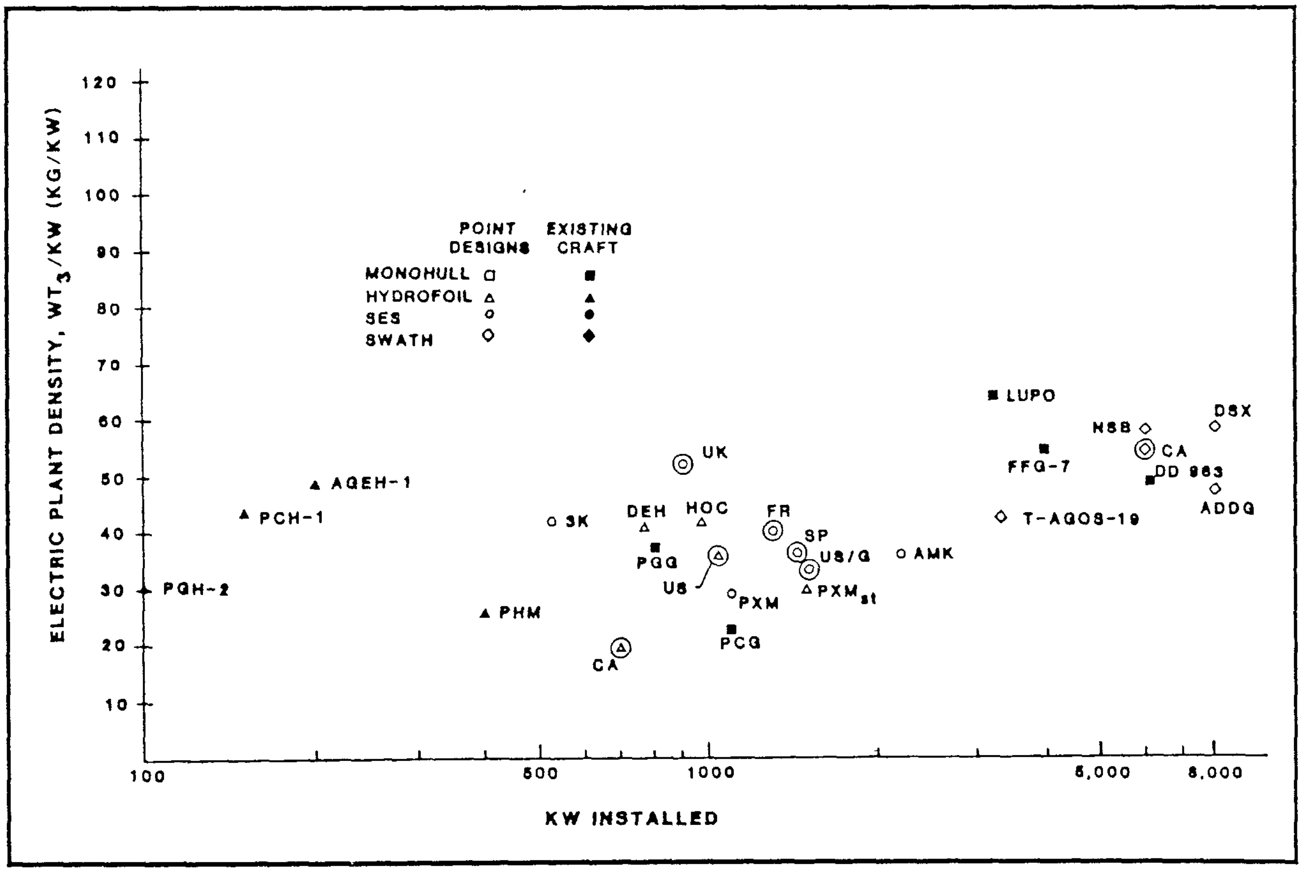


Figure 3.3.18-5. Electric Plant Weight Per KW

Theoretically, ANV power generation system weight should be comparable to a monohull of similar size unless changes in technology are introduced. Since the electrical generation system design parameters are primarily independent of platform type, the weights per installed KW in Table 3.3.18-3 show a larger spread than would be expected between the SES Point Designs and the CA Hydrofoil and FFG-7. The US/G SES weight per KW for power generation (group 310 and 340) is less than that of the FR and UK SES's, and the ANV's collectively are much lower than the FFG-7. The FR SES use of 2 gas turbine prime movers should result in a minimum wt/KW assuming all other factors are equal. It is not readily apparent from the generation equipment selected why these weight differences exist. The FR SES uses (2)-320 KW diesel generators and (2)-320 KW emergency gas turbine generators. The UK SES has (4)-300 KW diesel generators and the US/G SES has (3)-500 KW diesel generators. The weights reported for the US/G SES group 310 are consistent with manufacturer weight data. The difference could be associated with the subbase or foundations and acoustic isolation techniques.

Table 3.3.18-3. Weight Parameters for Electric Power Generation and Distribution

	UK SES	FR SES	US/G SES	SP SES	FFG 7	U.S. Hydrofoil	SWATH
$\frac{SWBS\ 310+340\ (MT/KW)}{KW}$	0.020	0.025	0.016	0.028	0.037	0.021	0.024
$\frac{SWBS\ 320+330\ (kg/m^3)}{VOL}$	1.34	1.09	1.92	1.28	7.05	3.21	4.48

The weights per volume of groups 320 and 330 are presented in Table 3.3.18-3. The FR SES design specifies standard cabling and switchgear yet when compared to the US/G SES, which uses lightweight cabling and switchgear, the distribution system weight per volume is roughly half. All three of the SES Point Designs demonstrate a rather high degree of efficiency in the distribution of power throughout the ship. The U.S. Hydrofoil, though slightly higher than the SES's, also shows a large reduction in weight per unit volume for the power distribution system compared to the FFG-7 monohull weights. This is not that unexpected given the relative complexity of the ANV electric systems as compared to the larger frigate and the attention to weight reduction. Technological advances, such as the use of lightweight electric equipment and the functional arrangement of spaces on ANV's, can account for part of the difference. The use of lightweight switchgear and cabling on the US/G SES can account for the difference between the U.S. Hydrofoil and the US/G SES. The relatively light weight of the FR SES distribution system may be attributable to the lower functional electric load and simpler electrical system; however, this has not been explicitly presented in the design report.

The Canadian SWATH design is the only point design to use an integrated Electric Propulsion System that is tied into the Ship Service Power Generation System. There are 2-3000 KW power converters that supply power to the ship service bus system. Emergency power generation is provided by the main propulsion diesel generators. The use of integrated electric power generation results in a lower weight per kilowatt of power than the four other SWATH designs and the FFG-7 Monohull since apparently only the weight of power conversion equipment is included. The SWATH Electric Plant has a weight/KW value very similar to the SES Point Designs. Comparing its Groups 320 and 330 per unit volume, as shown in Table 3.3.18-3, to the SES Point Designs, results in a value similar to the SES designs and lower than the FFG-7. This may partly result from the configuration of the integrated electric plant, but some of the SWATH reduction could be a result of the lack of need to send power to areas of the struts and lower hulls.

Group 400 - Command and Control Weights

The weights associated with group 400 Command and Control should be primarily independent of platform type except for I.C. systems which are not a driver of group 400. The ANV's have all met the requirements of the Study type there are certain anomalies in the estimated two digit weights. In particular, the group 400 weights for the US/G SES and U.S. Hydrofoil exhibit several apparent anomalies considering the similarity of the two systems. The navigation radar, exterior communications, surface surveillance and fire control system are identical yet there are substantial differences in the estimated weights.

The interior communication system weights for the US/G and UK SES's seem lower than expected considering the much higher internal volume in comparison to the U.S. Hydrofoil. The weight estimated for countermeasures for the

U.S. Hydrofoil seems rather low compared to the US/G SES even considering the additional degaussing and SLQ 32 equipment on the SES. A comparison to the FFG-7 weight for countermeasures shows that the US/G SES is 17.2 LT greater than the FFG-7. The reason for this is unclear considering the subsystem similarity and larger size of FFG-7. These differences and anomalies may be due to the use of weight estimating algorithms or other methods of weight prediction. However, these methods of determination are not presented to the level of detail necessary to perform an indepth assessment.

The CA SWATH weight for group 400 is considerably higher than all of the Point Designs. The majority of the difference is a result of the very large size of the SWATH, its increased capability and the use of off-the-shelf components for the major elements of these systems. Only systems such as degaussing are noticeably affected by the SWATH configuration.

The majority of the weight differences are found in the surface surveillance, underwater surveillance and countermeasures weight groups. This is a result of the use of the AN/SPS 49 and the G.E.3D Air Defense Radar. The underwater surveillance systems used in the SWATH design are also existing shipborne systems. The degaussing weight for the SWATH design is considerably higher than corresponding weight on the FFG-7. This is largely a result of the SWATH configuration that yields a higher wetted surface area with two struts.

Group 500 - Auxiliary System Weights

The group 500 auxiliary densities for the ANV's and other vessels or designs are presented in Figure 3.3.18-6. The low densities for the UK and FR SES's are presumably due to the large enclosed hull volumes for relatively similar auxiliary systems requirements, although one would expect HVAC to be impacted by the larger enclosed volumes. The US/G SES auxiliary density appears to fall within the gross. The U.S. Hydrofoil follows conventional US Hydrofoil practice, having an auxiliary density between that of the PHM and PCH-1 class of hydrofoils. The CA Hydrofoil auxiliary density is at the lower end of hydrofoil auxiliary densities, as a result of its less complex non-retractable foil system.

Nonetheless, all the hydrofoils, both proposed and existing vessels, have fairly high auxiliary densities. This is directly attributable to the inclusion of foils and struts within this weight group.

Within the specific weight groups for auxiliary equipment there are several anomalies which were identified; however, these could not be reconciled because of the lack of detail within the reports. The UK SES design assigns 2.0 MT for ship control while the FR SES design, employing the same waterjet, assigns no specific impacts. There is a larger variation in weights of fuel/lube oil handling and stowage equipment; 6.0 MT (UK), 3.0 MT (FR) and 16.7 MT (US). Some of these anomalies may be due to differences in weight accounting or different early stage design weight estimation methods. The CA SWATH design group 500 density is higher than that of the SES Point Designs, but lower than the DD 963. Its density is lower than the three other SWATH designs used for comparison. This may be due to a larger amount of unaccessible volume in this SWATH configuration or due to use of different weight estimating algorithms.

Group 600-Outfit and Furnishing Weights

The weights associated with outfit and furnishings can be separated into two groups: Hull outfitting items, including ship fittings, hull compartmentation, and preservatives and coatings; and habitable spaces, including living, service, working and stowage spaces.

The weight densities of the hull outfitting items for the ANV's except for the SWATH are significantly lower than conventional monohull frigate densities, particularly for the UK and FR SES's, Table 3.3.18-4. The UK SES weight for preservatives and coatings is significantly lower than the FR or US/G SES's accounting for part of the lower density. This is due to the use of pigmented GRP structure requiring no painting or coatings above the hullborne waterline.

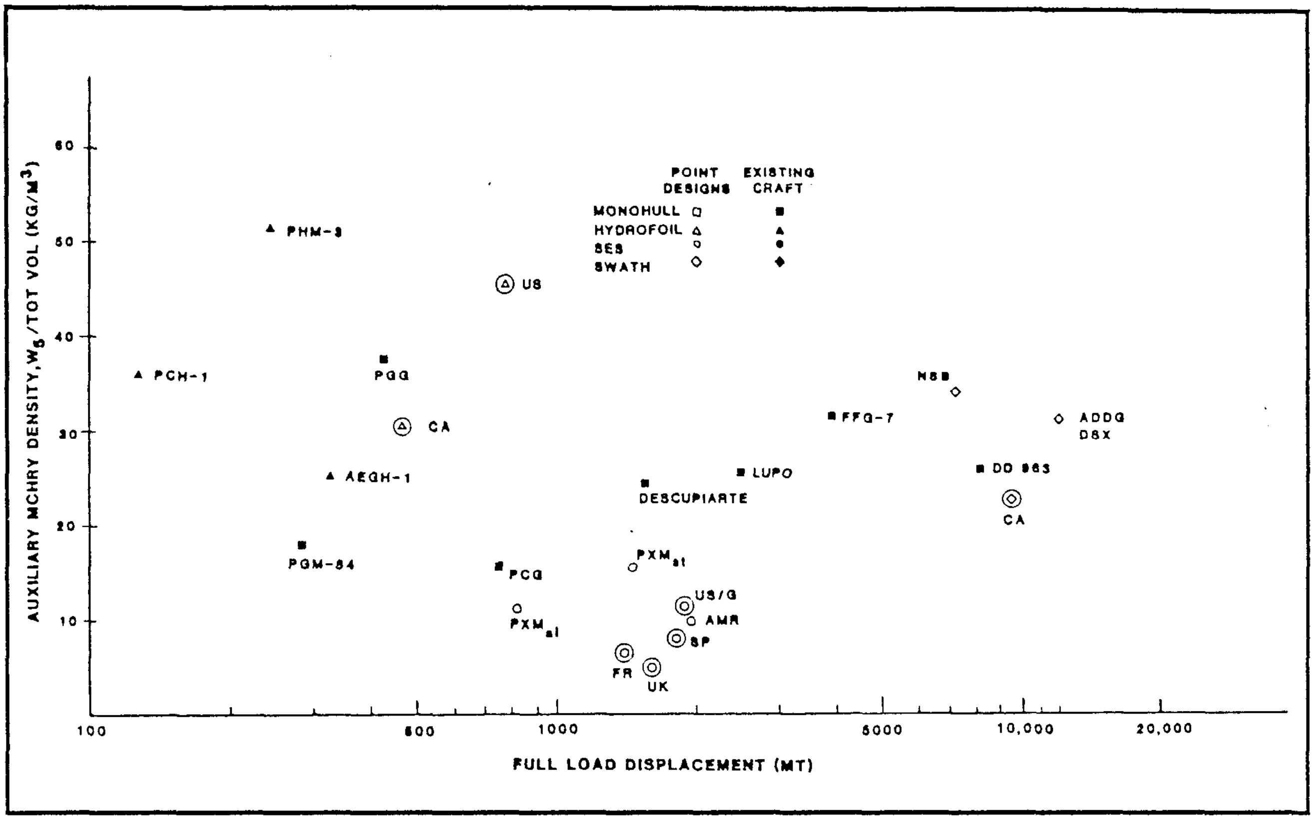


Figure 3.3.18-6. Auxiliary Systems Density

Table 3.3.18-4. Outfit and Furnishing Weight Densities

	UK SES	FR SES	US/G SES	SP SES	FFG 7	U.S. Hydrofoil	SWATH	DD 963
Ship Outfitting: $\frac{SWBS\ 610+620+630}{TOTAL\ VOLUME}\left(\frac{KG}{M^3}\right)$	2.24	2.21	5.39	3.6	12.9	8.71	9.88	10.9
Habitable Spaces: $\frac{SWBS\ 640+650+660+670}{\#\ OF\ ACCOMMODATIONS}\left(\frac{MT}{MAN}\right)$	0.27	0.24	0.41	0.26	0.69	0.37	0.56	0.51

All SES designs specify the use of standard lightweight nonstructural bulkheads, which may further account for some of the differences. Using the FFG-7 as a baseline, the weight densities range from 15% (UK) to 60% (Hydrofoil) of the FFG-7 value. The reason for this significant difference cannot be determined without extensive definition of the specific outfitting items; however, most reports cite the use of lightweight materials for group 600 items where at all possible. It is assumed that the UK SES makes maximum use of composites in this area.

The CA SWATH design values are much higher than the SES Point Designs and slightly higher than the U.S. Hydrofoil Point Design in terms of outfitting density. This could be due to the larger surface area needed to be protected by preservatives and coatings relative to the other ANVs. The outfitting density is slightly less than that of the monohulls which cannot be readily explained because the SWATH generally requires more structure to enclose the same amount of volume, and the weight of outfit could be expected to be a function of surface area.

The weight of habitable spaces per number of accommodations (Table 3.3.18-4) follows a pattern similar to the outfitting weight densities. The FR and UK SES values appear low in comparison to the US/G SES and U.S. Hydrofoil and these weights, in turn, are substantially less than for the monohull and SWATH. The major disparity, however, remains the relatively low values for the UK and FR SESs. The SWATH value is closer to that of the monohull and may not reflect as strong a dependence on lightweight components. No details of the Group 600 weight are available for the CA Hydrofoil. The low-cost objective of this concept would suggest that the habitability fraction would be somewhat small for this vessel.

Group 700 - Armament Weights

Since armament weights, SWBS group 700, are a function of the installed weapon system equipment and other payload type items, they would seem to be independent of platform type. A comparison of two digit weights shows a difference in anti-aircraft weapon weights between the US/G SES and the comparable system on the FFG-7, which is not explained. Additionally, the UK armament weights are significantly lower than the other ANV Point Designs. This is primarily attributable to a lesser dependence on missile systems and a greater reliance on its helicopter; however this is an operational philosophy independent of ANV design philosophy.

The CA SWATH Design has a higher Group 700 weight than all of the other Point Designs. This is due primarily to its very large size and its Combat and Weapon Systems as compared to the suites fitted to the other designs. The weights appear consistent with published data that describe the specific systems.

Aside from these anomalies, group 700 weights appear to accurately represent the installed armament equipment and show no significant deviation from conventional surface ship practice.

Loads

The total weight of load items includes: Ships force, troops, passengers, ordnance and delivery systems, stores and petroleum and nonpetroleum based liquids. These weights are not considered a function of the type of platform but rather relate to manning, combat suite and speed and range characteristics. Thus load item weights for ANV's should not deviate significantly from conventional monohull experience. The load weights as a percentage of full-load displacement for the UK and FR SES's and the CA Hydrofoil are higher than the US/G SES, FFG-7 and U.S. Hydrofoil and SWATH. The actual load item weights appear to be accurate.

3.3.18.3 Summary

With the exception of the SWATH, the ANV weights are less on a density basis than those of conventional monohulls and some other high performance monohulls, indicating the probable use of lighter weight systems and design practices leading to weight reduction. This is to be expected for ships where weight and performance are closely linked; however, in most cases it should be understood that weight reduction initiatives may involve increased cost and possible risk on a system/subsystem level.

In a gross sense the weights presented for the ANV Point Designs appear reasonably consistent with other design studies. Given the lack of definition of weight estimating approaches used in the development of the point designs and the limited subsystem descriptions, it is difficult to validate the weights used or to make rigorous comparisons to other designs. It is also difficult to determine the relative impact that weight estimating techniques, relationships, algorithms, etc., played in the weight values presented. The limited weight data base and heavy reliance on other design studies as points of reference, can add another variable to the overall comparison, thus masking design practice and technology differences. The development of rational, consistent weight estimating approaches ultimately supported by returned weights and relationships will play an important role in the success of any ANV program.

3.3.19 Volumes

Volume data for the point designs are compared in Table 3.3.19-1. This table provides values for volume classified according to the modified version of the U.S. Navy's Ship Space Classification System (SSCS). Additionally, normalized volume data is provided where appropriate, such as installed main propulsion power per unit volume or personnel space per man, etc. A small ASW monohull combatant under development has been included as a reference for the smaller ANV's. A FFG-7 class vessel has also been included as it is more representative of SES total volume, and the DD-963 has been included as being more representative of SWATH volume parameters.

Based on this data it can be seen that there are obvious differences in the space allocations used in each of the point designs. These variations may represent differences in the national design philosophy of the four participating nations, as well as variations in the mission requirements of the vessels, and the way volumes were cataloged.

3.3.19.1 Main Propulsion Volume

With respect to main propulsion volumes, three parameters are available for assessment: 1) total main propulsion volume, 2) main propulsion-volume fraction, and 3) main propulsion power density, which is a measure of installed power per machinery space volume.

From the standpoint of total main-propulsion volume the value for UK SES is significantly higher than for the other SES designs. This is partially due to the inclusion of stacks and all shaft-alley spaces. Additionally, the UK SES design apparently includes designated volume allocated for machinery silencing purposes, although the specifics of this have not been defined or quantified. The main propulsion volume of the FR SES appears low, but this value does not include the central control station or stack volume. The value for the US/G SES, which falls between these two designs, includes the central control station but not the stack volumes. These volumes were not delineated in the FR and UK reports; therefore, it was difficult to rigorously reconcile the differences. The volume fractions tend to reflect this trend, with the UK SES volume fraction approximately twice that of the FR SES. With respect to power density, the FR SES has a density almost three times as great as the density of the UK SES, indicating a fairly compact arrangement. The US/G SES falls somewhere in between, as would be expected.

The power density for the UK SES is approximately half that of the FR and US/G SES designs, indicating the use of additional volume for the purpose of quieting the machinery. The trend in volume fraction also supports this assertion.

The volume of the main propulsion systems of both Hydrofoils' is much smaller than the volumes of the SES's, but the volume fractions fall in the midrange of the SES values. The power density of the hydrofoils are very close to each other and much higher than the SES values, reflecting the goal of keeping the ship as small and light as possible.

The propulsion system volume for the SWATH is comparable to that of the SES's. The main propulsion volume fraction is, however, much lower than that of the other ANV point designs or the DD 963. This is due, in part, to the low power installed for a ship of this size and also due to the fact that central control is not included in the main propulsion volume. The power density is within the range of the SES's and is approximately equivalent to the ASW monohull and the FFG 7. It is higher than the DD 963, indicating a more densely packed system, which is surprising given the electric drive and some of the volume inefficiencies associated with SWATH lower hull arrangements.

The US/G SES and FR SES show similar lift-system volumetric requirements. The volume estimate for the UK SES is higher since the UK SES design has a larger lift-engine power and a larger lift-fan volume than the US/G SES and FR SES designs. The UK SES also includes the ride control systems in this category.

In terms of total volume of propulsion system (lift and main propulsion), the UK design has approximately twice that of the other SES Point Designs. Because total installed propulsion power is roughly equivalent on all the SES's (approximately 50,000 kW), the power density of the UK SES is about half the other SES's. Interestingly, the percentage of total volume devoted to all propulsion equipment on the UK SES (33%) is the same as that of the SP SES (30%), but is somewhat higher than the US/G SES (23%) and twice as high as the FR SES (16%).

Table 3.3.19-1. Volume Comparison

	UK SES		FR SES		US/G SES		SP SES		US HYDROFOIL		ASW MONOHULL		CA SWATH		FFG 7		LUPO		DESCUBIERTA		CA HYDROFOIL		DD 963	
	M^3	%	M^3	%	M^3	%	M^3	%	M^3	%	M^3	%	M^3	%	M^3	%	M^3	%	M^3	%	M^3	%	M^3	%
Main Propulsion	3931	24%	1711	12%	2062	19%	1605	15%	563	16%	4660	51%	2150	6%	1554	10%	1166	14%	1467	26%	260	11%	5412	18%
	(11.9 KW/m^3)		(30.9 KW/M^3)		(22.8 KW/m^3)		(26.2 KW/m^3)		(45.5 KW/m^3)		(17.2 KW/m^3		(18.6 KW/m^3)		(19.7 KW/m^3)		(39.3 KW/m^3		(8 KW/m^3)		(45.9 KW/m^3)		(1.3 KW/m^3)	
Lift System	1540	9%	619	4%	428	4%	1605	15%	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	(6.9 KW/m^3)		(14.2 KW/m^3)		(15.6 KW/m^3)		(7.7 KW/m^3)																	
Auxiliaries	1145	7%	1283	9%	1095	10%	501	5%	597	17%	620	7%	3255	9%	2437	16%	917	11%	441	8%	291	12%	3271	11%
Payload	2584	16%	3009	21%	2445	23%	1727	16%	429	12%	607	7%	8215	23%	3650	24%	1720	20%	925	16%	501	21%	6182	21%
Personnel	2478	15%	2658	18%	1775	17%	1705	16%	894	26%	921	10%	7585	21%	3030	20%	2743	33%	1370	24%	655	27%	5241	18%
	(19.8 m^3/man)		(25.5 m^3/man)		16.3 m^3/man)		(16.2 m^3/man)		(14.9 m^3/man)		(23.9 n^3/man)		(27.2 m^3/man		(14.0 m^3/man)						(16.4 m^3/man		(16.6 m^3/man)	
Tankage	644	4%	614	4%	463	4%	580	5%	325	9%	1542	17%	2115	6%	1162	8%	450	5%	420	7%	309	13%	2322	8%
Passage	1056	6%	1354	9%	959	9%	903	8%	240	7%	220	2%	1315	4%	1982	13%	725	9%	348	6%	124	5%	3473	12%
Other	663	4%	501	3%	761	7%	1093	10%	348	10%	265	3%	3980	11%	1214	8%	363	4%	602	11%	237	10%	2501	8%
UNA	2261	14%	2808	19%	612	6%	1103	10%	91	3%	391	4%	7310	20%	121	1%	363	4%	101	2%	32	1%	1071	4%
Total	16,302	100%	14,557	100%	10,600	100%	10,822	100%	3,487	100%	9,226	100%	35,925	100%	15,150	100%	8,447	100%	5,674	100%	2,409	100%	29,473	100%

NOTES:
1 Percentage of total enclosed volume.
2 Power densities based on main propulsion or lift propulsion values provided.
3 Round off may result in individual percentages adding to values slightly less than 100%.
4 FR volumes reflect some values that were derived through measurements taken from sketches.

3.3.19.2 Auxiliary Machinery Volumes

Auxiliary Machinery includes equipment for electric-power generation and all other equipment not included in the main propulsion or lift system. Some difficulty was experienced in attempting to interpret the Point Design reports for this group; however, based on the information available, there appears to be consistency among the SES Point Designs. The volume fraction for auxiliary machinery volume is significantly higher for the U.S. Hydrofoil than for the other ANVs. This comes from the inclusion of the foil retraction spaces and from the absence of any auxiliary machinery in the propulsion-machinery spaces. The total fraction of main propulsion, lift, and auxiliary spaces shows the U.S. Hydrofoil to be comparable to the US/G SES and between the UK and FR SES's. The CA Hydrofoil, lacking retraction machinery and having large engine rooms, has a lower total volume and volume fraction for auxiliary machinery. The absolute volume for auxiliary machinery on the CA SWATH is significantly higher than for the other ANV's. This may be attributed, in part, to the dispersal of auxiliary machinery throughout the ship in the box, struts and lower hulls, thereby resulting in a somewhat inefficient packing. The volume fraction is consistent with the other ANV designs and is essentially equivalent to the large monohull (DD 963). The high volume fraction for the FFG-7 is likely due to cataloging differences as well as the emphasis on providing sufficient space to support whole equipment change-out as a maintenance philosophy.

3.3.19.3 Payload Volumes

The payload includes primarily military-mission related items such as command and communications, weapons and aviation. The magnitudes of these volumes are similar for the three SES's, with the FR SES being the largest. This is probably due to the inclusion of the central control station and an enclosed bow-missile compartment in the payload volume. The payload volume of the U.S. Hydrofoil is much smaller than either the SES's or the CA Hydrofoil due to the lack of aviation facilities and the fact that most of its combat systems, (for example, the sonar,) are deck mounted, whereas the CA Hydrofoil employs mount-type payload spaces. The payload volume of the CA SWATH is much larger than for the other point designs due to the SWATH's extended payload capabilities. The payload-volume fractions for all the vessels, with the exception of the hydrofoil and the small monohull are on the order of 20%.

3.3.19.4 Personnel Volumes

Personnel space, including all living and messing spaces, vary significantly between the Point Designs, on a volume per man basis. The FR SES includes accommodations spaces for a potential increase of 30% in the total manning. Removing this additional space requirement puts the FR SES in relative agreement with the other SES point designs, (which are comparable). More than a quarter of the total volume for the hydrofoils is devoted to personnel; however, the volume per man is smaller on the two Hydrofoils than on the SES designs. Personnel volume on the CA SWATH is more than three times larger than the volume on the next largest point design. This is due to the increased manning caused by increased payload and increased ship size. When the volume allocated per man is compared, the SWATH design is still higher, (only 6.6% higher than for the FR SES), but this can be accepted more readily than with the other point designs.

3.3.19.5 Other Volumes

The volume of SES tankage is the most consistent volumetric requirement analyzed. The tankage volumes include the requirement for all fuel oil, potable water and ballast. Voids are included in the unassigned volumes. Tankage on the Hydrofoils takes up more than double the relative space than on the SES Point Designs, as would be expected with the similarly rated machinery plant with a similar range requirement in a much smaller hull. The tankage volume on the CA SWATH is 3 to 4 times higher in magnitude than for the other point designs, but as a percentage of total volume, the value is consistent with the other point designs as well as with the DD 963 monohull. The increase in magnitude is a result of the larger ship size, larger crew and greater propulsion requirements.

The volumes required for passages and access are relatively consistent. The passage volume on the CA Hydrofoil is the least on the basis of a percentage of total volume, which illustrates the tightness of the internal arrangements on a small hull. These volumes are compared in Table 3.3.2-3 in Section 3.3.2, and do not include the machinery spaces which have access arranged within the space. The CA SWATH has a somewhat smaller volume fraction for access than the other point designs which is somewhat surprising since the more distributed hull form does not favor the use of centralized passageways. The volume fraction of the FFG-7 is higher, possibly because of the special consideration given to access to support the maintenance philosophy associated with whole-equipment changeout.

The unassigned (UNA) volume, which ranges from 6% for the US/G SES to 13% and 19% for the UK SES and FR SES, respectively, shows that the lower L/B SES's (UK SES and FR SES) are the least volume limited. The US/G SES is not volume limited either, but is closer to being so. The variation in total volume for the three SES's further illustrates the effect of varying L/B ratio and superstructure size, as evidenced by the near equivalency in total volume of the FFG-7 to the UK and FR SES designs. The SWATH compares more favorably to the DD 963 in total volume. The extremely low UNA volume in both magnitude and fraction for both Hydrofoils again reflects the goal of minimizing the ship size to reduce the weight and the geometry of the hulls. As can be seen, they are comparable to the ASW monohull in this area. The CA SWATH is larger in unassigned volume fraction than the other point designs. This is due to the large volume of inaccessible space in the struts and lower hulls, which is an inherent feature in SWATH designs due to the constraints placed on the struts and lower hull dimensions by hydrodynamic performance.

3.3.19.6 Monohull Comparison

The volume breakdown for the conceptual design of a recent fast ASW monohull has been included in Table 3.3.19-1 for comparison purposes. This particular monohull was chosen because its performance and mission requirements approximate (except for the SWATH) those for the SWG/6 ships, its CODOG propulsion system is almost identical to the propulsion systems on the SES and Hydrofoil Point Designs.

The power densities for the SES's, compared to the monohull, range from being somewhat lower for the UK SES to being much higher for the FR and US/G SES. The higher density can be partially explained by the fact that the SES's have most of their auxiliary machinery in separate spaces while monohulls have some auxiliary machinery in their main machinery spaces. Additionally, machinery spaces on both monohulls and SES's are usually sized based on subdivision length and available beam. Monohulls can have a relatively high beam and a low density. The available sidehull beam on the US/G SES is relatively small, leading to a high density. The FR SES and the UK SES have larger sidehull beams and thus, have lower densities than on the US/G SES. The power density on the U.S. Hydrofoil shows it to have by far the tightest machinery arrangements. The SWATH has a power density approximately the same as that of the smaller ASW monohull but higher than that of the DD 963. The reason why the SWATH has a higher density than the DD 963 may well be that the arrangement of its electric-propulsion drive system, is more flexible and that the transverse gas-turbine generator installations, provide a more efficient arrangement within subdivisions combined with the fact that the SWATH uses dedicated auxiliary machinery spaces. It is somewhat surprising that the power density for the SWATH is so high, given the volume inefficiencies associated with electric-drive components in the lower hull. Perhaps the athwartship mounting of prime movers in the box structure, and short shafting permitted by electric-motor driven propulsors, allow for a higher than expected power density.

The auxiliary volume fraction on the small ASW monohull is slightly less than on the SES's and SWATH and much less than that of the Hydrofoil due to the inclusion of some of the auxiliary machinery in the main machinery spaces. The auxiliary volume fraction on the FFG 7 is at the high end of the range, approximating the value for the Hydrofoil. As noted previously, this may be due to different volume cataloging used for the FFG 7.

The payload fractions for both the small ASW monohull and U.S. Hydrofoil are small; however, both ships lack a hangar. The additional hangar would bring the monohull and the U.S. Hydrofoil within the range of the payload fraction of the UK SES. The CA Hydrofoil is within this range because of the use of semi-enclosed installations that are included as payload. The FR and US/G SES payload fractions are larger due to a hangar that must garage two helicopters whereas the UK SES design only has one helicopter. This fraction is also a function of the different combat system on the monohull as compared to the SES and Hydrofoil designs. The CA SWATH also has a large fraction in keeping with its more capable combat suite. As noted previously, with the exception of the U.S. Hydrofoil and the small monohull, this fraction is fairly consistent at about 20%.

The personnel fraction for the ASW monohull is consistent with the point designs, given the additional space included for a potential 30% manning increase on the FR SES. The manning density on the FFG 7 is lower than any of the designs because of the habitability standards involved in its design.

Tank-volume percentage on the small monohull is substantially higher than for any of the point designs. This is not readily explainable, but the tank volume may also include some voids. The tank-volume fraction for the FFG 7, DD 963 and other monohulls are consistent with the ANV point designs.

Passage volume on the ASW monohull is much smaller than on the ANV Point Designs. This is due to the tight arrangement of this monohull and is not necessarily indicative of conventional monohull practice. Larger monohulls may have passage and access space on the order of 10% total volume, as evidenced by the FFG 7 and DD 963 volume fraction, although the percentage for the DESCUBIERTA is somewhat lower.

Shops and storerooms were minimized on the FR SES, CA SWATH and on the monohull as is borne out by their 3% fraction for "other" volume. On the ASW monohull this low value was due to volume restrictions, but it is unclear why the FR SES has such a small percentage relative to the other point designs. The volume fraction for the FFG 7 and for other monohulls are within the range of the ANV point designs.

The low UNA fraction on the ASW monohull and on the hydrofoils is also indicative of their tight arrangements relative to the non-volume-limited SES's and SWATH.

This is also indicative of the inefficiencies in arrangeable areas associated with SES designs due to sidehull size and configuration, and the unusable volume present in the SWATH struts and lower hulls. The low UNA volume fraction for the FFG 7 is attributable to the Lo-Mix maintenance philosophy which provides ample room for change-out of major equipment, and storage of spare equipment assemblies.

In conclusion, it is apparent that many categories of volumes on the SES's, SWATH's and monohulls, represented by these point designs, are comparable and are not greatly influenced by hull type. This includes auxiliaries, payload, other and personnel. Other categories, such as main propulsion, lift, passage, and UNA volume have differences that appear to be explainable by hull type. For example, the Hydrofoil volumes show extreme attention given to holding down the ship total volume based on performance requirements. A further breakdown of the actual space volumes for the FR and UK SES designs is required for a more in-depth comparison against monohull design. The SWATH design can only be compared with the other designs on a fractional basis or on a density basis (cu ft/SHP, etc.) due to its large size. If a monohull of comparable seakeeping and mission capability had been developed, some of the differences for the SWATH could perhaps have been explained.

3.3.20 Manning

3.3.20.1 Manning/Accommodations

Table 3.3.20-1 presents a comparison of the manning estimates for the NATO Point Designs. As noted in Section 3.3.1 a 10% accommodation margin is required by the Design Guidance Document. The manning requirements for the proposed designs are compared with the complements for existing and proposed U.S. Navy ships in Figure 3.3.20-1. The manning requirements for the NATO SES Designs fall reasonably within the current practice for ships of similar full-load displacement. A similar observation can be made about manpower requirements for the U.S. Hydrofoil and SWATH Point Designs.

Table 3.3.20-1. NATO Point Design Manning Comparison

	UK SES	FR SES	US/G SES	SP SES	U.S. Hydrofoil	SWATH	CA Hydrofoil
Officers	11	8	13	8	5	30	6
CPO	33	14	5	18	5	18	16
Enlisted	69	72	81	69	44	275	18
Manning	113	94	99	95	54	323	40
10% Margin	11	10	10	10	6	33	Unknown
Accommodations	124	104	109	105	60	356	(40 Assumed)

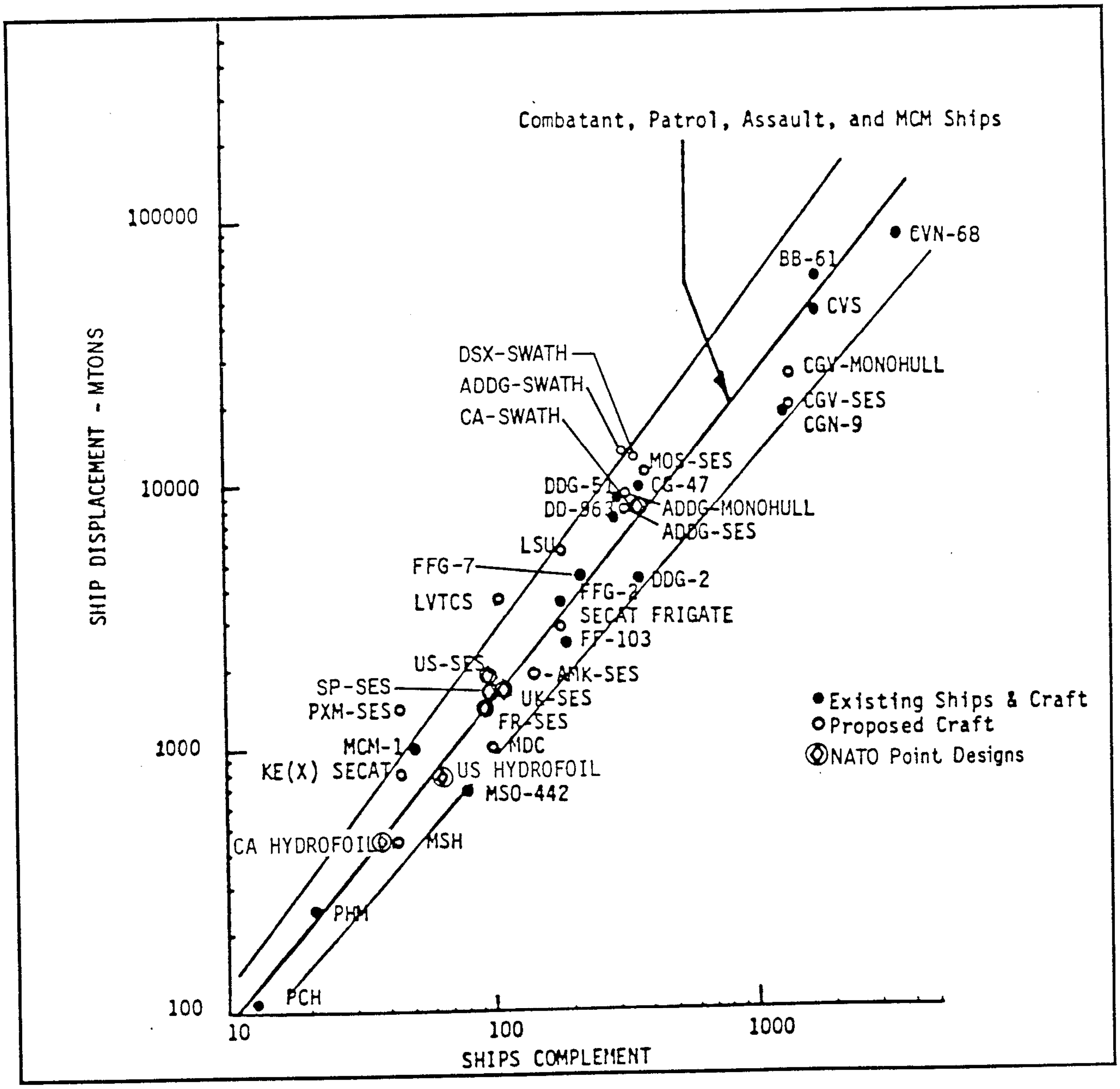


Figure 3.3.20-1. Comparison of Manning Requirements

3.3.20.2 **Functional Manning Breakdown**

Although the total manpower estimates for the three SES Designs are within 17% of each other, the functional breakdown given in Table 3.3.20-2 clearly shows a difference between the various methods of estimation at the system level. Some of this is due to differences in equipment and capability. For example, the UK Point Design has only one helo and thus, a reduced aviation support staff. However, the reasons for the large differences in the manning estimates for the combat systems and support areas are not so apparent. The combat systems are roughly equivalent, yet the manning varies from 18 (US/G) to 51 (UK). The manning analysis used for the UK SES Point Design was based on traditional UK MOD Complement Assessment Procedures. According to the UK Design Report, ship system automation was integrated into ship control, propulsion and weapons systems in an effort to minimize staffing. This does not seem to be supported by the comparative functional breakdown. The larger manning estimate for the UK SES in the combat system area may be a result of a greater organizational maintenance capability as compared to some of the other ANV designs. Different watch station, or rotation, philosophies or different manning estimation methods may also contribute to this disparity. This difference should be investigated further due to the significant ship weight and space impacts of an additional 20 to 30 personnel.

The US and FR SES designs also use the traditional manning estimation methods from their respective countries. The manning prediction for the FR SES was prepared from the Outfitting Draft established by the EMM, L'ETAT Major De La Marine Nationale. Ship systems were designed according to traditional practice and no study of automation was attempted. The FR SES report mentions the possible augmentation of the crew by 30% without any particular impacts. The nature of this increase in manning is not detailed enough to allow its intended purpose or impacts to be assessed.

Manning requirements for the US/G SES were based on a study performed for the 1500 LT Medium Displacement Combatant (MDC) using the Manpower Determination Model (MDM). This manning analysis compared proposed MDC equipment with similar equipment currently in use in the U.S. Fleet. The MDC Manning Study included the impacts of remote and automated operation of the ship's machinery and automated monitoring systems in mission-essential electronics and machinery. In light of these automation considerations it is interesting that the US/G SES has 50% more engineering personnel than the UK and FR designs.

Manning for the U.S. Hydrofoil was developed from past hydrofoil designs followed by a check of operational and maintenance requirements. It was based on standard U.S. Navy practice with minimal planned maintenance. A comparison with the other point designs shows the expected general reduction due to the smaller size of the ship. In addition, the Engineering Department is smaller due to the unsplit nature of the power plant and to the smaller number of components. The Operations and Combat Systems Departments reflect the Hydrofoil's reduced capabilities in these areas. The Support Department is comparable to the FR and US/G SES's indicating that there may be a minimum level of manning which has been reached. The lack of any helicopters eliminates the Aviation Department. It is not clear who will be responsible for the optional RPV's. If not already accounted for, these men would either reduce the 10% accommodations margin, further decrease habitability, or increase the ship's size. The CA Hydrofoil design report does not discuss the development of the manning figures for this vessel. It is important to note the high percentage of senior enlisted personnel as compared to the SWATH. This percentage (40%) is 10 percent higher than the next closest design. It may be that the maintenance and operating scenario is such that an experienced and proficient core crew is required to adequately man the ship.

The SWATH manning estimates were developed using initial stages of HARDMAN methodology and established Navy policy. The NAVSEA Enhanced Manpower Determination Model (EMDM) was used to establish feasibility level estimates and then refined using Ship Manpower Document (SMD) workloads for comparable ships. Although the total manning level is approximately 3 times that of the other ANV's, the number is consistent with displacement/manning trend lines, comparing favorably to the DD 963. The large aviation department manning figure results from the presence of 4 helicopters as well as 5 individuals to operate and maintain the RPV's. Increases in other areas reflect the larger size of the ship and more components to operate and maintain.

Table 3.3.20-2. Functional Manning Comparison

	UK SES	FR SES	US/G SES	SP SES	Hydrofoil	SWATH
CO	1	1	1	1	1	1
XO	-	1	1	1	1	1
Operations						
OFF	6	-	1	1	1	5
CPO	2	3	1	3	2	7
ENL	11	18	25	20	14	55
	19	21	27	24	17	67
Engineering						
OFF	1	1	2	1	1	5
CPO	6	3	2	6	1	3
ENL	10	12	20	14	11	65
	17	16	24	21	13	73
Combat System						
OFF	1	3	2	2	1	4
CPO	17	6	1	6	1	3
ENL	33	21	15	18	11	79
	51	30	18	26	13	86
Support						
OFF	-	-	-	-	-	2
CPO	5	-	-	1	1	2
ENL	13	7	8	10	8	37
	18	7	8	11	9	41
Aviation						
OFF	2	2	6	2	-	10
CPO	3	2	1	2	-	2
ENL	2	14	13	7	-	27
	7	18	20	11	0	39
TOTAL	113	94	99	95	54	308

3.3.20.3 **Summary**

The overall manning numbers for these designs correlate well with other ship types and indicate no unusual manning difference driven by ANV concepts. It should be pointed out, however, that ANV's, particularly at the smaller sizes, represent a unique opportunity to establish cost-effective manning policies tailored to ANV mission profiles and technology. This could result in increased automation and reduced manning with potential benefits with respect to ship size and overall Navy manning requirements.

3.3.21 Stability & Buoyancy

3.3.21.1 Statical Stability Hullborne

In general, SES designs have been found to have adequate intact and damage stability. This is due to the large initial waterplane moment of inertia provided by the wide separation of the sidehulls and the location of the wet deck close to the waterline. The small wet-deck clearance results in the cross structure entering the water after only a few degrees of list. The resulting increased waterplane limits the impact of off-center flooding and sinkage; consequently, larger subdivision lengths are acceptable on SES designs than on equivalently sized monohulls. Hydrofoils, on the other hand, act similarly to monohulls. The primary difference being that retracted foils raise the KG. Due to their small size, the hydrofoils benefit from reduced damaged stability requirements for damaged length, wind heel and roll.

SWATH stability was evaluated in a full-load displacement condition. SWATH intact stability is rarely a problem due to the large beam. When properly designed, SWATHs will perform at least as well as a monohull design. Damage stability is a weak point of the SWATH concept. The same attributes that contribute to its good seakeeping qualities, low waterplane area and longitudinal GM, contribute to its poor performance with respect to high initial list and trim in a damaged condition.

3.3.21.1.1 Intact Statical Stability

Stability analysis for each point design was performed using the methods and criteria required by DDS 079-1. Further evaluation was done by each country using currently available data. The UK SES design used data from the experimentation and experience at Vosper Hovermarine to substantiate the requirements given in DDS 079-1. The righting-arm curves for the FR SES showed the inherent excess stability of the catamaran hullform. The US/G SES design used stability data from the results of Test Series NSRDC-18 in its seakeeping assessment. Dimensionless force and moment coefficients were derived and regression analysis performed to ascertain the relationship of ship design and operating properties to stability. Four conditions were chosen for the U.S. Hydrofoil's intact stability analysis: full-load and minimum-operating condition with the foils both raised and lowered. The standard 100-knot wind was used to analyze the Hydrofoil in the foils-lowered condition and an 80-knot wind was used for the foils-raised conditions. This is justifiable since the U.S. Hydrofoil will operate with its foils down except when entering port. The KG was increased by incorporating the appropriate margins and corrected for free surface effects. The U.S. Hydrofoil met the criteria of DDS 079-1 for all conditions with the foils down; minimum-operating condition was limited due to the higher wind and due to the greater distance between the center of lateral resistance and the center of the windage area. The CA Hydrofoil met the criteria in DDS 079-1 and will withstand a 100-knot wind in beam seas for all operational loading conditions. Its fixed foil system permits it to easily satisfy the requirements compared to the U.S. Hydrofoil. The SWATH intact stability was analyzed using DDS 079-1 criteria as well. It was evaluated for two conditions (each with and without topside icing): 1) 100-knot beam wind, and 2) 19 knot turn. The SWATH easily met DDS 079-1 criteria in all cases. The beam-wind conditions produced the most heel due to the large projected area and the large heeling arm typical of a SWATH platform.

The displacement mode righting curves for the UK SES, FR SES, CA SWATH and FFG-7 are shown in Figure 3.3.21-1. These curves show the stability of the SES and SWATH platforms compared with that of the FFG 7. The difference in the FR and UK SES righting arm curves is primarily due to the wider beam of the UK SES design. Although US/G SES righting and heeling arm curves were not presented, it is assumed to be similar to the FR SES.

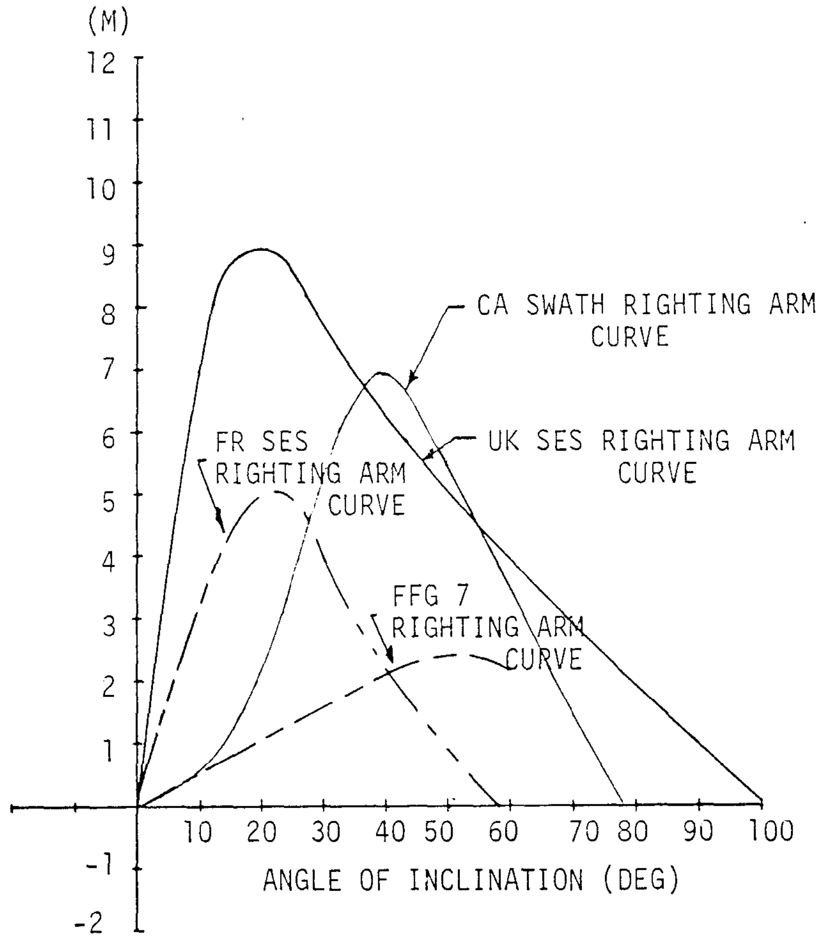


Figure 3.3.21-1. Intact Righting Arm

3.3.21.1.2 Statical Damage Stability

The basis of damage stability criteria are the requirements set in DDS 079-1. DDS 079-1 requires that for large air cushion type advanced marine vehicles, the worst of two damage cases must meet the governing criteria. The first case is a longitudinal shell opening of 15% of the design waterline extending transversely to the centerline. The second case is a cut extending longitudinally 50% of the design waterline and transversely to the first longitudinal bulkhead. The damage specified for the Hydrofoil, according to DDS 079-1, is the same as that for a monohull of the same size. For a hydrofoil this is the loss of any two adjacent compartments and a beam wind of 20 knots. By contrast, the average beam wind after damage is 27 knots for SES's and 37 knots for the SWATH because of their greater displacements. The governing criteria are:

a) Initial angle of heel does not exceed 15°, (20° for SWATH).

b) The ratio of the area, A1, between the righting and heeling arm curves from their intersection to 45°, to the area between the curves from the intersection to a distance 15° to the left, area A2, shall be greater than 1 for the SES's and SWATH , and 1.4 for the Hydrofoil. See Figure 3.3.21-2.

c) Minimum righting arm above heeling arm allowable is 0.1 m.

d) Final static heeled and trimmed waterline shall not submerge the bulkhead deck.

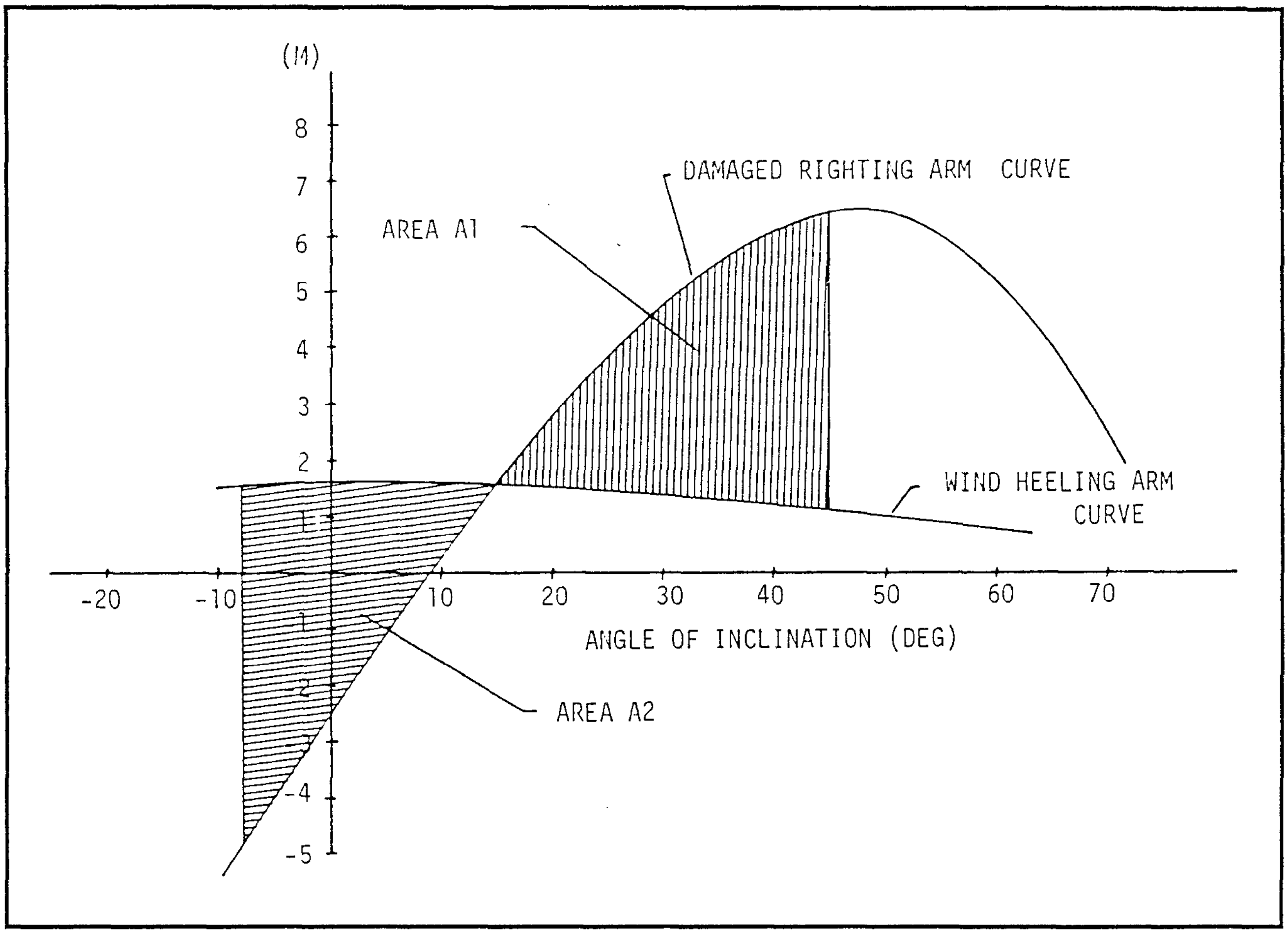


Figure 3.3.21-2. Damage Stability Curve

The UK SES design satisfied all cases of damage for the 15% LBP condition, with the worst case having a list of 12°, A1 equal to 2.48 times A2, and a righting area of 5.0 m. One damage case narrowly failed the 50% condition by submerging the bulkhead deck by 0.1 m.

The FR SES design worst case damaged conditions were well within safe limits for the 15% LBP case. Only 5.4° of initial heel is predicted with less than 7° in 100 knot winds. The 50% LBP damaged case produced initial heel angles of 18° and immersion of the bulkhead deck, failing the stability criteria; however, analyses suggest that the ship retains enough buoyancy to survive this case.

Although no damage stability analysis was reported for the US/G SES, the ship was designed to withstand 15% LBP length of damage. Common U.S. Navy design practice for steel SES's is to design for the 15% criteria, since it is considered that the 50% criteria is more applicable to ships constructed of other materials and with lighter scantlings. The rationale for 50% length criteria is damage resulting from collision, an effect considered to be less critical for steel hulls.

Damage at bulkhead 41 was the worst case for the U.S. Hydrofoil with the foils down in the minimum operating condition. For all conditions the list never exceeded 15^{o} and the ratio of A1 to A2 was always greater than 1.4. The CA Hydrofoil meets the DDS 079-1 requirements for damage stability in all cases. Although no details were given, a three-compartment standard was met throughout the ship.

The DDS 079-1 criteria for SWATH ships require an opening in the shell 15% of the equivalent monohull length that extends from baseline to sheer line and from centerline to side shell. After sustaining this damage the platform must satisfy the above criteria. A damage stability analysis of a SWATH of similar size and geometry to the CA SWATH and its results were given in the report. It is not clear why the actual SWATH design was not used in the analysis or whether the 15% of LBP flooding assumed corresponds to the 15% of equivalent monohull length. An equivalent sized monohull was apparently not developed for this analysis. The configuration with the 15% of its LBP opening, from baseline to the damage control deck, passed the heel requirement, but in its worst case damaged condition the bulkhead deck was immersed due to large values of trim. To solve this problem 100 tonnes of foam were added fore and aft, which is a typical approach for SWATH designs of this size. As stated in the report, geometry modifications, or tankage relocation could also be used to help alleviate the excessive trim problem. It should be noted that the U.S. Navy is currently reassessing the damage criteria for SWATHs. The opening length of 15% of an equivalent monohull is thought to be somewhat severe. A damage condition of 15% of strut length is being considered.

3.3.21.1.3 Comparison of Point Design Hull-borne Stability to the FFG-7

The curves of worst-case-damage righting and heeling arm for the FFG-7 and the UK SES are compared in Figure 3.3.21-3. This figure illustrates that the list angles for the UK SES, and by extrapolation SES platforms in general, tend to be significantly lower than a monohull. In this case the UK SES has a worst case damage list angle of 12^{o}, while the monohull worst-case list angle is approximately 22^{o}. For the Hydrofoil, the angle of list caused by wind heel, is reported to be 2^{o} for the worst flooding case. This indicates that no off-center flooding was assumed in the analysis. The general arrangements show that much of the fuel is stored in wing tanks and flooding of these will result in some additional list and a decrease in dynamic stability. This list will probably not exceed 15^{o} and the A1 to A2 ratio will be lowered somewhat. No cross-flooding ducts were specified but counter flooding could be used to reduce the list. The other comparison that may be made is the area under the righting-arm curves. DDS 079-1 stability criteria require that the ratio of A1 to A2 be greater than 1.4 for monohulls and hydrofoils and only 1.0 for SES's, which the UK SES easily meets with 2.48 and the U.S. Hydrofoil meets with 3.0.

3.3.21.2 On-Cushion Stability

As SES conceptual designs become larger, for ships of moderate speed $\left(v/\sqrt{gL} \le 1.0\right)$ the preferred length-to-beam ratio tends to increase on account of the advantages gained from reduced resistance. High cushion heights are also desirable for large ocean-going SES due to the desire to keep the wet deck clear of large waves and high wet-deck heights tend to imply high vertical c.g.'s. The combined effect has been to develop high, narrow ships for which roll stability during turns and in synchronous beam seas, especially in adverse weather, has become of greater concern.

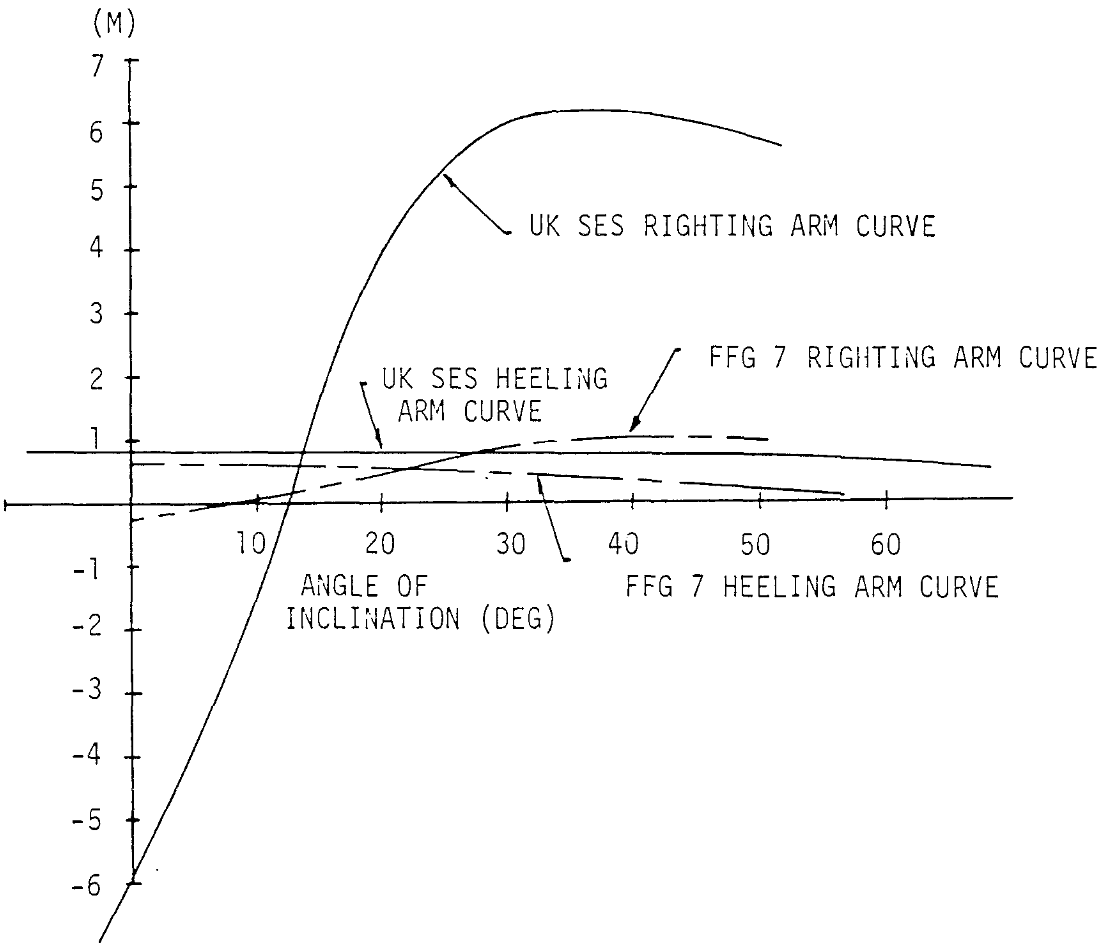


Figure 3.3.21-3. Worst-Case Damage Curves of Stability

In recognition of this trend, recent large SES designs (such as the NATO SES point designs) have generally featured sidehulls of relatively larger volume to increase stability and, in addition, they have been able to accommodate heavy machinery relatively low within these sidehulls to lower the vertical c.g. For the range of small SES built to date, the sidehulls have generally been too small for the installation of much machinery which otherwise must be located above the level of the cross-structure wet deck which has resulted in a relatively higher vertical c.g. In addition, for large SES, all the fuel is located in the lower extremities of the sidehulls to help lower the vertical c.g. in the full fuel-load condition.

Figure 3.3.21-4 compares the midship cross sections of the SES Point Designs while Table 3.3.21-1 gives a list of those leading particulars which have the greatest influence on stability for underway operation on-cushion.

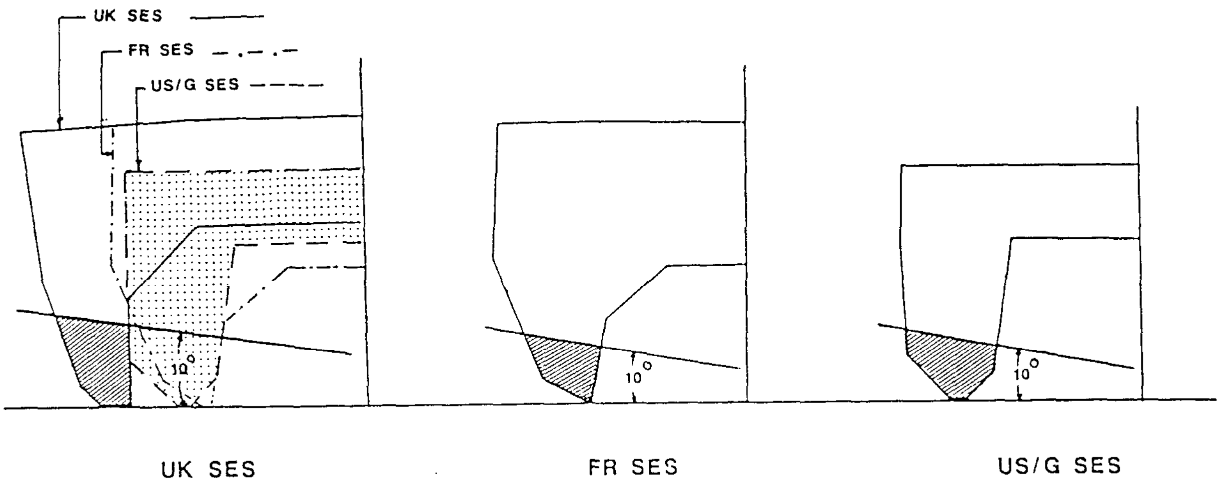


Figure 3.3.21-4. Comparison of Sidehull Cross-Sections

Table 3.3.21-1. Roll-Stability-Related Leading Particulars of SES Point Designs

		UK SES	FR SES	US/G SES
Full-Load Displacement	MT	1601	1400	1936.5
Cushion Area	m^2	1380	949	1425
Waterplane Area	m^2	122	145	187+
Percentage of Buoyancy	%	11.5	15.2	11.0
Beam Overall (BOA)	m	29	21.1	19.5
Cushion Beam (B_c)	m	20	13	15
Cushion Length (L_c)	m	69	76.5	95
Cushion Height (H_c)	m	7.5	5.4	6.7
L_c/B_c	--	3.45	5.88	6.33
H_c/B_c	--	0.375	0.415	0.447
KG (Full Load)	m	6.3	6.8	6.7
KG/B_c	--	0.315	0.523	0.447
KG + Margin (15%) = KG	m	7.25	7.82	7.71
GMT (Full-Load) On-Cushion Static	m	11.0	4.2	4.8
GMT/BOA	-	0.38	0.2	0.24
GMT/KG	-	1.52	0.54	0.64
Roll Radius of Gyration	m	9.6	6.9	6.3
+Note: This is a mean figure to allow for the bulge effect				

The design KGs referred to here include the specified 15% growth margin.

Important features affecting stability also include the sidehull length, volume and deadrise, the types of bow and stern seals, the size and location of skegs, fences and rudders, the type of propulsion system, the type of maneuvering system and the ship's angular moments of inertia. The large number of possible variations makes it difficult to develop stability standards and, to date, no universally accepted standards have been established.

The primary circumstances leading to a risk of capsizing, for example, include high-speed turning maneuvers, sudden helm reversal and/or sudden propulsor or steering-system failures at high speed, running with high winds and synchronous seas on the beam and operation in very steep following or quartering seas.

The pitch, roll and directional stability of each of the SES point designs when operating in such extreme conditions has been examined to varying degrees by the respective design teams using data from towing-tank models, or manned testcraft having characteristics similar, or identical, to those which have been proposed. Table 3.3.21-2 shows the extent to which this has been accomplished.

Table 3.3.21-2. Extent of Test-Verification of the Stability of SES Point Designs.

	UK SES	FR SES	US/G SES
Tow-Tank Models	Yes	Yes	Yes
Hull Form and Stability Characteristics Relative to Point Design	Similar	Identical	Similar
Manned Test Craft	Deep Cushion Craft (DCC)	MOLENES Test Craft	XR-5 Test Craft
Hull Form and Stability Characteristics Relative to Point Design	Similar	Identical	Similar L/B

Recent research conducted in the UK (Appendix E) has generated a greatly improved understanding of overall on-cushion stability requirements, to the extent that provisional criteria based on practical and purely numerical methods are expected to be set by the UK Civil Aviation Authority within the next few years. The comparative assessment which follows is based on the results of this research to date, and therefore represents the most up-to-date analysis currently available. However, until the work has been completed, any conclusions drawn must be regarded as provisional.

The research to date, which is described more fully elsewhere*, has shown, by the use of capsizeable radio-controlled models, that the principal problems to be addressed in assessing the on-cushion stability of an SES are:

(1) the behavior in high-speed turns (when the vessel is subjected to a large centrifugal overturning moment),

(2) the behavior in beam wind and sea conditions (when resonant rolling can cause capsize).

The stability limitations in terms of permissible center-of-gravity height (KG) are being determined by a continuing program of model tests, backed up by some limited full-scale trials.

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*"Recent Research into the Ultimate Stability of Surface Effect Ships" by A. G. Blyth, RINA International Conference on Ship Stability and Safety, London, June 1986.

(a) Metacentric Height (GMT)

Satisfactory initial stability, which is widely applied to conventional ships, is a practical requirement, even though it has little relevance to stability in waves, since it only describes the righting moment over the first few degrees of heel. Once the cushion has started to vent appreciably (beyond about 5 degrees of heel) the righting moment undergoes a radical change of character, and is substantially unaffected by factors that influence the initial stability viz: trim angle, height of skirts relative to the keel, and modest lift-power variations.

The following estimates of on-cushion GMT have been made using methods established for SES of conventional form when using full lift power, which have been correlated against experimental data. However, the unconventional form of the US/G design requires a slightly different treatment, since the large internal bulges that do not contribute to the stability when the vessel is perfectly upright progressively come into play as soon as the vessel heels. These figures cannot be regarded as precise for the reasons outlined above, but provide a basic comparison and have been used in deriving the "hydrostatic" element of the righting moments in high-speed turns. The values of the major parameters used are also shown, together, with non-dimensional presentations of the result. The ratio of GMT/Beam is commonly used, but the ratio of GMT/KG is preferred as there is no reason to suppose that increasing the beam of a vessel at constant KG should require an increase in GMT, since this parameter is significant only in assessing high-speed turns where KG is the lever of the primary capsizing moment.

Based on existing experience with propeller-driven SES models, acceptable levels of initial static stability are as follows:

	Absolute Minimum Limit	Preferable Minimum Limit
GMT/Overall Beam	0.15	0.20
GMT/KG	0.50	0.70

However, tests of SES models without propellers have been ovserved to lose stability at high forward speeds. SES models equipped with conventional propellers do not lose stability at high speeds as the propellers develop increased thrust and an increased upward component which has a stabilizing effect. This stabilizing effect would not be present for waterjets or for propellers on horizontal shafts. It is therefore considered that the US/G and French designs may have insufficient initial stability to allow for this effect.

(b) Stability in Waves

(i) Current Understanding

The UK test conducted with capsizable radio-controlled models demonstrated that SES are most vulnerable to capsize when operating beam-on to wind and sea, and that the environmental conditions required to cause capsize with a given KG are substantially unaffected by forward speed (up to Froude No. = 1.3). Model behavior in beam sea conditions was then studied in the controlled environment of the towing tank. These tests have shown that capsize is associated with steep waves of near resonant period, and that if the KG is below a critical height, capsize in realistic operating conditions is virtually impossible. A continuing program of model tests is being conducted to identify the effect of the dominant parameters on the critical KG. The major parameters so far identified are:

Mean sidewall width - directly affects righting moments

Cushion depth - affects onset of wet-deck damping

Cushion loading - increased weight reduces righting moments

Roll radius of gyration - dramatically affects resonant period

Sidewall section shape - affects roll-damping characteristics

Freeboard - affects righting moments and range of stability

(ii) Comparison of Designs

The merits of the three designs have been compared by calculating the Stability Coefficient of each in both the Deep and Light conditions, and deriving the critical KG in each case from the current version of an assessment chart developed from the tests described above. Since roll radius of gyration has a very powerful effect, and since this parameter cannot be determined accurately at this stage, a 15% margin has been added to the estimated value before calculating the Stability Coefficients. The Factor of Safety has been calculated as the ratio of Critical KG to Design KG, and includes no allowance for the full-scale wave steepness effect.

Similarly, no allowance has been included for the expected reduction in radius of gyration in the Light Condition, as it is not easily quantifiable at this stage. The values derived from this study together with some of the principal parameters used are tabulated below:

Design		UK SES	FR SES	US/G SES
Mean Sidehull Width	(m)	2.89	2.64	3.02
Mean Cushion Depth	(m)	7.50	5.65	6.19
Cushion Loading Coefficient	-	0.030	0.047	0.035
Radius of Gyration	(m)	9.6	6.9	6.3
KG - Deep Condition	(m)	7.25	7.82	7.71
KG - Light Condition	(m)	8.4	9.00	8.85
Factor of Safety - Deep	-	1.78	1.18	1.35
Factor of Safety - Light	-	1.83	1.22	1.23

It is clear from the figures tabulated that neither the US/G nor French designs have a very substantial margin against the anticipated effect of full-scale wave-slope (30 degrees compared to around 16 degrees at model-scale) or to allow for uncertainties in the, as yet, incomplete range of model data. However, the margin used on Radius of Gyration may prove to be excessive - a 5% difference would produce about a 10% change in the Factor of Safety.

(c) Stability in High-Speed Turns

(i) Current Understanding

Because of its high speed, an SES can generate substantial centrifugal forces in a turn, which are resisted by lateral forces generated on the "leading" (outboard) sidehull once a yaw angle has been induced. The lower, outboard face of the outboard sidehull during a turn produces both side force and lift. The objective is to achieve a roll-moment balance such that an inward heel angle is produced in high-speed turns. This is usually achieved by ensuring that the *resultant sidehull force vector passes above the center-of-gravity of the craft.*

The direction of this vector naturally depends on the roll attitude of the craft. In particular, it can rapidly become unfavorable as the chine at the top of the deadrise surface becomes immersed. The effect of the combined moments can be such as to produce a zone of neutral or even negative roll stiffness when turning, even though the "hydrostatic" roll stiffness (after allowance for the reduction due to the effects of forward speed) is positive. This is believed to be the cause of the violent coupled roll-yaw (dutch-roll) oscillation that have been observed on both radio-controlled models and full-scale craft under certain conditions, leading to extreme difficulty in control.

Consideration must also be given to the effect of helm reversal just after the start of a turn, as this could produce an unfavorable effect. In terms of criteria, the UK has stated (Appendix E) that the roll moment balance should be such as to produce an inward heel angle in a normal turn, and should not exhibit a zone of neutral/negative roll stiffness, or at least if this exists it should occur at a level of roll moment that is not achievable under any possible combination of circumstances. Violent changes of roll attitude during helm reversal should be avoided.

(ii) Comparison of Designs

A complete study of the roll moments at all angles of heel is beyond the scope of this report. However, by examining the moments at 0 and 5 degrees outward heel, a useful indication of the roll behavior in high-speed turns can be obtained, showing the general form of the moment curve in the critical zone. Planing force vectors have been derived by integrating over the length of the sidehull so as to take account of the important effect of variation of deadrise angle below the running waterline. It has been assumed that each vessel runs at a trim of about 1 degree with the undisturbed waterline passing through the sidehull forefoot. The resultant moments are summarized below, and should be seen as indicative rather than precise. The method has been validated by reference to a craft for which full-scale knowledge exists.

Design		Roll Angle	Total Roll Moment (kNm)*		
			UK SES	FR SES	US/G SES
Steady Turns	TCG = 0	0 Deg	+6320	+13550	+13840
		5 Deg Out	+11010	-690	+16640
Helm Reversal	TCG =0	0 Deg	+1660	+6510	-2500
		5 Deg Out	+6350	-7730	+310
MMT Due to Adverse TCG = 1% Beam			-4550	-2900	-3700

*Positive moments produce roll motion towards the center of the turn.

Comparison of the moments at 0 and 5 degrees for each design reveals that neither the UK nor US/G designs have a zone of neutral of negative roll stiffness. In contrast, the French design has a substantial net negative roll stiffness in this region due to immersion of a large amount of vertical sidehull surface in the region of the waterjet and a low chine that is immersed even when upright. This design still has an inward banking moment after helm reversal, and might therefore be considered satisfactory. However, this moment is rapidly eroded by even a modest transverse shift of center of gravity (TCG = 1% beam produces about 3 degrees static heel for this design).

The first line of roll moments shows that all the designs can be expected to bank inwards in a standard full-helm turn, but the US/G design will lurch to about 5 degrees outward heel if the helm is reversed suddenly, or substantially more if an adverse TCG exists. At 50 to 60 knots this would be potentially very dangerous and could result in capsize. It should be noted that this analysis assumes that, as observed at full-scale, in this condition the rudders lose all lift and do not in fact apply a reverse moment as waterjets can in fact do. The UK design is the only one to exhibit good characteristics in all respects, but even this will lurch to several degrees beyond the upright after helm reversal if an adverse TCG exists. The other two designs are unacceptable in this situation.

The analysis conducted above (by the UK) is still relatively unsophisticated in that it ignores the changes in yaw stiffness with heel angle. However, it has been found so far that this omission does not significantly affect the results.

It should be noted, however, that on the basis of their model and full-scale test-craft experience, both the U.S. and the French believe that their respective designs have sufficient stability. The U.S., however, admit that their ship "is close to the limit of acceptable stability in roll" and should be checked further during the next phase of design.

(d) Risk Assessment

The analysis presented here was conducted by the UK and has employed the latest methods in line with current research, taking account of as many relevant parameters as possible, and does not rely on arbitrary simplistic criteria.

However, the conclusions drawn should be reviewed when the current research effort has been completed, the methods used have been more fully proven, and detailed design information is available. The safety margins can then be assessed more accurately. Having regard to the state-of-the-art, and the implication of stability problems on vessels of this size and speed, it is important that analysis of this sort should be reinforced by a suitable model test program before undertaking construction of an actual ASW SES.

A thorough understanding of stability behavior is essential to the production of good SES designs, as it is only through this that conflicting requirements can be optimized. A high length-to-beam ratio has certain structural and hydrodynamic advantages, but the thin sidehulls and good wet-deck clearance desirable from both resistance and ride-comfort viewpoints can only be achieved simultaneously at the expense of stability. This is clearly illustrated by the three designs that have been evaluated.

The U.S. and French designs have opted for a relatively high length-to-beam ratio. In achieving a large wet-deck clearance, stability margins have been eroded. On the basis of the UK assessment, both these designs have barely sufficient Factors of Safety in beam seas, and appear to exhibit dangerous characteristics in high-speed turns.

In contrast, the UK design has achieved a greater cushion depth with good reserves of stability by adopting a significantly lower length-to-beam ratio (3.5 compared to 5.6 and 6.3). Further work on the relative merits of craft length, cushion depth, sidewall thickness and overall seakeeping and ride comfort is required to determine the best compromise. It is concluded from this comparison that high length-to-beam designs cannot sustain such high cushion depths. This represents an area of high risk.

It is recommended, that further RDT&E be accomplished, such as the conduct of free-running model or manned-craft tests and that a reliable set of dynamic stability criteria be established for all expected on-cushion operating modes.

3.3.22 Habitability

The Design Guidance Document provided general guidelines for weight and space per man for mission durations of less than 15 days and greater than 15 days. Table 3.3.22-1 provides a comparison of the space and weight per accommodation for the Point Designs to these general guidelines. The weights used are the weights per accommodation for outfit and furnishing items directly relating to personnel, provisions, personnel stores, crew and effects, potable water and general stores. The volumes include human support spaces, such as berthing, galleys and mess, administration offices, medical, recreation, ship store and personnel storerooms, and are also calculated on a per accommodation basis.

The comparison presented in Table 3.3.22-1 shows that none of the ANV Point Designs, nor the representative monohulls, meet the Design Guidance Document weight per man recommendations for a mission length greater than 15 days. The UK SES design weight per man is based on the UK-MOD allowance for a 30-day mission duration, and the UK SES report questions the design guidance recommendations. The US/G SES is also designed for a 30-day mission and the estimated weights for personnel related outfit and furnishing items are similar to the UK SES estimates. The mission length of the SWATH is specified at 30 days; however, the design weight per man fails to meet the design guidance values for this mission length.

Table 3.3.22-1. Habitability Weight and Space Comparison

	UK SES	FR SES	US/G SES	SP SES	FFG 7	U.S. Hydrofoil	CA SWATH	Design Guidance	DD 963
Weight (MT/Accom)	0.73	0.46	0.64	0.55	0.81	0.72	0.71	0.45* 1.09**	0.57
Volume*** (M^3/Accom)	19.9	21.7	16.2	16.5	14.0	14.9	21.3	14.0* 18.0**	16.9

* Less than 15-day mission
** Greater than 15-day mission
*** Ship Space Classification System (SSCS) Group 2 volume per accommodation

The design guidance space recommendations for a mission length greater than 15 days are met by the UK and FR SES's as well as by the CA SWATH, but not the US/G SES, although the US/G SES has been designed according to standard US Navy practice. It is interesting to note, however, that the FFG 7 and DD 963 Classes which have generally high habitability standards also fail to meet this criteria for the 15-day mission. The U.S. Hydrofoil has been designed for a 14-day mission and meets all of the space and weight per man recommendations. All four SES designs, the U.S. Hydrofoil and the SWATH meet the 15-day requirements.

Although in some cases the design guidance recommendations were not met, it appears the Point Designs have been designed to the habitability standards of their respective countries. These standards do not deviate significantly enough from conventional practice to represent a major area of concern for ANV development. For shorter mission durations relaxation of habitability standards to reduce weight and volume may be acceptable. Further, the emphasis on use of lightweight components on these ships may be inconsistent with a habitability goal of attaining a minimum acceptable weight per man.

3.3.23 Reliability, Maintainability, Availability

3.3.23.1 General

Reliability, maintainability and availability (RMA) are parameters that provide a measure of the operability of a particular equipment or system. Reliability can be expressed as the probability of equipment operation without failure over a specified time period, while maintainability is a measure of the time required to restore equipment to operational status in the event of a failure. Availability is then expressed as the fraction of total time that an equipment is available for use.

For the purposes of assessing impacts of advanced naval vehicle characteristics on RMA issues, only qualitative, comparative measures can be used. The feasibility levels of design and the selection of advanced equipment beyond the current state-of-the-art, do not permit realistic assignments of quantitative RMA predictions. Consequently, the emphasis in this section will be on the identification of RMA issues that differ significantly from current conventional practice.

In this context, reliability implies a measure of equipment operability as compared to existing equipment reliability. Maintainability then is a measure of complexity involved in performing maintenance on a particular equipment taking into consideration the elements of accessibility, equipment configuration and level of required technical expertise. All of the ANV Point Designs are much larger than any prior ANVs of the same type so that the extrapolation of RMA data from existing ships to the point designs can only be done with caution. Large numbers of SES have been built and operated for many years but none larger than 200T. The U.S. Navy has six PHM hydrofoils in service so that some RMA data are available for specific hydrofoil systems. Very few SWATH have been built in much smaller sizes than the point design. Form some of the subsystems on all of the ANVs RMA data may be similar to those of monohulls.

3.3.23.2 **Reliability Issues**

In general, reliability is a function of the equipment and systems installed on a particular vessel. In the case of the SES's, all have similar propulsion plants, seal systems, combat systems and support systems. Thus, it is anticipated that reliability will primarily depend on the specific vendor equipment selected.

The propulsion plants generally use state-of-the-art prime movers with proven values of reliability. The power transmission systems employ existing gear technology; however, the specific applications of these components for the SES designs are advancements of current applications, so that their reliability must be estimated from other applications. The FR SES transmission may require extensive development before reliability values are known.

The propulsors for the UK and FR SES designs are extrapolations of existing water jets produced by a vendor experienced in scaling up larger propulsors from smaller designs. In the case of the US/G SES concept more development is required to assure a reasonable configuration and demonstrated reliability for the semi-submerged, supercavitating propellers.

Of particular concern to reliability assessment of the SES's are the seals. Existing seal configurations on smaller vessels indicate service lives on the order of 2,000 hours, but that service life is predicated on frequent inspection and corrective maintenance. Reliability of the NATO SES seal concepts is an important design factor and must be considered in future phases of design.

In the area of SES combat systems, reliability is usually rigorously factored into the design of these components. It is not anticipated that reliability will be a significant concern for the ANV application of combat system components.

No significant technology differences were incorporated in the support systems of SES designs as compared to conventional monohull practice. It is thus expected that the reliability for conventional systems can be used to assess reliability of these systems on the three SES concepts.

The U.S. Hydrofoil has a combat system suite similar to that of the SES design, which suggests that reliability of components in this group will not be an issue. A major difference for reliability assessment purposes is in the method of propulsion. As with the SES designs, two types of prime movers are proposed, gas turbines and diesels. Both prime movers have previously been used in other naval applications with proven levels of reliability.

The complex transmission system is a variation of existing Hydrofoil transmission systems, but the number of different gear train boxes and their separation could have significant impact on system reliability. The controllable, reversible pitch propellers are an extrapolation of designs used on other naval high-speed craft with known reliability values.

In the case of auxiliary systems, previous Hydrofoil design practice has been to apply aircraft technology for marine use. This practice has resulted in significant reductions in installed weights, but is a more difficult approach to apply to the U.S. Hydrofoil because of the increased requirements of equipment of this large vessel. Therefore, this vessel incorporates more auxiliary ship components that are similar to conventional monohull naval vessels. A notable exception is in the hydraulic plant where aircraft type designs have been selected. Based on PHM experience, the use of aircraft components in hydrofoils does not yield values of reliability comparable to those of standard vessels. Consequently, reliability of this system may be a concern.

The CA Hydrofoil is similar to the U.S. Hydrofoil in general propulsion prime mover arrangements. The largest difference is in the propulsor configuration. Because the CA Hydrofoil has fixed foils, the same propulsor can be used for hullborne and foilborne operations. This feature plus the absence of retraction hydraulics may result in more favorable, reliable characteristics as compared to the U.S. Hydrofoil. Details of other systems are inadequate to form any other meaningful reliability projections.

The combat system on the SWATH is somewhat more extensive than that of the other ANVs, particularly in the ASW area. With the exception of the 3-D air-defense radar and the AMRAAM missile the components are primarily existing equipment with known levels of reliability.

The propulsion plant represents a unique approach with the use of an integrated electric CODAG plant. Several of the primary components including the composite shaft, the unique motor controller, the solid-state power converter and the complex machinery control system are all based on technology now under development. Furthermore, the selected prime mover, an intercooled, regenerative gas turbine, has not been proven in a marine environment, although the technology is available.

Support systems are generally more conventional, with the exception of two areas - the steering/control system and interior communications. The steering/control system is generally consistent with other SWATH designs and is comprised of fore and aft pairs of fins, where the aft fins provide steering. This configuration is a new application of existing technology and is expected, eventually, to have a reliability equivalent to that of submarine control surface or surface ship fin stabilizers. The unique portable terminals to be used for interior communications, as well as the fiber-optic distribution cables represent proven technologies in other applications, but uncertain reliability in shipboard use.

The French have observed that reliability may be sacrificed through the extensive use of advanced, light-weight components that may not have previous marine applications. Replacement of unreliable or problem components with more proven approaches during the design phase or as a backfit solution is always possible; however, it is usually accomplished at the expense of greater weight and/or cost.

3.3.23.3 Maintainability Issues

Maintainability considerations have been factored into the individual components and their configuration in the SES designs; however, somewhat different maintenance approaches among the three concepts results in differing levels of maintainability. As an example, the UK SES has allowed greater manning levels to allow for more maintenance to be accomplished at sea while, in the FR SES design, almost no maintenance is expected to be performed at sea.

The manning level of the FR SES Point Design is approximately 2.5 times less than the level on a ship with a comparable mission. This on-board complement is expected to be insufficient to perform significant corrective or preventive maintenance at sea. Consequently, few tools, component-handling systems or spare parts will be carried on board. Most maintenance is to be performed at shore-side facilities or on support ships. This scenario appears to be a deviation from conventional FR practice and would appear to warrant a reduction in the number of senior technical personnel comprising the crew. This is not true, however, as the percentage of crew made up of officers and petty officers had increased to 75% of the ships complement, as compared to 58% of the complement for conventional ships.

Issues related to accessibility of equipment and the configuration of the equipment facilitating maintenance are unknown, as they do not appear to be discussed in the design report. Where existing equipment is proposed for use, typical mean-time-to-repair (MTTR) values may be available for specific corrective maintenance procedures.

In the US/G SES design, maintainability has been considered through incorporation of routes for removal and replacement of major equipment and accessibility of equipment for in-place preventive and corrective maintenance. Soft patches provide access to prime movers while rails and other lifting fixtures have also been included to minimize maintenance man-hours.

Maintainability has been factored in the UK SES design through a number of different approaches. Examples include the use of special materials during hull and superstructure fabrication to reduce corrosion and fouling, and the specification of soft patches or removable casings for prime mover/removal installation. An additional capability is provided for obtaining access to the water jet for inspection or maintenance purposes.

For combat systems, it is anticipated that conventional maintenance procedures will be satisfactory and that no new or unique support capabilities will be required. Repair by replacement is anticipated, using modules from rotatable pools.

The on-board complement is also large enough to allow for a greater degree of on-board maintenance than is conceivable for either the US/G SES or FR SES concepts, although reliance on shoreside or ship repair facilities is expected after 30 days of operation.

The U.S. Hydrofoil is expected to use a replacement-before-failure maintenance philosophy that features the use of rotatable pool repair items, similar to those used on US FFG-7 Class vessels. The result of this approach has been to increase the size of the Engineering Operating Station. Additionally, longitudinal passageways on the ship's centerline have been provided to facilitate equipment movement below decks, while minimizing the need for soft patches on the main deck.

The criticality of weight on this design (as well as the other ANVs) precludes on-board storage of heavy rotatable pool repair items, thereby requiring some conventional corrective maintenance capability. Sufficient on-board repair parts are envisioned to allow for 30 days of operations with a 90% probability of availability.

The non-retracting foil system of the CA Hydrofoil has one adverse impact on maintainability. Because of the inability to gain easy access to foils and struts, inspection and maintenance (particularly anti-fouling) must be done by divers or when the ship is in dry dock. This negative factor is offset to a certain extent by the reduction in components to be maintained as there is no retraction system and the transmission system is simplified.

The SWATH maintenance concept is designed to reduce organizational maintenance requirements by applying the following approaches: accomplishing equipment repair through repair-by-replacement techniques, providing for equipment accessibility and equipment removal routes, minimizing preventive maintenance and the employment of an operator/ maintainer concept. Several of these ideas, notably the repair-by-replacement concept and the generous use of equipment accessibility and equipment removal routes, are more easily facilitated by the larger size of the SWATH as compared to the other ANVs, although accessibility to the lower hulls is limited.

The goal of the SWATH maintenance approach is to achieve stated vessel availabilities through the use of progressive overhaul activities of short work periods (SWPs) and docking work periods (DWPs). The SWPs are generally supported by an intermediate maintenance activity and do not exceed 20 effective working days. No more than three SWPs are planned per operational year. DWPs do not exceed 40 effective working days, at intervals of approximately 36 months. This period incorporates a SWP within it to allow for four weeks in a drydock.

The use of an operator/maintenance concept is intended to reduce overall shipboard manning through minimizing the number of non-watchstanding personnel dedicated to maintenance. Despite this approach, the SWATH has an approximate threefold increase in shipboard complement relative to the other ANVs. The manning is comparable to monohulls of the same size, and is expected to provide a greater organizational level maintenance capability.

3.3.23.4 Availability Issues

In addition to availability resulting from increased realibility and better maintainability features, availability can also be enhanced by providing redundancy in equipment as well as redundancy of functions. In this section availability resulting from redundancy in equipment or functions will be emphasized.

The configuration of the SES designs provides inherent increased availability. The two modes of operation namely: on-cushion propulsion via a gas-turbine and hullborne propulsion with a diesel engine provide some built-in redundancy. The division of power plants between the two side hulls also provides inherent redundancy for all the SES. Multiple weapon systems for specific combat missions such as ASW and AAW also provide a measure of increased availability.

In the UK SES design, a philosophy of duplication and redundancy has been adopted in order to provide a high standard of availability. Redundancy is incorporated in such items as fuel supply, lube-oil pumping and salt-water cooling for main engines. Additionally, automatic standby units are specified for such systems as fresh-water production, sewage treatment and air conditioning. Further redundancy is obtained by providing manual fall-back modes of operation for combat systems and prime-mover controls.

The US/G SES design with multiple fans and lift engines provides redundant lift capability that permits some reduced level of on-cushion propulsion should one of these systems become inoperable.

A smaller degree of of redundancy appears to have been included in the FR SES design, which may have reduced total-ship availability because of the limited on-board maintenance capability.

Increased availability through duplication of system and functions is expected to be achieved in the U.S. Hydrofoil design. This duplication exists in the propulsion system as well as the hydraulic system for foil/strut retraction and for steering.

Redundancy is included in the propulsion area by the presence of two shafts, and the option to use either of two prime movers on each shaft depending upon whether operating in a hullborne or foilborne condition. Additional availability is possible through the use of auxiliary propulsion units that are operated when the aft foil/strut assemblies are retracted.

The hydraulic system assures increased system availability by featuring groups of proven hydraulic pumps rather than a single large pump, and a distribution system that consists of smaller subsystems, each of which has a primary and an alternate source of hydraulic power that are independent of one another.

Other than the known redundancy of the CA Hydrofoil propulsion train, insufficient information about the remainder of the ship's systems is available to make an assessment of system/component availability.

With the exception of assessing the availability of ASW helicopters, no rigorous availability analyses were performed for the SWATH. The total ship availability goal for the SWATH is 85 percent, with a 75-percent level being mandatory. The integrated electric-propulsion system provides an inherent degree of redundancy in the areas of propulsion and electrical generation and distribution systems. Total availability of the propulsion system, however, cannot be adequately assessed at this time because of a number of unproven components such as the propulsion-motor controllers, the shafting and the power converter. Similarly, the SHINPADS command, control and communication systems rely on redundant data bases and large numbers of similar computers and display consoles to permit switching between components in case of failure of any one component.

Availability of auxiliary systems is expected to be comparable to that of existing monohulls as most of these components are conventional items. Other support systems such as outfit and furnishings, deck equipment, etc., for the SWATH are primarily independent of hull type, indicating availability levels consistent with those on existing ships.

3.3.24 Supply/Logistic Support Concept

Some of the aspects of integrated logistic support (ILS) have been addressed in Section 3.3.23 Reliability, Maintainability and Availability. Other important aspects of ILS include land-based test sites, special training requirements, supply support procedures, technical documentation and requirements for special tools or support equipment.

At this level of design, many of these elements have not been identified, however, where such information is available, these items have been addressed. In general the impacts of the SES and Hydrofoil designs on ILS considerations will be in the areas of manning and training, because shipboard complements are significantly reduced from those of vessels with comparable missions. In turn, reduced manning generally implies reduced capability for organizational-level maintenance.

With respect to at-sea replenishment, conventional means such as RAS and VERTREP should be enhanced because of the stable nature of the hull forms. Conversely, the weight sensitivity of these vessels results in lower potential fuel-load capability and increased frequency of fueling at sea.

For the UK SES design, an on-board maintenance capability for operational periods up to 30 days is included. Beyond 30 days, shore-based or support-vessel assistance for maintenance is anticipated.

A similar capability has been specified for the U.S. Hydrofoil with a 90% probability of attainment. It is noted that allocations of space and volume have been made for these on-board spare parts but that the weight reservation is only 67% higher than that of the PHM class which generally operate for much shorter durations. It should also be stated that typical operating profiles only require a mission duration of 14 days.

The FR SES design report does not specify any significant organizational-level maintenance capability. Only a minimum of on-board spare parts and special tooling is anticipated to be carried on-board.

Little information is provided in the US/G SES design report regarding supply support or other ILS elements. However, in general, routine maintenance is to be deferred for in-port availabilities and shore facility maintenance support. Additionally, the ratio of spare-parts weight to total full-load weight is on the order of that of the PHM Hydrofoil class where only a minimum of on-board spare parts are carried.

The SWATH provides an adequate allowance of on-board spares to sustain the ship for 90 days. Other support provisions support mission durations up to 45 days. The minimum capacity, other than fuel, is in chilled stores which allows for an endurance level of 30 days.

Repair parts and consumable requirements for the SWATH are to be determined through use of Failure Modes Effects Criticality Analyses (FMECA) and Level-of-Repair Analyses (LOR). These analyses are determined during development of Logistic Support Analyses, which is the principal tool for collecting ILS and RMA related information. These techniques are representative of conventional monohull design and ILS practices.

3.3.25 Overhaul Concepts

In general, information has not been provided in any significant detail for any of the vessels for the following major elements of the overhaul approach:

- Scheduling
- Long-lead time requirements
- Shipyard or other overhaul facility requirements including unusual drydock or mooring configurations
- Land-based test sites or other facilities.

For the US Hydrofoil, the use of a scheduled replacement approach and rotatable equipment pools indicate that designated repair facilities will be used to perform overhaul of removed components. A fix-before-fail maintenance approach and rotatable equipment pools have been used on FFG-7 Class vessels; other overhaul concepts would not be expected to diverge significantly from existing practices. Somewhat detailed overhaul concepts, consistent with exsiting Royal Navy practice, have been identified for the propulsion plant on the UK SES design.

No information is contained in the US/G SES or FR SES design reports regarding overhaul philosophy, but it is not anticipated that any significant divergence from existing overhaul approaches will be required.

The configuration of the CA Hydrofoil is such that the nonretracting foils will preclude conventional drydocks from being used. Instead a synchro-lift or similar capability will be required to support extensive maintenance of the hull or foil/strut systems.

As noted in the RMA section, overhaul of the SWATH is to be accomplished through the implementation of a progressive overhaul concept. This approach is currently being used to support conventional monohull vessels, and is essentially independent of hull type.

4.0 RDT&E NEEDS

Specific subsystems and technologies which have not been completely proven at full-scale, have been proposed for incorporation into each of the NATO ASW Point Designs. The advancement of these subsystems and technologies, to the level where they can be considered available for navy service use, or can be utilized in the design procedure with a high degree of confidence, will require varying degrees of engineering development testing and evaluation during ship acquisition.

4.1 EVALUATION OF REQUIRED TECHNOLOGIES

The subject subsystems and technologies for each of the point designs have been identified and evaluated utilizing the "Platform Technology Evaluation Methodology" described in detail in the NATO SWG/6 "Methodology for Assessing Vehicle Concepts," which has been referred to as the "Blue Book". This methodology was utilized to evaluate the subsystems and technologies of the NATO ASW Point Design on the combined basis of:

(a) need (relative to the mission(s) and proposed design),
(b) current state-of-development of the technology,
(c) current RDT&E activity (applicable to the technology), and
(d) development timeframe for the technology.

The results of these evaluations are summarized in matrices which are presented here as Tables 4.1-1, 4.1-2, 4.1-3, 4.1-4 and 4.1-5 for the UK SES, the French SES, the US/G SES, the Hydrofoil, and the SWATH Point Designs, respectively.

The descriptors which are utilized in the matrices to characterize the need, the state-of-development, the current RDT&E activity, and the development timeframe are defined in considerable detail in the aforementioned "Methodology for Assessing Vehicle Concepts." However, the descriptors utilized are relatively self explanatory and are therefore listed as follows, without definition, in order to assist in a general understanding of the evaluations presented in the matrices:

Need

- Essential
- Critical
- Enhancing

State-of-Development

- High
- Significant
- Moderate
- Low
- Minimal

RDT&E Timeframe

- Short Term (ST) - Less than 3 years
- Mid Term (MT) - 3 to 6 years
- Long Term (LT) - more than 6 years

Current RDT&E Activity

- None
- Some
- Considerable

The final numbers listed on the matrices for each technology, under "Platform Status", are a relative index of the RDT&E effort which will be required for that technology or subsystem in order to ensure that the predicted performance and mission capability of the subject Point Design will be realized. These numbers result from the PTE Methodology. While the detailed procedure is described in the Blue Book, it can be stated here, in summary, that the highest numbers result from combinations of greatest design need, lowest technology state-of-development, least current RDT&E activity, and longest required development timeframe. The technologies have been listed in the tables in the order of highest to least required development effort.

Table 4.1-1. UK NATO SES Platform Technology Evaluation Summary Sheet

PLATFORM TECHNOLOGY EVALUATION SUMMARY SHEET								
TECHNOLOGY	NEED	STATE OF DEVELOPMENT	PLATFORM TECHNICAL STATUS	CURRENT RDT&E ACTIVITY	RDT&E TIMEFRAME TO PROD	PLATFORM RDT&E STATUS	PLATFORM STATUS	COST (DEV) ($M)
(1) ASW Sonar Systems For High-Speed SES (Development, Integration, Operations)	Essential (ES, o, ES, ES)	Moderate (MO, o, MI, MO)	9 (9, o, 15, 9)	Some (S, o, N, S)	LT (LT, o, LT, LT)	2 (2, o, 2.5, 2)	18 (18, o, 37, 18)	—
(2) On-Cushion Seakeeping Prediction (Ride Control Systems)	Critical (C, C, (C, C)	Moderate (L, MO, L, MO)	6 (8, 6, 8, 6)	Some (S, S, N, S)	MT (LT, MT, MT, ST)	1.5 (2, 1.5, 2, 1.2)	9 (16, 9, 16, 7.2)	A-1.2 F-0.8 5.0 T-3.0
(3) Structural Loads Prediction	Essential (ES, C, ES, ES)	Significant (S, MO, MO, S)	6 (6, 6, 9, 6)	Some (S, S, N, S)	MT (MT, MT, MT, ST)	1.5 (1.5, 1.5, 2, 1.2)	9 (9, 9 18, 7.2)	A-2.0 M-1.2 4.0 T-0.8
(4) Long Life Restractable Unblown Drag Sheet Stern Seal	Critical (C, ES, ES, EN)	Significant (MO, S, MI, H)	4 (6, 6, 15, 1)	None (S, S, N, N)	MT (MT, MT, MT, ST)	2 (1.5, 1.5, 2, 1.5)	8 (9, 9, 30, 1.5)	A-0.4 M-0.4 3.4 F-0.8 T-1.8
(5) Hullborne Seakeeping Predictions (Hull Form, Active Roll Control)	Critical (C, C, C, C)	Moderate (S, MO, MO, MO)	6 (4, 6, 6, 6)	Some (S, S, S, S)	ST (ST, MT, ST, ST)	1.2 (1.2, 1.5, 1.5, 1.2)	7.2 (4.8, 9. 9, 7.2)	A-0.4 M-0.4 1.6 T-0.8
(6) Long Life Retractable Segmented Finger Bow Seal	Critical (C, ES, ES, EN)	Significant (MO, S MI, H)	4 (6, 6, 15, 1)	Some (S, S, N, S)	MT (MT, MT, MT, ST)	1.5 (1.5, 1.5, 2, 1.2)	6 (9, 9, 30, 1.2)	A-0.4 F-0.8 3.0 T-1.8
(7) Propulsion/Lift Transmission System	Critical (C, o, C, C)	Significant (S, o, S, S)	4 (4, o, 4, 4)	Some (S, o, S, S)	MT (MT, o, ST, MT)	1.5 (1.5, o 1.2, 1.5)	6 (6, o, 4.8, 6)	A-1.2 F-1.8 5.0 Q-2.0
(8) Fire Toxicity	Critical (C, o, C, C)	Significant (H, o, S, S)	4 (2, o, 4, 4)	Some (S, o, S, S)	ST (ST, o, ST, ST)	1.5 (1.2, o, 1.2, 1.5)	6 (2.4, o, 4.8, 6)	A-0.4 F-1.8 2.2
(9) Lightweight C^3I and Combat Systems	Critical (C, o, o, C)	Significant (S, o, o, S)	4 (4, o, o, 4)	Considerable (C, o, o, C)	LT (MT, o, o, LT)	1.5 (1.2, o, o, 1.5)	6 (4.8, o, o, 6)	67.6
(10) Lightweight Auxiliary Systems	Critical (C, o, o, C)	Significant (S, o, o, S)	4 (4, o, o, 4)	Some (S, o, o, S)	MT (MT, o, o, MT)	1.5 (1.5, o, o, 1.5)	6 (6, o, o, 6)	A-0.4 F-3.0 5.4 Q-2.0

Assessment Key: Assessment Team / (... FRG, [illegible], U.S)

Table 4.1-1. UK NATO SES Platform Technology Evaluation Summary Sheet (Continued)

PLATFORM TECHNOLOGY EVALUATION SUMMARY SHEET

TECHNOLOGY	NEED	STATE OF DEVELOPMENT	PLATFORM TECHNICAL STATUS	CURRENT RDT&E ACTIVITY	RDT&E TIMEFRAME TO PROD	PLATFORM RDT&E STATUS	PLATFORM STATUS	COST (DEV) ($M)
(11) Hullborne Resistance Prediction (Hull Form)	Critical (C, o, EN, C)	Significant (H, o, MO, MO)	4 (2, o, 2, 6)	Some (S, o, N, S)	ST (ST, o, MT, ST)	1.2 (1.2, o, 2, 1.2)	4.8 (2.4, o, 4, 7.2)	A-0.4, M-0.4, T-0.8 — 1.6
(12) GRP Lightweight Structure Fabrication	Critical (C, o, C, C)	Significant (S, o, S, S)	4 (4, o, 4, 4)	Considerable (C, o, C, C)	MT (ST, o, ST, MT)	1.2 (1, o, 1, 1.2)	4.8 (4, o, 4, 4.8)	A-2.0, F-1.8, Q-1.2 — 4.0
(13) Shock Load Prediction and Vulnerability (SES/GRP Structure)	Critical (C, o, C, C)	Significant (S, o, S, S)	4 (4, o, 4, 4)	Considerable (C, o, C, C)	ST (ST, o, ST, ST)	1 (1, o, 1, 1)	4 (4, o, 4,4)	A-0.4, T-1.8 — 2.2
(14) Electromagnetic Interference and Pulse Effects (GRP Structure)	Critical (C, o, EN, C)	Significant (H, o, S, S)	4 (2, o, 1.5, 4)	Considerable (C, o, S, C)	ST (ST, o, MT, ST)	1 (1, o, 1.5, 1	4 (2, o, 2.2, 4)	A-0.4, F-1.8 — 2.2
(15) On-Cushion Stability Prediction	Essential (ES, ES, C, C,)	High (H, S, L, H)	3 (3, 6, 8, 2)	Some (C, S, N, S)	ST (ST, MT, MT, ST)	1.2 (1, 1.5, 2, 1.2)	3.6 (3, 9, 16, 2.4)	A-0.4, M-1.2 — 1.6
(16) Mixed Flow Axial Waterjet @ 24,000 hp	Critical (C, o, EN, C)	High (H, o, S, H)	2 (2, o, 1.5, 2)	Some (C, o, S, S)	MT (MT, o, MT, MT)	1.5 (1.2, o, 1.5, 1.5)	3 (2.4, o, 2.2, 3)	A-0.4, F-1.8, Q-2.0 — 4.2
(17) Prediction of Vulnerability to Surface Weapons (SES/GRP Structure)	Enhancing (EN, o, EN, EN)	Moderate (MO, o, S, MO)	2 (2, o, 1.5, 2)	Some (S, o, S, S)	MT (MT, o, S, MT)	1.5 (1.5, o, 1.2, 1.5)	3 (3, o, 1.8, 3)	A-0.4, F-1.8 — 2.2
(18) Underwater Acoustic Signatures Reduction/Prediction (SES/Waterjet/GRP Structure)	Enhancing (C, EN, EN, EN)	Moderate (MO, MO, L, S)	2 (6, 2, 2.5, 1.5)	Some (S, S, N, S)	MT (MT, LT, MT, MT)	1.5 (1.5, 2, 2, 1.5)	3 (9, 4, 5, 2.2)	A-0.4, M-0.4, T-0.8 — 1.6
(19) Waterjet Fixed Geometry Flush Inlets	Critical (C, o, o, C)	High (H, o, o, H)	2 (2, o, o, 2)	Some (S, o, o, S)	ST (MT, o, o, ST)	1.2 (1.5, o, o, 1.2)	2.4 (3, o, o, 2.4)	A-0.4, M-1.2, F-0.8 — 2.4
(20) On-Cushion Resistance Prediction	Critical (C, C, C, C)	High (H, S, L, H)	2 (2, 4, 8, 2)	Some (S, S, N, S)	ST (MT, MT, MT, ST)	1.2 (1.5, 1.5, 2, 1.2)	2.4 (3, 6, 16, 2.4)	A-0.4, M-1.2 — 1.6

Assessment Key: Assessment Team / (UK, FRG, Italy, U.S.)

(o) Indicates No Assessment of this Technology

Table 4.1-1. UK NATO SES Platform Technology Evaluation Summary Sheet (Continued)

PLATFORM TECHNOLOGY EVALUATION SUMMARY SHEET

TECHNOLOGY	NEED	STATE OF DEVELOPMENT	PLATFORM TECHNICAL STATUS	CURRENT RDT&E ACTIVITY	RDT&E TIMEFRAME TO PROD	PLATFORM RDT&E STATUS	PLATFORM STATUS	COST (DEV)
(21) High-Speed FRP Lift Fan Impellers	Enhancing (C, o, o, EN)	Significant (S, o, o, S)	1.5 (4, o, o, 1.5)	Some (N, o, o, S)	ST (MT, o, o, ST)	1.2 (2, o, o, 1.2)	1.8 (8, o, o, 1.8)	A-0.4 F-0.8 — 2.4 Q-1.2
(22) Radar Cross Section Signature Reduction/ Prediction (SES/GRP Structure)	Enhancing (EN, o, EN, EN)	Significant (S, o, L, S)	1.5 (1.5, o, 2.5, 1.5)	Some (S, o, N, S)	ST (ST, o, MT, ST)	1.2 (1.2, o, 2, 1.2)	1.8 (1.8, o, 5, 1.8)	A-0.4 T-0.8 — 1.2
(23) Magnetic Signature Reduction/Prediction (SES/GRP Structure)	Enhancing (EN, o, EN, EN)	High (H, o, L, H)	1 (1, o, 2.5, 1)	Considerable (C, o, N, C)	ST (ST, o, MT, ST)	1 (1, o, 2, 1)	1 (1, o, 5, 1)	A-0.4 T-0.8 — 1.2
							TOTAL	128.2

Assessment Key: Assessment Team / (UK, FRG, Italy, U.S.)

(o) Indicates No Assessment of this Technology

Table 4.1-2. French NATO SES Platform Technology Evaluation Summary Sheet

PLATFORM TECHNOLOGY EVALUATION SUMMARY SHEET

TECHNOLOGY	NEED	STATE OF DEVELOPMENT	PLATFORM TECHNICAL STATUS	CURRENT RDT&E ACTIVITY	RDT&E TIMEFRAME TO PROD	PLATFORM RDT&E STATUS	PLATFORM STATUS	COST (DEV)
(1) ASW Sonar Systems for High-Speed SES	Essential (ES, o, ES, ES)	Moderate (MO, o, MI, S)	9 (9, o, 15, 6)	Some (S, o, N, S)	LT (LT, o, LT, ST)	2 (2, o, 2.5, 1.2)	18 (18, o, 37, 7.2)	—
(2) On-Cushion Seakeeping Prediction	Critical (C, C, C, C)	Moderate (L, MO, L, MO)	6 (8, 6, 8, 6)	Some (S, S, N, S)	MT (LT, MT, MT, ST)	1.5 (2, 1.5, 2, 1.2)	9 (16, 9, 16, 7.2)	A-0.4 F-0.8 T-1.8 3.0
(3) Structural Loads Prediction	Essential (ES, C, ES, ES)	Significant (S, MO, MO, S)	6 (6, 6, 9, 6)	Some (S, S, N, C)	MT (MT, MT, MT, ST)	1.5 (1.5, 1.5, 2, 1.0)	9 (9, 9, 18, 6)	A-2.0 M-1.2 T-0.8 4.0
(4) Hullborne Seakeeping Prediction	Critical (C, C, C, C)	Moderate (S, MO, MO, MO)	6 (4, 6, 6, 6)	Some (S, S, S, S)	ST (ST, MT, MT, ST)	1.2 (1.2, 1.5, 1.5, 1.2)	7.2 (4.8, 9, 9, 7.2)	A-0.4 M-0.4 T-0.8 1.6
(5) Retractable Bag and Finger Bow Seal	Critical (C, ES, ES, EN)	Significant (MO, S, MI, H)	4 (6, 6, 15, 1)	Some (S, S, N, S)	MT (MT, MT, MT, MT)	1.5 (1.5, 1.5, 2, 1.5)	6 (9, 9, 30, 1.5)	A-0.4 F-0.8 T-1.8 3.0
(6) Long Life Retractable Loop Stern Seal	Critical (C, ES, ES, EN)	Significant (S, S, MI, H)	4 (4, 6, 15, 1)	Some (S, S, N, S)	MT (MT, MT, MT, ST)	1.5 (1.5, 1.5, 2, 1.2)	6 (6, 9, 30, 1.2)	A-0.4 F-0.8 T-1.8 3.0
(7) Propulsion/Lift Power Transmission System	Critical (C, o, C, C)	Significant (S, o, S, MO)	4 (4, o, 4, 6)	Some (S, o, N, S)	MT (MT, o, MT, LT)	1.5 (1.5, o, 2, 2)	6 (5, o, 8, 12)	A-1.2 F-1.8 Q-2.0 5.0
(8) Lightweight Auxiliary Systems	Critical (C, o, o, EN)	Significant S, o o, S)	4 (4, o o, 1.5)	Some (S, o o, S)	MT (MT, o o, MT)	1.5 (1.5, o o, 1.5)	6 (6. o o, 2.2)	A-0.4 F-3.0 Q-2.0 5.4
(9) On-Cushion Stability Prediction	Critical (ES, ES, C, C)	Significant (H, S, L, S)	4 (3, 6, 8, 4)	Some (C, S, N, S)	ST (ST, MT, MT, ST)	1.2 (1, 1.5, 2, 1.2)	4.8 (3, 9, 16, 4.8)	A-0.4 M-1.2 1.6
(10) Fire Resistance (Aluminum Structure)	Critical (C, o, o, C)	Significant (S, o, o, S)	4 (4, o, o, 4)	Some (S, o, o, S)	ST (ST, o, o, ST)	1.2 (1.2, o, o, 1.2)	4.8 (4.8, o, o, 4.8)	A-0.4 F-1.8 2.2

Assessment Key: Assessment Team / (UK, FRG, Italy, U.S.)

(o) Indicates No Assessment of this Technology

Table 4.1-2. French NATO SES Platform Technology Evaluation Summary Sheet (Continued)

PLATFORM TECHNOLOGY EVALUATION SUMMARY SHEET									
TECHNOLOGY	NEED	STATE OF DEVELOPMENT	PLATFORM TECHNICAL STATUS	CURRENT RDT&E ACTIVITY	RDT&E TIMEFRAME TO PROD	PLATFORM RDT&E STATUS	PLATFORM STATUS	COST (DEV)	
(11) Hullborne Resistance Prediction	Critical (C, EN, EN, C)	Significant (H, S, MO, MO)	4 (2, 1.5, 2, 6)	Some (S, S, N, S)	ST (ST, ST, MT, ST)	1.2 (1.2, 1.2, 2, 1.2)	4.8 (2.4, 1.8 4, 7.2)	A-0.4 M-0.4 T-0.8	1.6
(12) Prediction of Ship Vulnerability to Shock Load	Critical (C, o, C, C)	Significant (S, o, MO, S)	4 (4, o, 6, 4)	Some (C, o, N, S)	ST (ST, o, MT, ST)	1.2 (1, o, 2, 1.2)	4.8 (4, o, 12, 4.8)	A-0.4 T-1.8	2.2
(13) On-Cushion Resistance Prediction	Critical (C, C, C, C)	Significant (H, S, L, S)	4 (2, 4, 8, 4)	Some (S, S, N, C)	ST (MT, MT, MT, ST)	1.2 (1.5, 1.5, 1, 1)	4.8 (3, 6, 16, 4)	A-0.4 M-1.2	1.6
(14) Mixed Flow Axial Waterjet Pump @ 28,000	Critical (C, o, EN, C)	High (H, o, S, H)	2 (2, o, 1.5, 2)	Some (C, o, S, S)	MT (MT, MT, o, MT)	1.5 (1.2, o, 1.5, 1.5)	3 (2.4, o, 2.2, 3)	A-0.4 F-1.8 Q-2.0	4.2
(15) Underwater Acoustic Signatures Reduction/Prediction	Enhancing (C, EN, EN, EN)	Moderate (MO, MO, L, S)	2 (6, 2, 2.5, 1.5)	Some (S, S, N, S)	MT (MT, LT, MT, MT)	1.5 (1.5, 2, 2, 1.5)	3 (9, 4, 5, 2.2)	A-0.4 M-0.4 T-0.8	1.6
(16) Lightweight C^3I and Combat Systems	Critical (C, o, o, EN)	High (S, o, o, H)	2 (4, o, o, 1)	Considerable (C, o, o, C)	LT (MT, o, o, LT)	1.5 (1.2, o, o, 1.5)	3 (4.8, o, o, 1.5)	67.6	
(17) Prediction of Ship Vulnerability to Surface Weapons	Enhancing (EN, o, EN, EN)	Moderate (MO, o, S, MO)	2 (2, o, 1.5, 2)	Some (S, o, S, S)	MT (MT, o, ST, MT)	1.5 (1.5, o, 1.2, 1.5)	3 (3, o, 1.8, 3)	A-0.4 F-1.8	2.2
(18) Waterjet Fixed Geometry Flush Inlet	Critical (C, o, o, C)	High (H, o, o, H)	2 (2, o o, 2)	Some (S, o o, S)	ST (MT, o o, ST)	1.2 (1.5, o o, 1.2)	2.4 (3, o o, 2.4)	A-0.4 M-1.2 F-0.8	2.4
(19) Magnetic Signature Reduction/Prediction (Aluminum Ship)	Enhancing (o, o, EN, EN)	Significant (o, o, L, S)	1.5 (o, o, 2.5, 1.5)	None (o, o, N, N)	ST (o, o, MT, ST)	1.5 (o, o, 2, 1.5)	2.2 (o, o, 5, 2.2)	A-0.4 T-0.8	1.2
							TOTAL	112.4	

Assessment Key: Assessment Team / (UK, FRG, Italy, U.S.)

(o) Indicates No Assessment of this Technology

Table 4.1-3. US/G NATO SES Platform Technology Evaluation Summary Sheet

PLATFORM TECHNOLOGY EVALUATION SUMMARY SHEET

TECHNOLOGY	NEED	STATE OF DEVELOPMENT	PLATFORM TECHNICAL STATUS	CURRENT RDT&E ACTIVITY	RDT&E TIMEFRAME TO PROD.	PLATFORM RDT&E STATUS	PLATFORM STATUS	COST (DEV)
(1) ASW Sonar Systems for High Speed SES	Essential (Es, o, ES, ES)	Moderate (MO, o, MI, MO)	9 (9, o, 15, 9)	Some (S, o, N, S)	LT (LT, o, LT, LT)	2.0 (2, o, 2.5, 2)	18 (18, o, 37, 18)	——
(2) Surface Piercing (Ventilated) CRP Propellers (27,000 hp)	Critical (o, EN, C, C)	Moderate (o, MO, L, MO)	6 (o, 2, 8, 6)	Some (o, S, N, S)	MT (o, MT, MT, MT)	1.5 (o, 1.5, 2, 1.5)	9 (o, 3, 16, 9)	12.7
(3) On-Cushion Seakeeping Prediction (Ride Control Systems)	Critical (C, C, C, C)	Moderate (L, MO, L, MO)	6 (8, 6, 8, 6)	Some (S, S, N, S)	MT (LT, MT, MT, MT)	1.5 (2, 1.5, 2, 1.5)	9 (16, 9, 16, 9)	A-1.2, F-0.8, T-3.0 — 5.0
(4) Structural Loads Prediction	Essential (ES, C, ES, ES)	Significant (S, MO, MO, S)	6 (6, 6, 9, 6)	Some (S, S, N, S)	MT (MT, MT, MT, ST)	1.5 (1.5, 1.5, 2, 1.2)	9 (9, 9, 18, 7.2)	A-2.0, M-1.2, T-0.8 — 4.0
(5) Retractable Transversely Stiffened Membrane Bow Seals	Critical (C, ES, ES, EN)	Significant (MO, S, MI, S)	4 (6, 6, 15, 1.5)	None (N, N, N, N)	MT (MT, MT, MT, ST)	2 (2, 2, 2, 1.5)	8 (12, 12, 30, 2.2)	A-0.4, M-0.4, F-0.8, T-1.8 — 3.4
(6) Retractable Planing Stern Seal	Critical (C, ES, ES, EN)	Significant (MO, S, MI, H)	4 (6, 6, 15, 1)	None (N, N, N, N)	MT (MT, MT, MT, ST)	2 (2, 2, 2, 1.5)	8 (12, 12, 30, 1.5)	A-0.4, M-0.4, F-0.8, T-1.8 — 3.4
(7) Hullborne Seakeeping Prediction (Lenticular Hulls, High L/B)	Critical (C, C, C, C)	Moderate (S, MO, MO, MO)	6 (o, 6, 6, 6)	Some (S, S, S, S)	ST (ST, MT, MT, ST)	1.2 (o, 1.5, 1.5, 1.2)	7.2 (o, 9, 9, 7.2)	A-0.4, M-0.4, T-0.8 — 1.6
(8) Hullborne Resistance Prediction (Lenticular Hulls)	Critical (o, EN, EN, C)	Moderate (o, S, MO, MO)	6 (o, 1.5, 2, 6)	Some (o, S, N, S)	ST (o, ST, MT, ST)	1.2 (o, 1.2, 2, 1.2)	7.2 (o, 1.8, 4, 7.2)	A-0.4, M-0.4, T-0.8 — 1.6
(9) Propulsion/Lift Power Transmission System	Critical (C, o, C, C)	Significant (S, o, S, S)	4 (4, o, 4, 4)	Some (S, o, S, S)	MT (MT, o, ST, MT)	1.5 (1.5, o, 1.2, 1.5)	6.0 (6, o, 4.8, 6)	A-1.2, F-1.8, Q-2.0 — 5.0

Assessment Key: Assessment Team / (UK, FRG, Italy, U.S.)

(o) Indicates No Assessment of this Technology

Table 4.1-3. US/G NATO SES Platform Technology Evaluation Summary Sheet (Continued)

PLATFORM TECHNOLOGY EVALUATION SUMMARY SHEET

TECHNOLOGY	NEED	STATE OF DEVELOPMENT	PLATFORM TECHNICAL STATUS	CURRENT RDT&E ACTIVITY	RDT&E TIMEFRAME TO PROD.	PLATFORM RDT&E STATUS	PLATFORM STATUS	COST (DEV)
(10) Lightweight Auxiliary Systems	Critical (C, o, o, C)	Significant (S, o, o, S)	4 (4, o, o, 4)	Some (S, o, o, S)	MT (MT, o, o, MT)	1.5 (1.5, o, o, 1.5)	6 (6. o, o, 6)	A-0.4, F-3.0, Q-2.0 — 5.4
(11) On-Cushion Stability Prediction (High L/B)	Critical (ES, ES, C, C)	Significant (H, S, L, S)	4 (3, 6, 8, 4)	Some (C, S, N, S)	ST (ST, MT, MT, ST)	1.2 (1, 1.5, 2, 1.2)	4.8 (3, 9, 16, 4.8)	A-0.4, M-1.2 — 1.6
(12) On-Cushion Resistance Prediction	Critical (C, C, C, C)	Significant (H, S, L, S)	4 (2, 4, 8, 4)	Some (S, S, N, S)	ST (MT, MT, MT, ST)	1.2 (1.5, 1.5, 2, 1.2)	4.8 (3, 6, 16, 4.8)	A-0.4, M-1.2 — 1.6
(13) Shock Load Prediction and Vulnerability	Critical (C, o, C, C)	Significant (S, o, S, S)	4 (4, o, 4, 4)	Some (C, o, S, S)	ST (ST, o, MT, ST)	1.2 (1, o, 1.5, 1.2)	4.8 (4, o, 6, 4.8)	A-0.4, T-1.8 — 2.2
(14) Underwater Acoustic Signatures Reduction Prediction (SES/Ventilated Propeller)	Enhancing (C, EN, EN, EN)	Moderate (MO, MO, L, MO)	2 (6, 2, 2.5, 2)	None (S, S, N, N)	MT (MT, LT, MT, MT)	2.0 (1.5, 2. 2, 2)	4 (9, 4, 5, 4)	A-0.4, M-0.4, T-0.8 — 1.6
(15) Lightweight C^3I and Combat Systems	Critical (C, o, o, EN)	High (S, o, o, H)	2 (4, o, o, 1)	Considerable (C, o, o, C)	LT (MT, o, o, LT)	1.5 (1.2, o, o, 1.5)	3 (4.8, o, o, 1.5)	67.6
(16) Prediction of Vulnerability to Surface Weapons	Enhancing (EN, o, EN, EN)	Significant (M, o, S, H)	1.5 (2, o, 1.5, 1)	Some (S, o, S, S)	ST (MT, o, ST, ST)	1.2 (1.5, o, 1.2, 1.2)	1.8 (3, o, 1.8, 1.2)	A-0.4, F-1.8 — 2.2
							TOTAL	117.9

Assessment Key: Assessment Team / (UK, FRG, Italy, U.S.)

(o) Indicates No Assessment of this Technology

Table 4.1-4. NATO Hydrofoil Platform Technology Evaluation Summary Sheet

PLATFORM TECHNOLOGY EVALUATION SUMMARY SHEET								
TECHNOLOGY	NEED	STATE OF DEVELOPMENT	PLATFORM TECHNICAL STATUS	CURRENT RDT&E ACTIVITY	RDT&E TIMEFRAME TO PROD	PLATFORM RDT&E STATUS	PLATFORM STATUS	COST (DEV)
(1) ASW Sonar Systems for Hydrofoils	Essential (o, ES, ES, ES)	Moderate (o, L, L, MO)	9 (o, 12, 12, 9)	Some (o, S, N, S)	LT (o, LT, LT, LT)	2.0 (o, 2, 2.5, 2)	18 (o, 24, 30, 18)	—
(2) Mechanical Foilborne Transmission (Right-Angle Bevel Gearboxes @ 17,000 hp)	Essential (ES, ES, ES, ES)	Significant (S, S, MO, S)	6 (6, 6, 9, 6)	Some (N, S, S, S)	MT (MT, MT, MT, MT)	1.5 (2, 1.5, 1.5, 1.5)	9 (12, 9 13, 9)	18.8
(3) Foil Strut/Steering System	Critical (ES, o, C, C)	Significant (MO, o, S, S)	4 (1, o, 4, 4)	None (N, o, S, N)	ST (MT, o, MT, ST)	1.5 (2, o, 1.5, 1.5)	6 (18, o 6, 6)	A-0.4 M-0.4 — 2.4 F-0.8 T-0.8
(4) Shock Load Prediction and Vulnerability	Critical (o, o, C, C)	Significant (o, o, MO, S)	4 (o, o, 6, 4)	Some (o, o, S, S)	MT (o, o, MT, MT)	1.5 (o, o, 1.5, 1.5)	6 (o, o, 9, 6)	A-0.4 T-1.8 — 2.2
(5) Lift System Structural Design	Critical (Es, o, C, C)	Significant (H, o, S, S)	4 (3, o, 4, 4)	Some (S, o, S, S)	ST (ST, o, ST, ST)	1.2 (1.5, o, 1.2, 1.2)	4.8 (4.5, o, 4.8,4.8)	A-2.0 M-1.2 — 4.0 T-0.8
(6) Fire Resistance (Aluminum Structure)	Critical (o, C, C, C)	Significant (o, S, S, H)	4 (o, 4, 4, 2)	Some (o, S, S, S)	ST (o, MT, ST, ST)	1.2 (o, 1.5, 1.2, 1.2)	4.8 (o, 6, 4.8,2.4)	A-0.4 F-1.8 — 2.2
(7) Automatic Control System	Essential (ES, ES, ES, ES)	High (H, H, H, H)	3 (3, 3, 3, 3)	Some (S, S, S, S)	ST (MT, ST, ST, ST)	1.2 (1.5, 1.2 1.2, 1.2)	3.6 (4.5,3.6 3.6,3.6)	A-2.0 F-0.8 — 4.6 T-1.8

Assessment Key: Assessment Team / (FRG, Canada, Italy, U.S.)

(o) Indicates No Assessment of this Technology

Table 4.1-4. NATO Hydrofoil Platform Technology Evaluation Summary Sheet (Continued)

PLATFORM TECHNOLOGY EVALUATION SUMMARY SHEET

TECHNOLOGY	NEED	STATE OF DEVELOPMENT	PLATFORM TECHNICAL STATUS	CURRENT RDT&E ACTIVITY	RDT&E TIMEFRAME TO PROD	PLATFORM RDT&E STATUS	PLATFORM STATUS	COST (DEV)
(8) Fully Submerged Transcavitating CRP Propeller (17,000 hp)	Critical (ES, o, C, C)	High (H, o, S, H)	2 (3, o, 6, 2)	None (N, o, N, N)	ST (MT, o, ST, ST)	1.5 (2, o, 1.5, 1.5)	3 (6, o, 9, 3)	A-0.4 M-1.2 T-0.8 2.4
(9) Hydroelastic Stability Prediction	Critical (o, o, C, C)	High (o, o, H, H)	2 (o, o, 2, 2)	None (o, o, N, N)	ST (o, o, ST, ST)	1.5 (o, o, 1.5, 1.5)	3 (o, o, 3, 3)	A-0.4 M-0.4 F-1.8 T-0.8 3.4
(10) Underwater Acoustic Signatures Reduction/Prediction	Enhancing (C, ES, EN, EN)	Moderate (MO, L, L, S)	2 (6, 12, 2.5, 1.5)	Some (S, N, N, S)	MT (MT, MT, MT, ST)	1.5 (1.5, 2.2, 2, 1.2)	3 (9, 24, 5, 1.8)	A-0.4 M-0.4 T-0.8 1.6
(11) Lightweight Integrated C^3I and Combat Systems	Critical (ES, C o, EN)	High (H, MO o, H)	2 (3, 6, o, 1)	Considerable (S, S, o, C)	MT (ST, MT, o, MT)	1.2 (1.2, 1.5, o, 1.2)	2.4 (3.6, 9, o, 1.2)	67.6
(12) Lightweight Auxiliary Systems	Critical (ES, o, o, EN)	High (H, o, o, H)	2 (3, o, o, 1)	Some (S, o, o, S)	ST (ST, o, o, ST)	1.2 (1.2, o, o, 1.2)	2.4 (3.6, o, o, 1.2)	A-0.4 F-3.0 Q-2.0 5.4
(13) Lift System Hydrodynamic Development	Enhancing (o, o, o, EN)	Significant (o, o, o, S)	1.5 (o, o, o, 1.5)	None (o, o, o, N)	ST (o, o, o, ST)	1.5 (o, o, o, 1.5)	2.2 (o, o, o, 2.2)	A-0.4 M-1.2 T-1.8 3.4
(14) Surface Weapons Vulnerability Prediction	Enhancing (o, C, EN, EN)	Significant (o, H, S, M)	1.5 (o, 2, 1.5, 2)	None (o, S, S, N)	ST (o, ST, ST, ST)	1.5 (o, 1.2, 1.2, 1.5)	2.2 (o, 2.4, 1.8, 3)	A-0.4 F-1.8 2.2
(15) HY-130 Anti-Corrosion Resistant Coatings	Enhancing (C, ES, EN, EN)	Significant (S, H, MO, S)	1.5 (4, 3, 2, 1.5)	Some (S, S, S, S)	MT (MT, MT, MT, ST)	1.5 (1.5, 1.5, 1.5, 1.2)	2.2 (6, 4.5, 3, 1.8)	A-0.4 F-1.8 T-0.8 3.0

Assessment Key: Assessment Team
(FRG, Canada, Italy, U.S.)

(o) Indicates No Assessment of this Technology

Table 4.1-4. NATO Hydrofoil Platform Technology Evaluation Summary Sheet (Continued)

PLATFORM TECHNOLOGY EVALUATION SUMMARY SHEET

TECHNOLOGY	NEED	STATE OF DEVELOPMENT	PLATFORM TECHNICAL STATUS	CURRENT RDT&E ACTIVITY	RDT&E TIMEFRAME TO PROD	PLATFORM RDT&E STATUS	PLATFORM STATUS	COST (DEV)
(16) Magnetic Signature Reduction/Prediction (Aluminum Ship)	Enhancing (o, o, o, EN)	Significant (o, o, o, S)	1.5 (o, o, o, 1.5)	None (o, o, o, N)	ST (o, o, o, ST)	1.5 (o, o, o, 1.5)	2.2 (o, o, o, 2.2)	A-0.4, T-0.8 — 1.2
(17) Radar Cross-Section Signature Reduction/Prediction	Enhancing (o, o, EN, EN)	Significant (o, o, L, S)	1.5 (o, o, 2.5, 1.5)	Some (o, o, N, S)	ST (o, o, MT, ST)	1.2 (o, o, 2, 1.2)	1.8 (o, o, 5, 1.8)	A-0.4, T-0.8 — 1.2
(18) Infrared Radiation Signature Reduction/Prediction	Enhancing (o, o, EN, EN)	High (o, o, L, H)	1 (o, o, 2.5, 1)	Some (o, o, S, S)	ST (o, o, MT, ST)	1.5 (o, o, 1.5, 1.5)	1.5 (o, o, 3.7, 1.5)	A-0.4, T-0.8 — 1.2
(19) Lightweight Hydraulic System Components	Enhancing (C, o, EN, EN)	High (MO, o, H, H)	1 (6, o, 1, 1)	Some (S, o, S, S)	ST (MT, o, ST, ST)	1.2 (1.5, o, 1.2, 1.2)	1.2 (9, o, 1.2, 1.2)	A-1.2, F-1.8, Q-1.2 — 4.2
							TOTAL	131.0

Assessment Key: Assessment Team / (FRG, Canada, Italy, U.S.)

(o) Indicates No Assessment of this Technology

Table 4.1-5. NATO SWATH Platform Technology Evaluation Summary Sheet

PLATFORM TECHNOLOGY EVALUATION SUMMARY SHEET									
TECHNOLOGY	NEED	STATE OF DEVELOPMENT	PLATFORM TECHNICAL STATUS	CURRENT RDT&E ACTIVITY	RDT&E TIMEFRAME TO PROD	PLATFORM RDT&E STATUS	PLATFORM STATUS	COST (DEV)
(1) UDFFC Motor Controller and 22 Mw LCI Motor	Critical	Moderate	6	Some	LT	2	12	A-0.4 F-3.0 Q-1.2 — 4.6
(2) Solid State Power Converter	Critical	Moderate	6	Some	LT	3	12	A-0.4 M-1.2 F-0.8 Q-0.4 — 2.8
(3) 20 Mw LCS Synchronous Generator	Critical	Significant	4	Some	MT	1.5	6	A-0.4 F-1.8 Q-1.2 — 3.4
(4) Stabilizer Steering	Critical	Significant	4	Considerable	ST	1	4	A-0.4 M-0.4 T-0.8 — 1.6
(5) Composite Propeller Shaft	Enhancing	Significant	1.5	Some	LT	2	3	A-0.4 M-0.4 F-1.8 Q-1.2 — 3.8
(6) Prediction of Ship Vulnerability to Surface Weapons	Enhancing	Moderate	2	None	ST	1.5	3.0	A-0.4 F-1.8 — 2.2
(7) Prediction of Ship Vulnerability to Underwater Weapons	Enhancing	Moderate	2	None	ST	1.5	3.0	A-0.4 F-1.8 T-0.8 — 3.0
(8) Magnetic Signature Reduction/Prediction	Enhancing	Moderate	2	None	ST	1.5	3	A-0.4 T-0.8 — 1.2
(9) Intercooled Regenerative Gas Turbines	Critical	High	2	Some	ST	1.2	2.4	Q-1.2 — 1.2

Assessment Key: Assessment Team

Table 4.1-5. NATO SWATH Platform Technology Evaluation Summary Sheet (Continued)

PLATFORM TECHNOLOGY EVALUATION SUMMARY SHEET								
TECHNOLOGY	NEED	STATE OF DEVELOPMENT	PLATFORM TECHNICAL STATUS	CURRENT RDT&E ACTIVITY	RDT&E TIMEFRAME TO PROD	PLATFORM RDT&E STATUS	PLATFORM STATUS	COST (DEV)
(10) Underwater Acoustic Signature Reduction/Prediction	Enhancing	Moderate	2	Some	ST	1.2	2.4	A-0.4 M-0.4 — 1.6 T-0.8
(11) Radar Cross-Section Signature Reduction/Prediction	Enhancing	Significant	1.5	None	ST	1.5	2.2	A-0.4 M-0.4 — 1.6 T-0.8
(12) Resistance Prediction	Critical	High	2	Considerable	ST	1	2	A-0.4 M-0.4 — 1.6 T-0.8
(13) Fiber Optic Distributed Data Bus System	Enhancing	High	1	Considerable	ST	1	1	A-0.4 F-1.8 — 2.2
							TOTAL	30.6

Assessment Key: Assessment Team

In order to put these ratings into proper perspective, it is necessary to consider that a technology would receive a Platform Status rating of 22.5 if it is:

(a) essential to the construction/operation of the platform (no fall-back solution),

(b) at only a moderate state of development (preliminary sub-scale tests only),

(c) receiving no current RDT&E activity, and

(d) requires a long term development program,

On the other hand, a technology would receive a Platform Status rating of only 1.8 if it is:

(a) enhancing to the construction/operation of the platform (existing technologies would prove adequate),

(b) at a significant state-of-development (has been proven at a large scale on manned testcraft),

(c) receiving some current RDT&E activity, and

(d) requires a short term development program,

The average Platform Status rating for all of the technologies identified as requiring some RDT&E for the SES point designs is only 5.6, for the Hydrofoil point design only 4.0, and for the SWATH only 4.1.

As a result of the assessments summarized in Tables 4.1-1 through 4.1-5, it is perceived that no proposed systems or technologies would require RDT&E efforts beyond what would normally be considered to remain to be accomplished at an early stage of an advanced naval vehicle development and acquisition program.

The platform technology evaluations for the SESs, the Hydrofoil, and the SWATH are based upon multiple-source information accessed by the Assessment Team. The assessments were principally influenced by inputs from the SWG/6 nations in the form of national responses to the Blue Book data requests, national responses to specific questions asked about their point designs at SWG/6 meetings, and the general exchange of information between the cognizant experts of the SWG/6 nations. Platform Technology Evaluation Summary sheets for some or all of the Point Designs were completed by the United Kingdom, Italy, Federal Republic of Germany, United States, and Canada and submitted to the Assessment Team. These inputs are included for reference in the PTE summary sheets of Tables 4.1-1 through 4.1-5. In general, the Assessment Team's evaluations agree very closely with those of the individual nations.

4.1.1 Need and State-of-Development

Detail discussions of the various technologies identified in the tables of Section 4.1 can be found in Appendix B. Discussions of these technologies are also given in Section 3.3 of this present assessment report under the appropriate subsystem heading. These subsections of Section 3.3 evaluate the Point-Design needs for proposed subsystems, the predicted subsystem performance, and the prediction technologies utilized in developing the designs. Potential fall-back technologies are identified and the state-of-development of the various hardware systems and design prediction technologies, relative to current capabilities and prior experience, are discussed. The validation and background for the need and state-of-development assessments assigned to each technology in the matrices, therefore, are contained in Section 3.3 and Appendix B.

4.1.2 Current RDT&E Activity

The assessment of current RDT&E activity for the subject technologies are straightforward and relatively self explanatory. Some RDT&E activity has been identified for the majority of the SES point design technologies, primarily because of active French, FRG, Norwegian, Spanish, U.S. and U.K. SES RDT&E programs. France, FRG and Spain are the only countries with active programs to develop a high-speed ocean-going SES. The French program is currently targeted at designing and building a 200-ton craft as a test bed for their 1200 ton ASW SES. The FRG is at an advanced stage in developing a 700 ton fast SES corvette, and Spain is constructing a 16 meter testcraft with anticipation of developing a 300 ton coastal patrol craft. In the U.S., a $5M SES technology development effort has recently been initiated. This activity includes development of surface-piercing propellers, and advanced ride-control systems, and will also examine SES producibility, seakeeping, resistance and stability. The U.S. Special Warfare Craft Medium (SWCM) program is presently considering alternatives for continuing with a design and acquisition program which could lead to the production of an SES SWCM class of about 175 tons. The low-speed MSH SES acquisition program was recently terminated. After completing its European and Canadian test and evaluation tour in 1986, the U.S. Navy's SES 200 is to be used to support the R&D effort aimed at high-L/B SES technology. This craft is also being used as the official USN at-sea test platform (site) for the Sea Vulcan 25 gunmount and fire-control weapon system. The SES 200 is also expected to support development testing for risk-reduction efforts on the special-warfare SWCM craft. In the UK, research sponsored by the USCG and UK MOD is continuing through 1987 on establishing the "Ultimate Stability Boundaries of SES" utilizing the results of extensive model testing. Production of commercial SES ferries of about 120 tons is active in Sweden and in Norway where the Navy is considering SES for MCM and coastal patrol missions.

With the exception of a few technologies which are being developed relative to other conventional ship programs, almost no SES related technologies are assessed as currently receiving the considerable RDT&E activity which could develop them to maturity, relative to a large oceangoing SES, within several years. In contrast to this is the period of the late 1970's by which time over 400 million dollars had been spent on the research, development, detail design and initial construction of the very high-speed (80 knot) 3000 ton US 3K SES.

Many of the Hydrofoil Point Design technologies are assessed as receiving no current RDT&E activity, which is attributable to the fact that no country has any national or private programs directed towards developing large sized hydrofoils. Italy, and Israel have shown little interest in developing hydrofoils beyond their Sparviero, and Shimrit classes. In the US, the PXM program is a program for follow-on ships to the PHM hydrofoils. Monohull, hydrofoil and SES variants were developed for consideration. Currently, however, the U.S. Navy plans to acquire ships built to an existing operational design, from either a domestic or foreign source.

Grumman Aerospace of the U.S. no longer has a hydrofoil division and Boeing Marine Systems has ceased active marketing of their commercial Jetfoils. The assessments of other Hydrofoil related technologies as receiving some current RDT&E activity are due primarily to programs relating to other ship types or to continued testing and evaluation of the U.S. PHM hydrofoils and PCH-1 Highpoint test craft.

Some technologies proposed for the SWATH Point Design are receiving considerable RDT&E activity relative to the U.S. T-AGOS SWATH acquisition. Also, the USCG has completed a contract design on a 600-ton SWATH patrol craft. Acquisition planning was stopped, however, due to the lack of a clearly defined mission and inability to support the project with R&D funds. The UK, FRG and Canada have active SWATH study programs, but at a minimal level with no specific acquisition program. The FRG, in cooperation with the U.S., is expected to conduct SWATH model tests within the year. Other technologies proposed for SWATHs relating to integrated electric propulsion, multiplex data distribution, are receiving some activity because of their application to conventional ships. Prediction technologies relating to combatant SWATH ships have the least active RDT&E programs.

4.1.3 RDT&E Timeframe to Production

With only a few exceptions, none of the subject technologies for the SES Point Designs, the Hydrofoil Point Designs, or the SWATH Point Design are assessed as requiring more than five years to develop and the majority are assessed as requiring less than three years. The reasonableness of these assessments is supported by the fact that the U.S. 3000 ton 3K SES design and subsystem development program went from contract award to start of construction in less than three years with only the data base developed by the 100 ton SES 100A and SES 100B development and test programs as a technology "head start"; that the 238-ton U.S. PHM hydrofoil went from contract award to start of construction in less than three years with the technology data base developed by the 57 ton PGH-2, and that the low-speed U.S. T-AGOS SWATH is being constructed to a design developed in several years from the technology base of much smaller SWATH platforms.

The technologies assessed as requiring more than five years for the SES and Hydrofoil are mission related and are 1) advanced integrated lightweight combat systems and 2) ASW sonar systems capable of countering future threats and integrating with the SES and Hydrofoil Point Design hull forms, size, and payload capabilities Components of the SWATH integrated electric propulsion system which will require full-scale development, testing, and certification are also assessed as requiring more than five years to receive approval for production.

4.2 RDT&E PRIORITIES

As was previously stated, none of the subject technologies identified as requiring or benefiting from RDT&E efforts relative to the SES, Hydrofoil, and SWATH Point Designs are considered to require development prior to the initiation of an ANV development and acquisition program. However, the platform status ratings developed for each of the technologies as presented in Tables 4.1-1 through 4.1-5, can be utilized to identify some general priority groupings of technologies for RDT&E prioritization.

4.2.1 SES RDT&E Priorities

The following lists are presented as general guidance in prioritizing RDT&E needs as they relate to corvette-sized ocean-going military ASW SESs. The technologies are listed in the order of their PTE platform status numbers which are a relative index of the effort which will be required to develop each subsystem or technology for incorporation in the lead ship. The needs have been presented in four groups as a matter of convenience, since the technologies within each group may share similar or identical platform status numbers. Not all of the technologies listed have been proposed for, or are relevant to, each SES Point Design and these technologies are so noted in the lists. Even the general SES technologies may have varying degrees of relevance to each Point Design.

The priority groupings for SES RDT&E needs are as follows:

1) SES Priority Group 1

- Advanced (Future Threat) ASW Sonar Systems for Small High-Speed Ships

2) SES Priority Group 2

- On-Cushion Seakeeping Prediction
- Structural Loads Prediction
- Surface Piercing (Ventilated) CRP Propeller (US/G)
- Transversely Stiffened Membrane Bow Seal-Retractable (US/G)
- Planing Stern Seal-Retractable (US/G)
- Unblown Drag Sheet Stern Seal-Retractable (UK)
- Hullborne Seakeeping Prediction
- Bag and Finger Bow Seal-Retractable (FR)
- Segmented Finger Bow Seal-Retractable (UK)
- Loop Stern Seal-Retractable (FR)
- Propulsion/Lift Power Transmission System
- Lightweight Auxiliary Systems

3) SES Priority Group 3

- Fire Toxicity (GRP) (UK)
- Fire Resistance (Aluminum Structure) (FR)
- Hullborne Resistance Prediction
- GRP Structural Fabrication for Large Ships (UK)

- Shock Load Prediction and Vulnerability
- On-Cushion Stability Prediction
- On-Cushion Resistance Prediction
- Lightweight C^3I and Combat Systems
- EMP Interference and Pulse Effects (GRP Structure) (UK)

4) SES Priority Group 4

- Prediction/Reduction of Underwater Acoustic Signatures
- Large Mixed-Flow Axial Waterjets (UK, FR)
- Prediction of Vulnerability to Surface Weapons
- Waterjet Fixed Geometry Flush Inlets (UK, FR)
- High-Speed FRP Lift-Fan Impellers (UK)
- Prediction/Reduction of Radar Cross-Section Signature
- Prediction/Reduction of Magnetic Signature (GRP & Al. Hull) (UK, FR)

Figure 4.2.1-1 shows a graphical comparison of the Priorities for SES RDT&E.

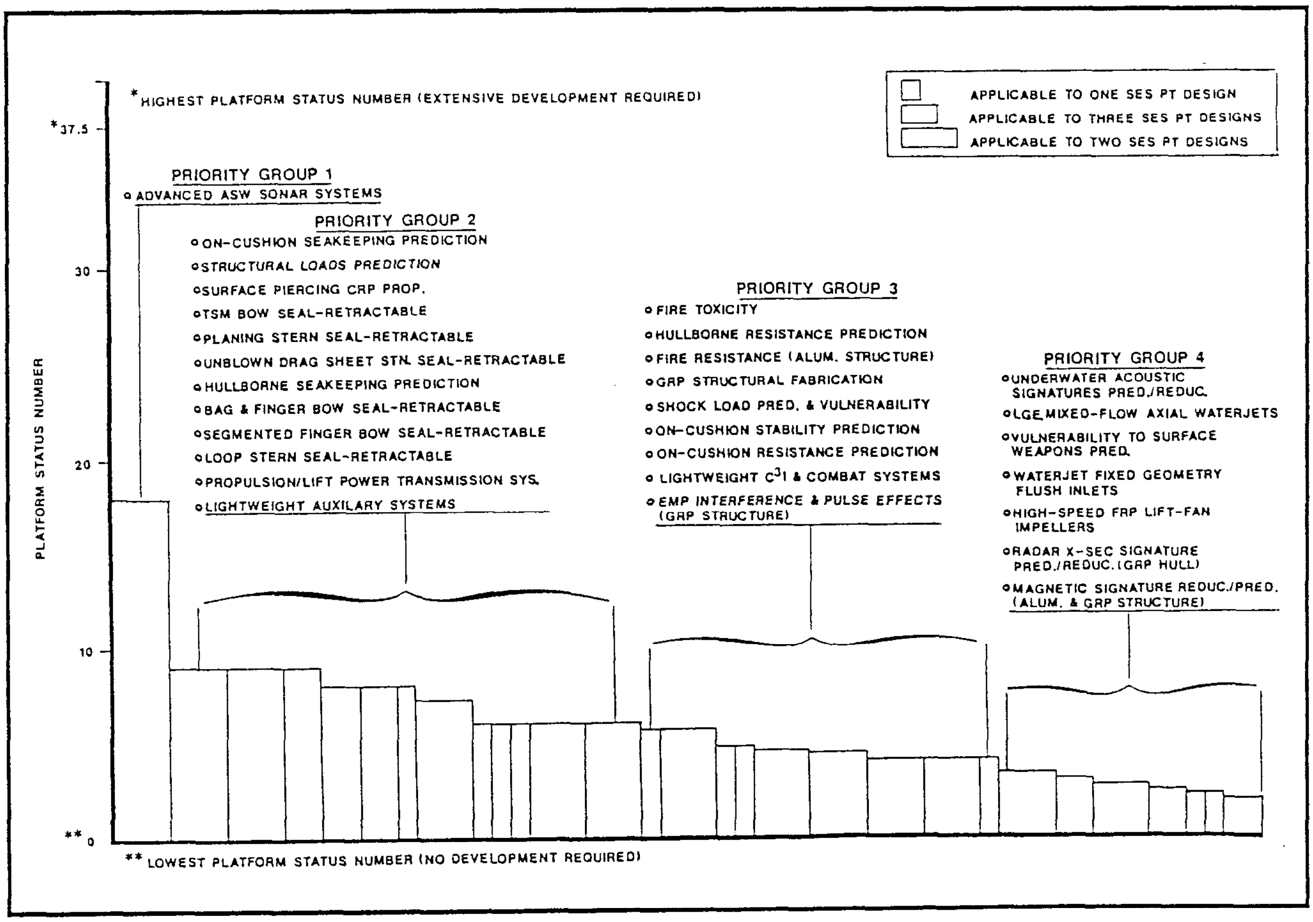

Figure 4.2.1-1. Prioritization of SES RDT&E

4.2.2 Hydrofoil RDT&E Priorities

The following list provides guidance in prioritizing RDT&E needs for ocean-going military ASW hydrofoils in general and the NATO SWG/6 Hydrofoil Point Design in particular:

1) Hydrofoil Priority Group 1

- Advanced (Future Threat) Sonar Systems for Small High-Speed Ships

2) Hydrofoil Priority Group 2

- Mechanical Foilborne Transmission (Z-Drive)
- Foil/Strut Steering System
- Prediction and Vulnerability to Shock Load

3) Hydrofoil Priority Group 3

- Lift-System Structural Design
- Fire Resistance (Aluminum Structure)

4) Hydrofoil Priority Group 4

- Automatic-Control System
- Fully-Submerged Transcavitating CRP Propeller
- Hydroelastic-Stability Prediction
- Reduction/Prediction of Underwater Acoustic-Signature
- Lightweight Integrated C^3I and Combat Systems
- Lightweight-Auxiliary Systems
- Lift-System Hydrodynamic Development
- Reduction/Prediction of Magnetic-Signature
- HY-130 Anti-Corrosion Resistant Coatings
- Prediction of Ship to Surface-Weapons
- Reduction/Prediction of Radar-Cross-Section
- Reduction/Prediction of Infrared-Radiation Signature
- Lightweight-Hydraulic System Components

Figure 4.2.2-1 shows a graphical comparison of the Priorities for Hydrofoil RDT&E.

4.2.3 SWATH RDT&E Priorities

The following is a list of RDT&E priorities for the SWATH Point Design:

1) SWATH Priority Group 1

- UDFFC Motor Controller and 22 mw LCI Motor
- Solid-State Power Converter

2) SWATH Priority Group 2

- 20 mw LCS Synchronous Generator

3) SWATH Priority Group 3

- Stabilizer Steering
- Composite Propeller Shaft
- Prediction of Ship Vulnerability to Surface Weapons
- Prediction of Ship Vulnerability to Underwater Weapons
- Reduction/Prediction of Magnetic-Signature

4) SWATH Priority Group 4

- Intercooled Regenerative Gas Turbine
- Reduction/Prediction of Underwater Acoustic-Signature
- Reduction/Prediction of Radar-Cross-Section Signature
- Resistance Prediction
- Fiber-Optic Distributed Data-Bus System

Figure 4.2.3-1 shows a graphical comparison of priorities for SWATH RDT&E.

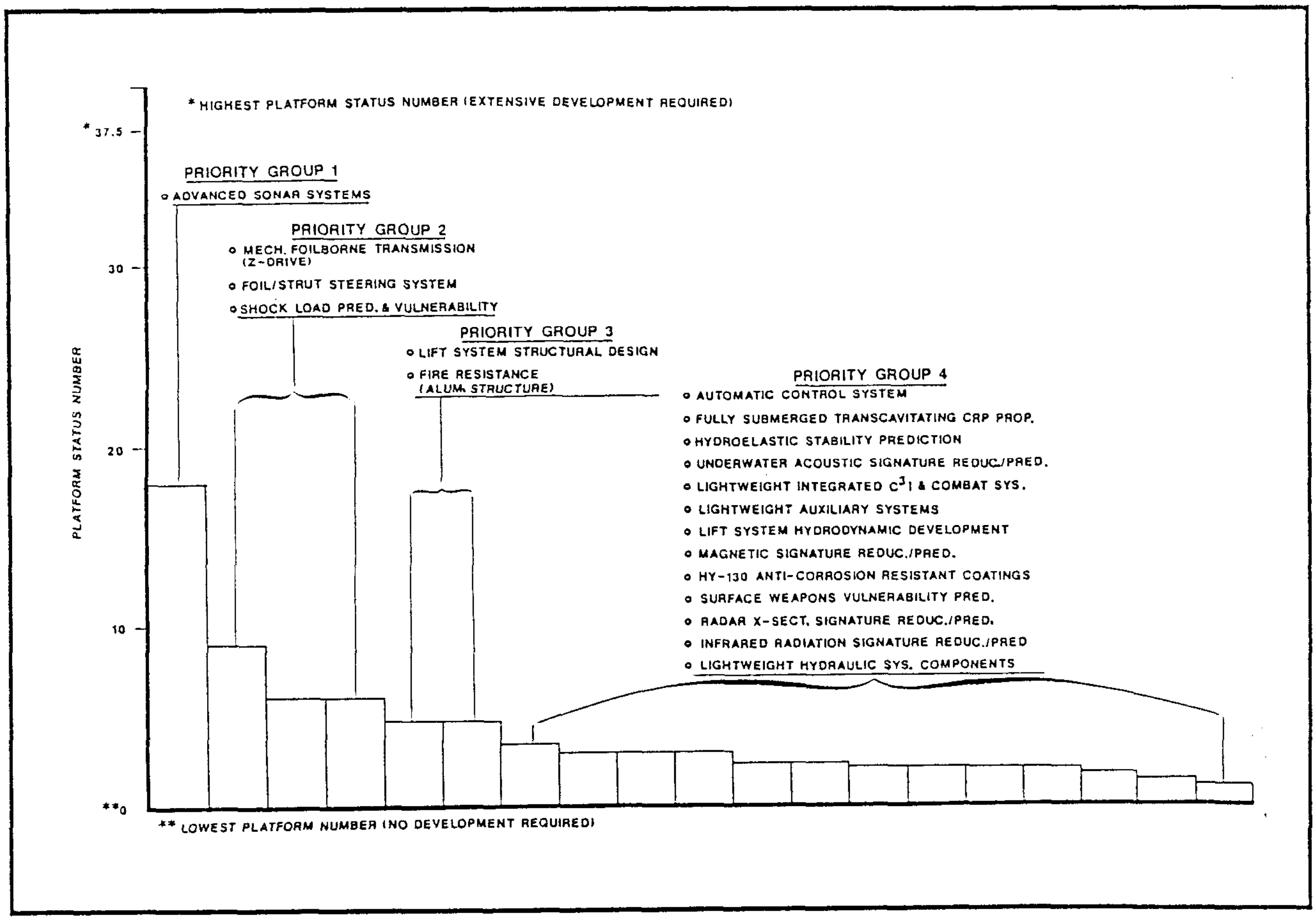

Figure 4.2.2-1. Prioritization of Hydrofoil RDT&E

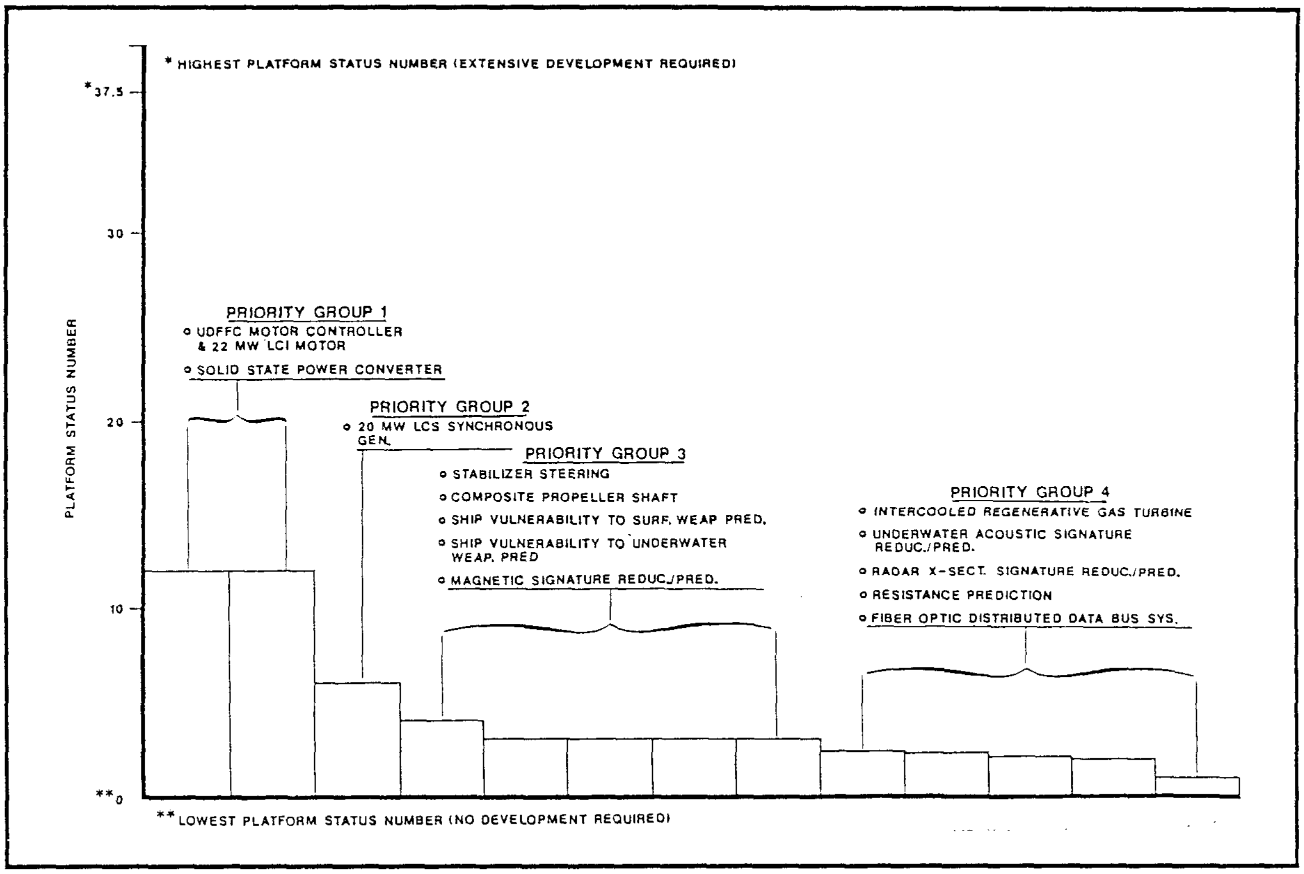

Figure 4.2.3-1. SWATH RDT&E Needs Prioritization

4.3 RDT&E COSTS

The RDT&E costs presented for each technology in the tables of Section 4.1 are estimates generated by the assessment team. These costs are the costs to develop, test, evaluate, and qualify components that are not currently approved for production. All costs are given in constant 1986 U.S. dollars.

With the exception of the development of some combat systems, all of the subsystem and technology development which is considered to be required falls into the category of Advanced Engineering Development. For example, within the U.S. ship research, development and acquisition procedure, funding for this activity would be included in a ship acquisition program as Subsystem Development and Land-Based Test-Site Funds.

Figures 4.3-1 and 4.3-2 show notional development and acquisition schedules for an ASW Corvette Point Design, with and without a smaller platform as an intermediate step, and identifies the phases during which RDT&E funds for subsystem development should be available. The schedules presented in Figures 4.3-1 and 4.3-2 follow closely, chronologically, the actual acquisition schedules for the U.S. 100A and 100B SESs, the U.S. PHM Hydrofoil, the Japanese SWATH Kaiyo, the U.S. LCAC ACV, and other advanced naval vehicle lead-ship or prototype development programs. Extensive development of subsystems and performance prediction technology was undertaken during the design phases of all of these programs. Of course, the RDT&E needs identified for the SES, Hydrofoil, and SWATH in the previous sections will benefit from continued development separate from any specific acquisition program, just as the technology for conventional ships is continually developed in national labs for application to future ships.

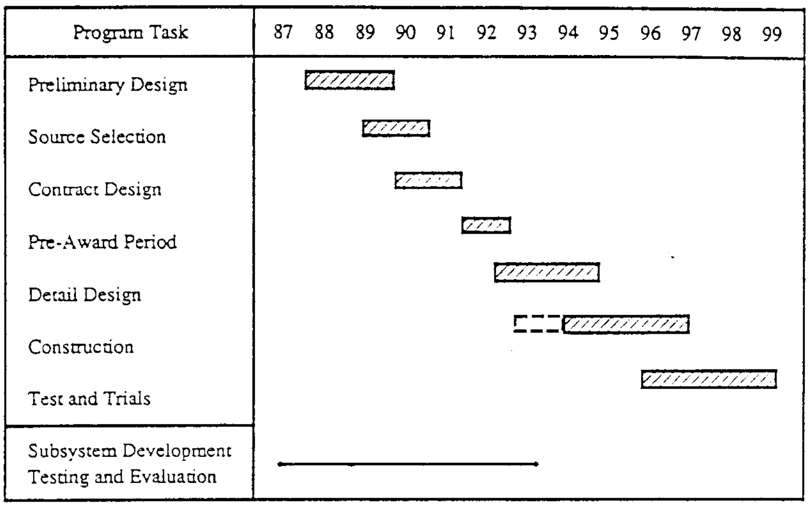

Figure 4.3-1. Notional Acquisition Schedule for ASW Corvette Point Design With No Intermediary Platform

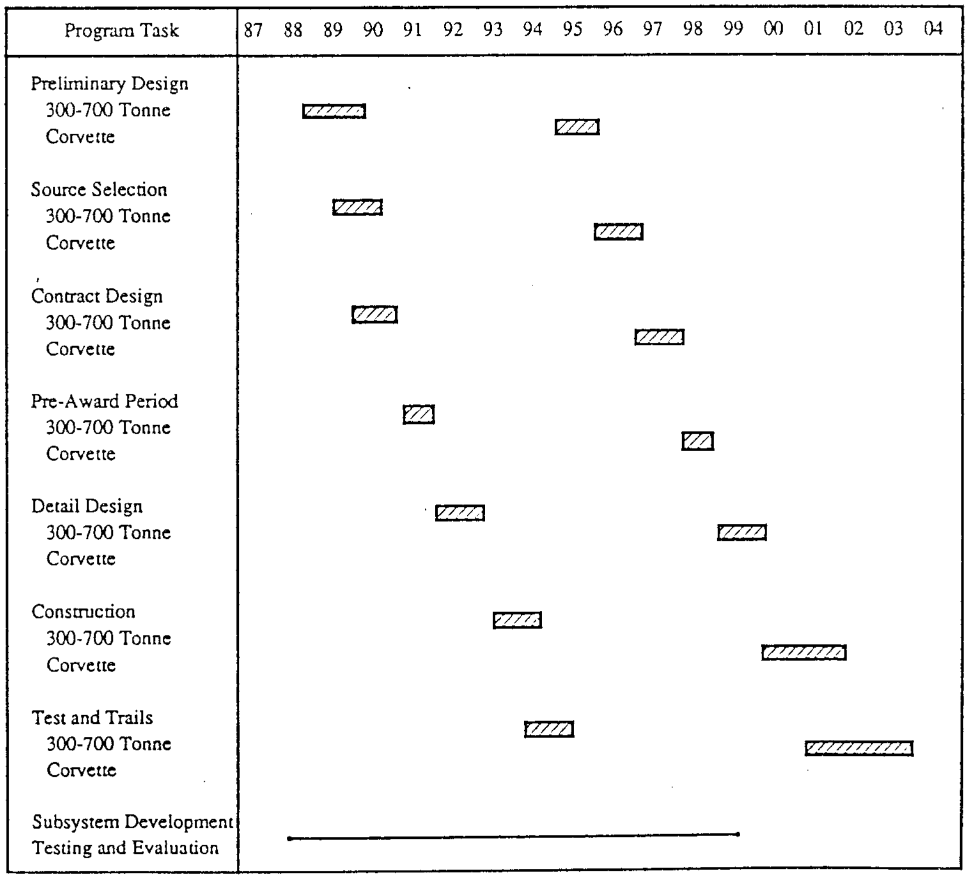

Figure 4.3-2. Notional Acquisition Schedule for ASW Corvette Point Design With an Intermediate Platform

RDT&E costs for developing the Sonar Systems that are required for each Point Design have not been included in the estimate. It was felt that accurate estimates could not be made from information available to the assessment team and that development of the sonar system would be accomplished, to a large extent, in programs not directly related to acquisition of one of the NATO ASW Point Designs. However, RDT&E costs for the Lightweight C^3I and Combat Systems have been estimated based on development cost estimates for the U.S. PXM SES (1400 LT).

The development costs for each of the Point Design technologies were estimated by the following procedure, using the rating system of Figure 4.3-3:

1) Select the program elements considered to be required to develop each technology to the level were they can be considered available for Navy service or ship design use.

2) Select the level of activity (funding) required within each program element.

Section 4.1 Tables Key	Program Element	Level of Activity	Cost* ($M)
A	Analysis & Engineering	High	2.0
		Medium	1.2
		Low	0.4
M	Model Tests & Subscale Tests	High	2.0
		Medium	1.2
		Low	0.4
F	Full-Scale Land-Based Tests	High	3.0
		Medium	1.8
		Low	0.8
T	Testcraft Tests	High	3.0
		Medium	1.8
		Low	0.8
Q	Qualification Testing	High	2.0
		Medium	1.2
		Low	0.4

*Constant 1986 U.S. Dollars

Figure 4.3-3. Estimating Procedure for Technology Development Costs

The program elements and funding level assessed to be required for each technology are listed in the last column of Tables 4.1-1 through 4.1-5 along with the total cost. For those technologies where only a single cost number appears in this column, the estimate was based on a more rigorous development cost estimate from other programs. It should be noted that the funding proposed to be required for subsystem development includes the costs of subsystem design studies, subsystem trade-off studies, engineering design and analysis, performance analysis, subsystem fabrication drawings and specifications, subsystem fabrication costs, test facilities, test personnel, test instrumentation, test plans, testcraft support, documentation, management, and administration. These costs will be incurred by the Navy, other Government agencies (shipyards, laboratories, research centers), and by private contractors.

It will be noted that testcraft tests are one of the proposed development program elements. It is considered that a testcraft of suitable scale will be available for the development of the various technologies. The cost of designing and building, or modifying, an existing testcraft is estimated at $15M for each of the Point Designs.

Table 4.3-1 summarizes the development costs (costs incurred by the Navy to develop a ship's design from feasibility studies to award of the lead-ship construction contract) for each of the Point Designs. The design development costs (feasibility studies, preliminary design, contract design, pre-award period) presented in Section 5.1 of this report are included in Table 4.3-1.

Considering that the total development costs presented in Table 4.3-1 represent only about 2.0% of the total life-cycle cost of a 12-ship buy, as presented in Section 5.2, for each of the Point Designs, the development costs for each Point Design are very similar. The slightly higher Technology Development costs for the U.K. SES relate directly to the use of GRP structure for a large high-speed combatant ship and the development of this technology. The slightly lower Technology Development costs for the SWATH relate to its use of fewer advanced technologies.

Table 4.3-1. Development Costs for NATO ASW Point Designs

Development Costs for NATO ASW Point Designs in Millions of FY 1986 Constant U.S. Dollars					
Cost Element	UK SES	FR SES	US/G SES	US Hydrofoil	CA SWATH
Design Development (from Section 5.1)	30.0	30.0	30.0	30.0	53.0
Technology Development*	60.6	44.8	50.3	63.4	30.6
Development Testcraft	15.0	15.0	15.0	15.0	15.0
Total	105.6	89.8	95.3	108.4	98.6

*Does Not Include Combat, C^3I, and Sonar Systems

5.0 ACQUISITION AND LIFE-CYCLE COST

Life-cycle cost (LCC) is the total cost of development, investment, operation and support of a class of ship. Table 5.0-1 is a summary of the LCC estimates made by the U.S. Navy for each Point Design. Comparable payload costs were not estimated by the U.S. for the UK SES, the FR SES, the SP SES, the CA Hydrofoil, or the SWATH and so total LCC estimates for these are not presented in Table 5.0-1. Payload-cost estimates for these Point Designs were made, however, by the Assessment Team (based, in some cases, on National inputs) and are included in Volume I. For comparison, Table 5.0-1 also displays investment and operations and support costs for 12 FFG 7s. All estimates are presented in millions of FY-86 constant dollars. Because the estimates were developed from U.S. historical cost data, the estimates reflect U.S. practices for design, construction, operations, maintenance, and budgeting. The estimates were based on the following additional assumptions:

1. although designed by NATO requirements, a single country (the U.S.) will design and build all ships of each design
2. the design development period will last 36 months
3. all platform and combat-system equipment will be in production by the time each lead ship is built
4. 12 ships of each design will be built in series in a single yard
5. each ship will operate 2700 steaming hrs/yr underway and 1950 steaming hrs/yr not underway
6. each Hydrofoil and SES will operate for 20 years
7. and each SWATH and FFG 7 will operate for 30 years.

The following paragraphs briefly explain what costs are included in the estimates for development, investment, and operations and support.

5.1 Development Costs

Development costs include the costs incurred by the Navy to develop a ship's design from feasibility studies to the award of the lead ship's construction contract. These costs are for design studies and engineering to perform trade-off studies, to analyze performance, to develop ship-maintenance and training plans, and to develop the shipbuilding specifications and guidance drawings. The costs include NAVSEA's design effort, support from other government agencies (shipyards, laboratories, research centers), and the support of private contractors. The payroll cost of NAVSEA personnel involved in the design are not included in the estimate. For this estimate, NAVSEA's in-house costs are considered a Navy overhead function.

Table 5.1-1 lists the design development estimate for the designs. The pre-award period represents the time between the formal completion of contract design and the award of the contract to build the lead ship. During this period, negotiations with the shipbuilder often require changes to drawings and to specifications and other additional engineering effort.

The cost to develop and to qualify components and technologies that are not currently approved for production may significantly effect the RDT&E costs of an advanced naval vehicle. However, because the R&D may be funded separately or may be shared with other programs, these costs are not included in the estimates of development costs. These R&D costs were addressed in Section 4 of this report.

Table 5.0-1. Life-Cycle Cost Estimates in Millions of FY-86 Constant Dollars
Rough Order of Magnitude Estimates*

	UK SES	FR SES	SP SES	US/G SES	U.S. Hyd	CA Hyd	SWATH	FFG 7
Design Development	30	30	30	30	30	30	53	0
Investment (w/o Payload)	1280	1200	1290	1525 +	1625 +	1020	3915	1945
Payload	**	**	**	740	680	**	**	1110
Operations and Support	2909	2424	2501	2302	1771	1394	8568	4129
12 Ship Total (w/o Payload)	4219	3654	3821	3857	3426	2444	15,537	6074
Average Cost (w/o Payload)	352	305	318	321	286	204	1045	506
12 Ship Total (w/Payload)	**	**	**	4597	4106	**	**	7184
Average Cost (w/Payload)	**	**	**	383	342	**	**	599

*These estimates reflect U.S. practices for design, construction, maintenance, operations, and budgeting and are suitable for comparison purposes within the scope of this study.

+Cost estimates for payload equipment were based on the projected costs of the latest production equipment most similar in function to those specified. Cost was not included for the notional towed array on the US/G SES.

**Payload costs were estimated by the assessment team for the purpose of developing the cost summaries and comparisons presented in Volume I (Synopsis). These estimates were not official U.S. Navy estimates and are not presented in this table.

Table 5.1-1. Design Development Costs in Millions of FY-86 Dollars
Rough Order of Magnitude Estimates

	SES/Hyd	SWATH
Feasibility Studies (6 mo.)	1.5	3.7
Preliminary Design (6-8 mo.)	5.2	13.0
Contract Design (12 mo.)*	20.9	32.2
Pre-Award Period (12 mo.)	2.2	3.7
TOTAL	29.8	52.6

*Includes the cost for three shipyards to participate in contract design.

5.2 Investment Costs

Investment costs include all procurements that would be paid for with Shipbuilding and Conversion, Navy (SCN) funds. SCN funds cover the cost of ship construction, government-furnished payload equipment, outfitting and post delivery work, and the cost of miscellaneous programs. Estimates of investment costs are displayed in Table 5.2-1. The costs displayed for FFG 7 are based on the average cost of ships procured from 1980 through 1983.

Table 5.2-1. Invest Costs in Millions of FY-86 Constant Dollars
Rough Order of Magnitude Estimates

	UK SES	FR SES	SP SES	US/G SES	US Hyd	CA Hyd	SWATH	FFG 7**
Lead Ship								
Construction	145	135	135	165	195	115	425	-
Payload	-	-	-	115 +	110 +	-	-	-
Misc. Costs & Reserves	40	40	40	45	45	40	70	-
Outfit & Post Del.	10	10	10	10	10	10	30	-
Lead Ship (w/o Payload)	195	185	185	220	250	165	525	-
Lead Ship Total	-	-	-	335	360	-	-	-
11 Follow Ships								(12 ships)
Construction	905	850	915	1100	1150	685	2620	1660
Payload	-	-	-	625 +	570 +	-	-	1110
Misc Costs & Reserves	105	100	105	110	110	90	435	125
Outfit & Post Del.	75	65	85	95	115	80	335	160
Follow Ships (w/o Payload)	1085	1015	1105	1305	1375	855	3390	1945
Follow Ship Total	-	-	-	1930	1945	-	-	3055
Program (w/o Payload)	1280	1200	1290	1525	1625	1020	3915	1945
Average Cost (w/o Payload)	107	100	108	127	135	85	326	163
Total Program Investment	-	-	-	2265	2305	-	-	3055
Average Cost Per Ship	-	-	-	189	192	-	-	255

*These estimates reflect U.S. practices for design, construction, maintenance, operations, and budgeting and are suitable for comparison purposes within the scope of this study.

**Based on the average cost of procuring FFG 7s between 1980 and 1983.

+Cost estimates were based on the projected costs of the latest production equipment most similar in function to those specified. Cost was not included for the notional towed array on the US/G SES.

Ship construction costs include funds normally paid to the shipbuilder. These are covered by the SCN major categories of Plan Costs, Basic Construction, Change Orders, and Escalation. (Budgetary definitions for these and other SCN major categories can be found in the NAVSEA Financial Management Manual (NAVSEAINST 7000.1) or in NAVCOMPT Manual 024500.)

Plan costs include the costs of detail design; construction plans; engineering specifications; and the preparation of manuals, damage control books, general information books, and other software deliverables associated with a ship. Plan costs were assumed only to occur with a lead ship. The cost of incremental changes, that are made to a design as a class is built, is covered by change orders.

Basic construction costs include the costs of labor, material, overhead, and profit to build a ship in a private shipyard. This category includes the cost to install payload equipment but not the cost of the equipment itself. The estimates for the 11 follow ships of each design reflect cost-quantity improvements resulting from applying learning-curve theory to the lead ship's labor costs. No cost-quantity reductions were applied to the material portion of the estimate for the lead ship. All ships were assumed to be built in a single yard.

Change-Order cost cover the costs associated with changes to a shipbuilding contract during a ship's construction.

Escalation cost is an allowance to cover shipbuilding costs expected to increase during the construction period due to economic factors beyond the control of the shipbuilder. Because the LCC estimates are in constant dollars, escalation is not included.

Payload cost includes the cost of all mission electronics, armament, and information supplied to the shipbuilder by the Government. Payload does not include the cost of embarked helicopters and expendable ordnance. For the notional combat system equipment on the U.S. Hydrofoil and the US/G SES, estimates were based on the projected cost of the latest production equipment most similar in function; or, if not in production for the U.S. Navy, estimates were based on inputs from prospective contractors. Comparable cost estimates of payload were not developed by the U.S. Navy for the UK SES, the FR SES, the SP SES, the CA Hydrofoil, or the SWATH, but estimates of these were made by the Assessment Team and included in Volume I.

Miscellaneous costs and reserves include costs of planning to maintain and to service a ship's subsystems; government-furnished engineering support services; transportation; the commissioning ceremony; and the project manager's growth reserve. These equate with the SCN major categories of Other Costs and Project Manager's Growth.

Outfitting costs include costs for government-furnished outfitting material. Post delivery cost is an allowance for work items on the INSURV worklist approved by the project manager for the correction of defects and deficiencies, and for work deferred while a ship is under construction.

5.3 Operating and Support Costs

Operations and support (O&S) costs for the designs are presented in Table 5 5.3-1. the costs displayed for FFG 7 are based on O&S cost reported by the project entitled "Visibility and Management of Operating and Support Costs-Ships" (VAMOSC-SHIPS) for 1981 through 1985. Definitions for the cost elements are given in the following paragraphs.

Table 5.3-1. Annualized Operating and Support Costs in Millions of FY-86 Dollars
Rough Order of Magnitude Estimates

	UK SES	FR SES	SP SES	US/G SES	U.S. Hyd	CA Hyd	SWATH	FFG 7+
Direct Personnel	2.83	1.88	1.99	1.91	1.29	0.97	4.99	3.71
Operations (less Fuel)	1.72	1.09	1.51	1.11	1.11	0.81	2.10	1.63
Fuel	4.27	3.74	3.79	3.79	1.77	1.02	5.18	1.94
Direct Maint. & Mod.	2.98	2.81	2.54	2.20	2.66	2.39	10.32	3.50
Recurring Investment	0.47	0.47	0.47	0.47	0.47	0.47	0.84	0.43
Indirect Costs	0.15	0.11	0.12	0.11	0.08	0.16	0.37	0.26
Annual O&S Cost Per Ship	12.12	10.10	10.42	9.59	7.38	5.82	23.80	11.47
Years of Service Life	20	20	20	20	20	20	30	30
Lifetime O&S Cost Per Ship	242.40	202.00	208.40	191.80	147.60	116.20	714.00	344.10
Number of Ships	12	12	12	12	12	12	12	12
Total Lifetime O&S Cost	2908.80	2424.00	2500.80	2301.60	1771.20	1394.40	8568.00	4129.20

+Based on the average cost of operating an FFG 7 between 1981 and 1985 as reported by the VAMOSC-SHIPS project office.

Direct personnel cost includes the cost of pay and allowances for the ship's crew and the cost of temporary additional duty pay (TAD). TAD is the cost of travel for training, administrative purposes, and crew rotation.

Direct operations cost less fuel cost is composed of the costs for repair parts, supplies, training expendable stores, and purchased services. Repair parts cover the cost of repair parts used by a ship's crew in maintaining the ship and installed equipment. Supplies include the costs of consumables that are not classified as repair parts and of repair material used by the ship's crew during overhauls. Training expendable stores is the cost of ammunition, training missiles, and pyrotechnics expended by the ship in non-tactical operations and training exercises. Purchased services is the cost for the ship to buy printing services and publications not carried in Government's standard stock; to rent automatic data processing equipment and related services; and to pay for rents, utilities, long distance-telephone services, postal charges, and other miscellaneous services which are not provided by Navy activities.

Fuel cost is composed of the cost of fossil fuel; and other petroleum, oil, and lubricants (POL). Fossil fuel is the cost of fuel consumed each year in peacetime operations by the propulsion plant and by the electric plant. The cost of fuel is a direct computation of the estimated fuel used each year and the cost per ton to buy, store, and deliver fuel. Based on FFG 7-class usage, each design is assumed to operate 2700 steaming hrs/yr underway and 1950 steaming hrs/yr not underway. From this assumption and fuel burn rates, the estimated fuel consumptions are 10,511 t/yr for each UK SES; 9242 t/yr for each FR SES; 9352 t/yr for each SP SES; 9323 t/yr for each US/G SES; 4372 t/yr for each U.S. Hydrofoil; 2522 t/yr for each CA Hydrofoil; and 12,845 t/yr for each SWATH. As a point of reference, the VAMOSC-SHIPS database reports the average fuel consumption over the last five years of an FFG 7-class ship as 4796 t/yr. Because the two hydrofoils, the three SESs, and the SWATH are assumed to operate the same number of hours per year as an FFG 7, the difference in yearly fuel consumption is due to differences in the propulsion plants and differences in the speed-time operating profiles. The price of fuel used in the estimate is $403/t. This amount includes $255/t as the purchase price of the fuel, $22/t for storage, and $126/t as a delivery charge. The delivery charge is a pro-rata share of the cost to own and operate the AOs, AOEs, and AORs used to deliver fuel at sea. Other POL is the cost of fuel for portable self-powered equipment, lubricants, and hydraulic oil.

Direct maintenance cost is the cost of intermediate- and depot-level maintenance of the ship. Intermediate-maintenance activity (IMA) covers the cost of material and labor expended by a tender, repair ship or an ashore IMA to repair, or alter, a ship. Depot maintenance covers the cost of work done in a shipyard to maintain and modernize a ship, to overhaul ordnance and HM&E equipment that are removed from the ship and sent to depots for repair, to pay for the design services allocation program, and to purchase material that the Navy supplies to shipyards without charge.

Recurring investment cost is composed of the cost of exchanges and issues. Exchanges cover the pro-rata share of the cost to repair repairable parts which a ship draws from the supply system. Issues consist of the pro-rata share of the cost to replenish spares stocks as a result of condemning repairable parts as being beyond economic repair, or for other reasons.

Indirect costs cover other services and items that are required during the service life of the ship but not directly relatable to a particular ship. For the SWG/6 designs, the indirect costs are composed of training; publications; engineering and technical services; and ammunition handling. Training is the cost to operate and maintain training facilities which provide general or specialized training to the ship's crew. Publications are the pro-rata share of replenishment publications ordered by a ship. Engineering and technical services cover the costs for services which are provided to the ship by the various naval-system commands during other times than IMA or Depot availabilities. Ammunition handling costs is the cost of on-loading and off-loading ammunition by coastal weapon-handling stations and their annexes.

5.4 Independent Estimate For ANV Acquisition Cost

Estimates for acquisition costs of the SWG/6 Point Designs have been developed by some of the participating nations. As with the costs developed by the Chairman's Assessment Team, these costs reflect national practices and economic conditions; therefore, caution must be exercised in making direct comparisons.

Table 5.4-1 contains a summary of the UK estimate for lead-ship acquisition costs for the three SWG/6 SESs. Only lead-ship costs have been included and costs have been converted to 1986 U.S. dollars. These costs exclude "value-added tax" and are based on average builder's labor, overhead, and profit rates. UK equipment and material prices have been assumed where the various national prices were not known.

Table 5.4-1. UK Estimated SES Acquisition Cost

	UK SES	FR SES Acquisition Cost	US/G SES M
Basic Ship With Margins	70.4	61.7	82.6
Contingency	7.1	6.2	7.7
Total Platform	77.6	67.9	90.3
First of Class Costs	35.0	30.9	32.0
Design	17.0	15.4	20.7
Weapons	29.9	Not Known	Not Known
NOTE: Exchange rate used for 1986 = $1.47/1£			

Table 5.4-2 presents a French estimate of "prototype" costs for the SES point designs. The costs were originally in 1986 Francs and have been converted to 1986 dollars.

Table 5.4-2. French Estimate - SES Prototype Acquisition Costs ($M)

	FR SES	UK SES	US/G SES
Design & Development	35.9	32.7	40.8
Industrial Investment	13.1	19.6	9.8
Trials & Logistics	16.3	16.3	16.3
Ship w/o Payload	132.3	130.7	148.7
TOTALS	197.7	199.3	215.7
NOTE: Exchange rates used: $1 = 6.25 Francs			

Table 5.4-3 contains a summary of an estimate made by Spain for their SES point design. The values are in $M and have been converted from Pesatas using 1986 exchange rates. Since no year was given for the Spanish estimate, 1986 was assumed.

Table 5.4-3. Spanish Estimate - Spanish SES Lead-Ship Acquisition Costs ($M)

Design (Feasibility Studies - Detail Design)	22.0
Basic Ship Construction w/o Payload	64.4
Shipyard Building Contingency	2.5
Contingency (Other)	6.7
TOTAL	95.6
NOTE: Exchange rate used" $1 = 140.04 Pesatas	

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Shipyard Building Contingency	2.5
Contingency (Other)	6.7
TOTAL	95.6
NOTE: Exchange rate used" $1 = 140.04 Pesatas	

A cost estimate was also prepared by the Federal Republic of Germany for the US/G SES, and is presented in Table 5.4-5 in 1986 $M.

Table 5.4-4. FRG Estimate - US/G SES Lead-Ship Acquisition Costs ($M)

Detail Design and Engineering	33.5
Product Planning	0.5
Jigs, Models, etc.	2.9
Basic Construction w/o Payload	186.8
Test and Trials (w/o Shock Tests)	7.1
Management	10.7
Logistic Support	10.1
Cost Margin	11.2
TOTAL	262.8

As a summary comparison the various SES lead-ship basic construction costs are shown in Table 5.4-5.

Table 5.4-5. Lead-Ship SES Cost Summary ($M)

Ship	FR			UK			US/G				SP	
Source of Est	FR	UK	U.S.	FR	UK	U.S.	FR	UK	U.S.	FRG	SP	U.S.
Basic Constr Cost*	132.3	61.7	185.0	130.7	70.4	195.0	148.7	82.6	220.0	186.8	64.4	185.0
Total Lead-Ship Cost	197.7	114.2	214.8	199.3	129.6	224.8	215.7	143.0	249.8	262.8	95.6	214.8

*Does not include design, contingencies, industrial facilities, trials, etc.

Differences in a national economies, shipbuilding industries, cost-estimating procedures, and interpretations of the costs inherent in the technologies proposed for the SES point designs make meaningful comparisons of these costs difficult. The following observations can, however, be made:

- Generally, the US/G SES is perceived to be the most expensive design, apparently because of its large size
- The FR and UK SESs are seen to be similar in price and significantly less expensive than the US/G SES design.
- The estimates made by the UK and France are much lower than those made by the U.S. for the same ships, with the UK estimates being particularly low. The UK and France have noticed that their estimates are lower than they should probably be.
- The Spanish estimate for their SES is very low considering its similarity to the US/G SES.

Even given these differences, the trends indicated by all of the cost estimates are relatively consistent. This is particularly evident when one considers the accuracy inherent in feasibility level cost estimates (up to ±40%), the unknowns in the technologies associated with these ships, and the differences in national ship-building practices including productivity, labor rates, and the invocation of rigid military-equipment standards (Mil Spec).

ANV Relative Costs - The Federal Republic of Germany also provided comments regarding the costs of ANV's relative to a conventional monohull. In this case the approach was to assume a fixed amount of funds available for construction of a conventional monohull frigate or an ANV (SWATH, SES, or Hydrofoil). Combat-system costs are not included, and the comparison is predicated on a selected set of performance characteristics for each hullform that do not necessarily result in complete equivalence. As stated in their assessment, Germany admits that an accurate comparison of costs can only be done on the basis of the different ship concepts being designed to meet the same mission requirements.

Given equal acquisition costs rough ship-size correlation indices have been developed by Germany and are presented in Table 5.4-6.

Table 5.4-6. Comparative ANV and Monohull Indices - FRG Estimates

	Displacement Index
Conventional Monohull	1.0
Hydrofoil (fully sub. foils)	0.2
SES	0.5
SWATH	1.0

Table 5.4-6 presents an approach that suggests that the platform cost of a monohull frigate of 4000 tonnes full-load displacement and 30 knot maximum calm-water speed is roughly the same as that of an 800 tonne, 45 knot hydrofoil with fully submerged foils or a 2000 tonne, 50 + knot SES, or a 4000 tonne, 25 knot SWATH ship.

5.5 Canadian SWATH Cost Estimate

As part of their SWATH Design, Canada provided an order-of-magnitude estimate for construction cost, developed using the cost algorithms contained in the Design computer program "SWATH ASSET Version I". SWATH ASSET is an early stage SWATH design and analysis computer model developed by the David W. Taylor Naval Research and Development Center. All costs are in 1987 U.S. dollars.

Table 5.5-1 contains a summary of the construction costs for the CA SWATH (using SWATH ASSET VI). This estimate includes the installation of the payload but lists payload acquisition as a separate line item. Construction costs also include shipyard design and engineering (SWBS 800), and construction services (SWBS 900) costs.

On a per-lightship-ton basis, the follow-ship costs agree reasonably well with the assessment team's estimate, although it is not clear which follow ships are included in the Canadian estimate. The Canadian lead-ship cost is heavily skewed by $400M design and engineering costs. It is not known what was included in this category by Canada, but does not include long-term R&D. Reducing this value to $150M, which is believed to be more appropriate for design services, including detail design, would bring the Canadian estimate into the same range as the assessment team.

Table 5.5-1. CA SWATH Acquisition Costs

	Lead Ship ($M)	Follow Ship ($M)
Construction Cost	596	222
Profit (10% Const Cost)	60	22
Price	656	244
Change Orders (12%/8% of Price)	79	20
Owner Support (2.5% of Price)	16	6
Post Delivery Charges (5% of Price)	32	12
Outfitting (4% of Price)	26	10
Total Ship Cost	809	292
Estimated Payload Cost	160	150
Ship Plus Payload Cost	969	442

5.6 Summary

The cost estimates presented must be considered very preliminary in nature, and rigorous comparisons amongst the various estimates can be misleading. These costs do, however, corroborate the conventional wisdom that ANVs are generally more expensive on a specific cost (cost/ton of lightship displacement) basis than monohulls. An exception is the the Canadian SWATH whose costs on a per lightship ton basis, are quite competitive with those for monohulls and reflect perceptions of SWATH producibility. Depending upon configuration, SWATH's can be easier to fabricate, and, therefore, may be less costly on a per ton basis, but ultimately they cost more from a total ship viewpoint because they are usually larger than the equivalent monohull.

Further analysis and development of these cost estimates will be required particularly in adjudicating absolute cost differences among different nations' cost estimates and better estimating the costs of non-standard systems/subsystems.

The development of realistic cost estimates for ANV's is obviously an essential part of the performance-risk-cost trade-off. Realistic does not imply overly optimistic or overly conservative; therefore, care needs to be taken to ensure that any further cost estimates or analysis are supported by available data and traceable analytical processes. The shortage of return cost data on ANV's, emphasizes the criticality of proper analyses.

The primary factor to consider in evaluating costs is, what is the real measure of merit of an ANV as compared to a conventional monohull, i.e., the cost to accomplish a specific mission in the context of an overall force. Additionally, cost is not the absolute parameter for assessing value of a warship as it is in the case of commercial ships. Military decisions are not always made on an economic basis.

6.0 NATIONAL ATTITUDES TOWARDS ADVANCED NAVAL VEHICLE

The SWG/6 assessment of Advanced Naval Vehicles includes a review of national technology developments, design capabilities, manufacturing capabilities, operational experiences, national needs, and national perceptions. This information was requested of all SWG/6 and IEG/6 nations via the SWG/6 "Methodology for Assessing Vehicle Concepts" (Blue Book) in the form of narrative inputs and in the form of completed questionnaire and data tables. Responses to this request for information were received from Canada, France, the Federal Republic of Germany, Italy, Norway, Spain, the United Kingdom, and the United States.

The complete responses are presented unabridged in Appendix C which appears in Volume III of this report. Additional relevant information concerning National program and perceptions can be found in Appendix F of Volume III. A summary of this information is presented in the following sections. This summary, however, does not necessarily represent the conclusions of the SWG/6 assessment, nor are the national perceptions necessarily supported by the findings of the completed assessment effort. However, consideration of these national perceptions, policies, and capabilities is valuable since it helps to define the current political, military, and technical interest in the continued development of ANV platform types.

Figure 6.0-1 presents an overview of the current climate for interest in near term development of the SES, Hydrofoil, and SWATH platforms for National military missions, as perceived on the basis of National inputs to the SWG/6 assessment effort. Table 6.0-1 summarizes current SWG/6 nations activity in ANV development. More detailed discussion of these programs can be found in Section 4.1.2.

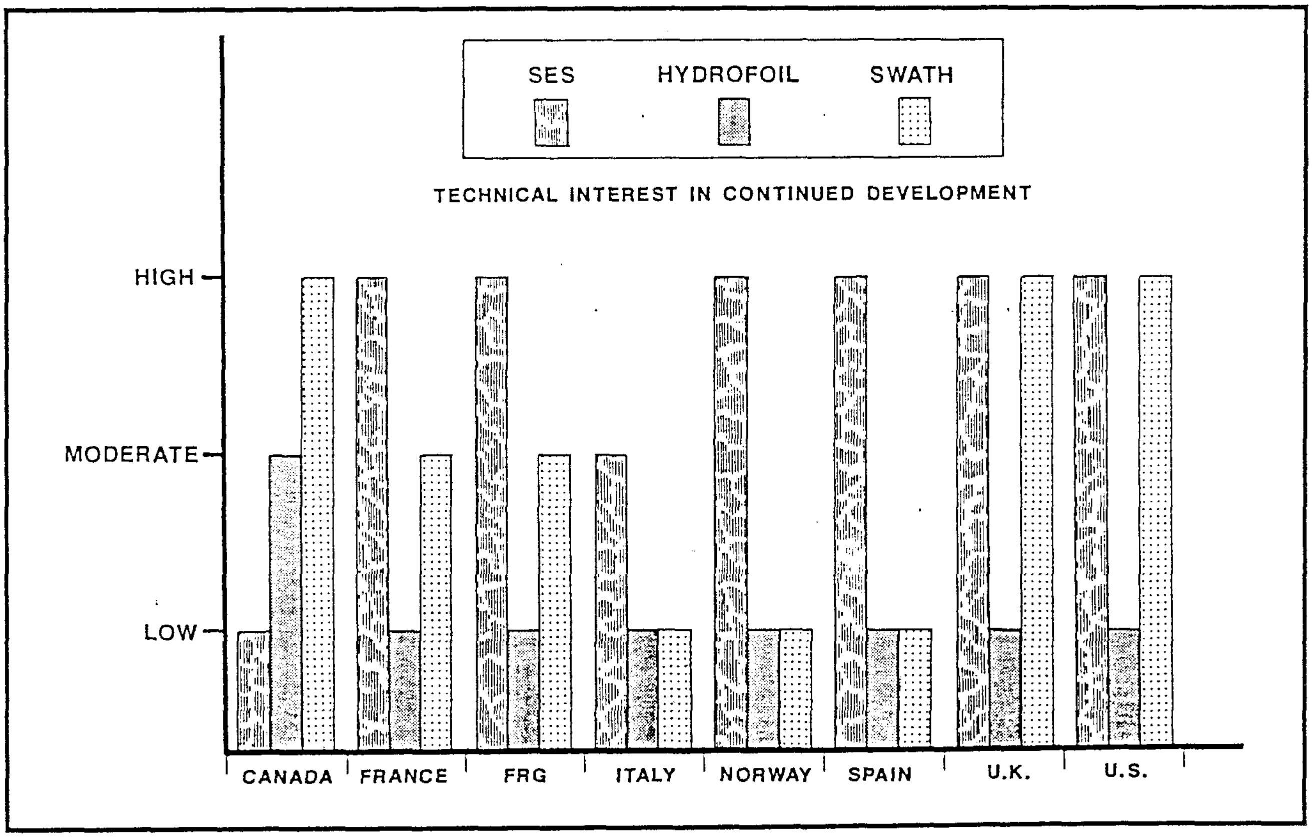

Figure 6.0-1. National Interest in ANVs (1987)

Table 6.0-1. Summary of SWG/6 Nations' ANV Programs

	Active Study Programs			Active Model Test Programs			Active Prototype Development Programs			Active Ship Acquisition Programs		
Country	SES	Hydrofoil	SWATH	SES	Hydrofoil	SWATH	SES	Hydrofoil	SWATH	SES	Hydrofoil	SWATH
Canada			M			M						
France	M		M				M					
Federal Republic of Germany	M		M	M		M				M		
Italy											C	
Norway	M									C		
Spain	M						M					
United Kingdom	M		M			M				C		
United States	M		M	M		M				M		M

M = Military Program C = Commercial Program

The following sections are meant only as an overview of the considerable inputs received via the Blue Book questionnaire. They are not a summary of the preceding sections of the main SWG/6 assessment.

6.1 National Government Perceptions of ANVs

The information requested in this area relates to qualitative overviews of the potential advantages and disadvantages of the SES, Hydrofoil, and SWATH platforms as perceived by cognizant technical and military organizations of the SWG/6 nations. The extensive SWG/6 assessment of ANV capabilities, effectiveness, cost and technical feasibility has been presented in the previous sections of this report. However, the national perception - "right" or "wrong", informed or uninformed - are important since they help to define the current climate for the development of ANVs. The following general perceptions were evident in the responses.

SES

A majority opinion is that the SES is the only option for high-speed in large ships and that this high-speed capability has significant potential in various military missions, particularly ASW, MCM and patrol missions. The SES is perceived by all nations as having potential as both an inland-sea or coastal-zone combatant and as a long-range ocean escort. The ability of the SES to operate hullborne for endurance and cushionborne for high speed is seen as contributing significantly to its military mission flexibility.

The SES is seen as a moderately higher cost option compared to a conventional monohull. Concerns include the weight sensitivity of the platform, the ability to design and build lighter-weight ships within existing Navy design practices, reliability and maintainability, and uncertainty of the seakeeping predictions of the SES.

Hydrofoil

The hydrofoil is perceived by all nations as having a seakeeping capability (foilborne) superior to other ships of much larger size and of having an all-weather high-speed capability. The high-speed maneuverability of the hydrofoil is considered to be excellent. A majority perception is that the hydrofoil has only moderately improved seakeeping in the hullborne mode (foils deployed) relative to conventional monohulls of similar displacement. (A minority view holds that a 200-tonne hydrofoil has hullborne motions comparable to those of a 3000-tonne monohull.) Maximum hydrofoil displacements are believed to be practically limited to less than 1000 tonnes so that the mission payloads of hydrofoils are less than conventional ships, which limits its flexibility in multi-mission roles.

The acquisition and maintenance costs of the hydrofoil are considered, by the majority of nations, to be very high relative to other ship types. Except by one nation, the hydrofoil is not considered to be viable for long-range open-ocean escort. It is considered by the majority of the nations to be suitable for coastal patrol and interdiction missions. Concerns include the weight sensitivity of the platform, the "speed gap" between hullborne and foilborne operational modes, high maintenance and operating costs, and a high draft which limits operations in shallow coastal waters and inland seas. The difficulty of avoiding marine growth on non-retracting hydrofoils also causes concern.

SWATH

The SWATH is perceived by all nations as having excellent seakeeping in high sea states. The majority view is that the SWATH is not size limited and will have superior seakeeping relative to monohulls even in sizes of 10,000 to 20,000 tonnes. A minority view is that SWATH seakeeping advantages over conventional monohulls are significant in sizes below about 8000 tonnes but not significant in sizes above 10,000 tonnes. The SWATH is considered by the majority of nations to be practically limited to maximum speeds less than those of comparably sized monohulls and to require higher power at all speeds. However, the SWATH is perceived as being capable of maintaining maximum speed in higher sea states. The SWATH is considered to require minimal technological developments and is perceived as providing greatly improved seakeeping at minimal increased platform cost.

Majority perception is that the SWATH may have some operability restrictions due to draft limitations but it is viewed as a viable platform for both open-ocean and coastal/inland-sea operations.

General

In addition to the general perceptions above, a number of specific and significant comments were submitted concerning the advantages and disadvantages of the ANV types. The topics of many of these comments have been addressed in detail in previous sections of this report. However, some of the comments relate to areas that have received no, or minimal, evaluation due to a lack of technical data and/or the modest scope of the SWG/6 assessment effort. These national comments are presented verbatim, as follows, for consideration in subsequent design and evaluation efforts:

- "The lack of effectiveness of Soviet wakehoming weapons on this platform [Hydrofoil] has not been studied but could also prove to be favorable for this platform."
- "Some minor difficulty may be experienced at commercial or foreign naval yards where berthing arrangements for the hydrofoil are not considered practical due to the foil/strut configuration or if a defect occurs with the housing mechanism of the retractable foils."
- "The hydrofoil is volume constrained, putting greater stress on the habitability and thus work performance of the crew members. Generally crowded work areas will also affect maintenance and repair of systems. The design has not proposed any additional noise reduction modifications either for habitability or to reduce radiated noise. Both will have a marked affect on crew performance and detectability of the vessel." [Noise and vibration effects on SES crews may also be significant at high speeds.]
- "Additionally, the increase in complex systems [Hydrofoil] have meant individuals are also required to be highly trained, costing more money in training requirements."
- "To maintain that position [SWATH design waterline], every significant weight loss must be compensated for by a corresponding gain. Since it would be unconscionable to provide clean ballast to match the total fuel load, the fuel system will probably have to be fully compensated. This brings problems of potential contamination both of the fuel and the ballast water, together with special procedures and equipment to prevent both. The fresh water tanks will have to be

kept full or likewise compensated by ballast. As stores and ammunition are expended, the same requirement applies. Not only are the weights themselves important, but their distribution is critical. The low stability exaggerates the effects on list and trim of any imbalance. It is probable that in a large ship an elaborate control system would be required to measure the amount and distribution of the variable loads, compute the effects of changes, and prescribe corrective measures. It might even be necessary for the system to be automatic."

- "Even as SES and Hydrofoils show lower power requirements than conventional vessels when compared on the basis of the same displacement and the same (high) speed, it should be remembered that the Point Designs have higher fuel consumption than conventional ships designed to achieve more moderate speeds. This is because the Point Designs exploit the higher inherent speed potential of the concept. If fuel costs rise inproportionately this will significantly increase operating costs. This could be an area of potential concern."

- "Reservations against aluminum are substantial, stemming from experienced fatigue and fire resistance problems in aluminum structures. There is a clear preference to use steel wherever adequate."

- "There is however with hydrofoils an operational limitation, i.e., the impossibility to employ it in the range speeds between the maximum speed in hullborne mode and take-off speed. [Impact of this speed gap on a specific mission should be considered.]"

- "However, before defining the military need for an SES, it awaits the validation of operating for several weeks without excessive personnel fatigue. [Could also be a problem for Hydrofoils]"

- "In our typical coastal waters with varying depth, foils (fixed or operable) may be a problem towards vulnerability in peace and war. In our coastal waters with varying depths and narrow harbor areas, the useful operational capabilities of a SWATH will, in general, be limited." [A study of NATO nations' coastal waters and harbors, relative to draft operability limitations on Hydrofoils and SWATHs, might prove valuable.]

- "While sprint-and-search tactics with a passive sonar sensor would be suitable for ASW escorts on an outer screen displaced at a significant distance from an escorted mainbody, such would not necessarily be the case for those ships stationed on the inner screen. At relatively short ranges from the main body, passive sonars would be less effective and it is probable that an active acoustic sensor would be required to counter the diesel-powered submarine or the SSN that has slipped through the outer screen. This requirement for defence-in-depth will become even more critical as enemy submarines become progressively quieter."

- "The report notes the requirement for UNREP while escorting convoys, military shipping and major combatants. Current forecasts predict that "fast" convoys may have SOAs of up to 25 kts while major combatants may transit open ocean areas or choke points at speeds up to or even surpassing 30 kts. Therefore, the capability of an ANV to UNREP at these speeds (or at lower speeds for that matter) will be critical to its success as an ASW escort. The possibly enhanced stability of ANVs is mentioned in other documents as a factor in improving their UNREP capability over monohulls. However, in regard to this UNREP capability, while some mention is made in the assessment report of directional stability none is made of precise speed control. Both of these are essential factors in a vessel's ability to successfully maintain a close alongside station. Indeed there is evidence that both the SES and the hydrofoil may have speed "humps" during which precise speed control may be difficult. Certain ANVs are said to be highly directionally stable, but this itself could pose problems if large rudder angles are continually required to maintain current UNREP distance. Moreover, the ability to of an SES to maintain station on full cushion with its minimal draft, especially in higher wind and sea states, should also be investigated. Another difficulty may arise due to the relatively short length of the ANV being adversely affected by the large pressure and suction areas alongside a major combatant or large logistic ship at high speed."

- "To be effective as future ASW escorts, ANVs must be designed with acoustic signatures at levels at least as good as, if not better than modern monohulls. Although ANVs may be less vulnerable to torpedoes, if they are easily detected by submarines they will still be vulnerable to anti-ship missile attack." "Noise reduction on high-speed ANVs is very difficult."

6.2 National Capabilities for ANV Design and Construction

The information requested in this area relates to national capabilities to predict ANV performance, to develop the required ANV subsystems, and to produce the Point Designs.

The subject of the NATO nations' collective capability in the areas of ANV performance predictions and subsystem developments has been summarized in Section 4 (RDT&E Needs) of this report and is discussed in detail in Appendix B.

National inputs relative to industrial capabilities to design and manufacture the specific components and subsystems required by the Point Designs and to produce the ship structures are summarized in Table 6.2-1. It is considered that this summary relates to current capabilities and is not meant to imply that nations could not acquire these capabilities.

A review of Table 6.2-1 indicates that, collectively, the SWG/6 nations have some capability in all of the areas addressed by the survey.

6.3 National Navy Policies in Design and Acquisition of ANVs

Conclusions based on national inputs in the areas of Navy policy for the design and acquisition of ANVs are:

1. There are very few specific policies for ANVs as opposed to conventional ships

2. National policies in the areas of design and acquisition strategy can vary significantly.

Beyond these generalizations, little more can be said on the basis of the inputs received. The subjects of design practice and margins are discussed in Section 3.3.1 of this report.

6.4 National Needs and Missions for ANVs

On the basis of national inputs relating to ANV attributes, advantages, and shortfalls, certain mission areas, where ANVs may have significant potential to provide cost-effective improvements over current capabilities, have been identified.

Table 6.4-1 lists missions versus the SES, Hydrofoil, and SWATH and indicates the number of SWG/6 nations that specifically identified a platform type as having cost-effective potential for a certain mission. A larger number of nations than indicated in the table may well perceive a potential for an ANV in the missions listed, but did not specifically identify this perception in their inputs to the assessment team.

Significant conclusions should not be drawn from Table 6.4-1 since the SWG/6 nations were not specifically asked to list all missions where they believed ANVs have cost-effective potential. However, it is obvious that ANVs are considered to have potential in a number of naval missions.

Table 6.2-1. National Capabilities in Design and Manufacture of ANVs

System As it Relates to Point Designs	Canada	France	FRG	Italy	Norway	Spain	U.S.	U.K.
Light Gauge High-Strength Steel Structure	N	-	C	C	S	-	S	C
Aluminum Structure	S	-	C	C	-	-	C	N
GRP Structure	N	-	N	S	N	-	S	N
Surface Piercing Super-cavitating Propellers	N	-	S	S	S	-	S	-
Fully Submerged Super-cavitating Propellers	S	-	S	C	S	-	C	-
Waterjets	N	-	N	C	S	-	C	-
Bow and Stern Seals	N	-	S	N	-	-	S	-
Lift Air Fans	S	-	S	S	S	-	C	-
Ride Control Systems (SES)	N	-	N	N	S	-	S	-
Epicyclic Gear Transmissions	S	-	C	C	N	-	C	C
Foil Lift Systems	C	-	N	C	N	-	C	-
Foil/Strut Steering Systems	S	-	N	C	-	-	S	-
Z-Drive Power Transmissions	S	-	S	S	N	-	C	N
Automatic Control Systems (Hydrofoil)	N	-	N	C	N	-	C	-
Coatings for High Strength Steel Foils/Struts	S	-	N	C	N	-	S	-
Integrated Electric Propulsion Systems	C	-	C	-	N	-	C	C
Degaussing Systems	S	-	C	C	N	-	C	C
Active Fin Stabilizers (SWATH)	S	-	N	S	N	-	S	C

C = Considerable Capability
S = Some Capability
N = No Capability
- = No Input Received

Table 6.4-1. National Missions for ANVs

Mission	SES	Hydrofoil	SWATH
ASW Escort (Low Speed of Advance)	••••	•	•
ASW Escorts (High Speed of Advance)	•••••	•	
Coastal Patrol and High Speed Interdiction Craft	••••	•••	
Peace Time, Surveillance, Patrol and Maritime Law Enforcement	••	••	•
Mine Countermeasures	•••		•
SUW Convoy Escort	•		•
AAW Convoy Escort	•		•
SUW/AAW Coastal Patrol	•	•	••
Long Endurance Underwater Surveillance			•••
Oceanographic Survey			••
Offshore Patrol		•	•

Note: Each dot represents the expressed interest of one nation in using a particular ANV for a particular mission.

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 General Conclusions

(a) SWG/6 studies have ***confirmed*** the MO2005 assumption ***that ANV platforms offer significant speed and/or seakeeping improvements*** compared with conventional ships.

(b) Acquisition and operating costs have been assessed. Cost increases associated with ANVs can be offset by operational advantages resulting in ***reduced overall mission costs.***

(c) All three platform concepts studied by SWG/6 ***are technically feasible*** for operational service by the year 2000 and will be capable of performing the designated missions.

(d) ***There are development requirements*** associated with each concept.

(e) Intermediate size ships may be required between existing ANVs and the SWG/6 designs.

(f) The nations of SWG/6 have been participating for four years in a carefully focused cooperative exchange of experiences and technology. This has benefited, and will continue to benefit, national ANV programs.

(g) The effort has also deepened and broadened the collective experience of SWG/6, and has enhanced the group's ability to employ an effective systems approach to the NNAG's needs in the Group's area of expertise.

7.2 Specific Conclusions

7.2.1 High-Speed SES and Hydrofoil Point Designs

(a) Objective: Military Value

(i) Several factors combine to make the high-speed ANVs (SES and Hydrofoil) very attractive for escort roles:

- The capability of protecting high-speed groups ***that existing forces cannot provide***
- For slower groups, the capability to conduct sprint-and-search ASW operations allows similar protection to be provided ***by a smaller number of escorts***
- The enhanced capability of attacking slower surface and subsurface ships and, likewise, the capability of more readily evading attack.

(ii) The SES is ***the only option for high-speed in large ships*** and this high-speed capability has significant potential in various military missions. The SES has potential as both an inland-sea or coastal-zone combatant and as a long-range ocean escort. The ability of the SES to operate hullborne for endurance and cushionborne for high speed is seen as contributing significantly to its military mission flexibility. The SESs, because of their relatively wide beams, are well suited to the deployment/retrieval of multiple towed array sonars, and to the operation of helicopters. Also, because of their machinery systems being divided between their two hulls, they have greater survivability potential against the expected threat.

(iii) The forward acceleration and deceleration performance of the SES Point Designs is better, by as much as a factor of 2, compared to a conventional monohull. This is attributed to the lower resistance and much higher power to weight ratio for the SES.

(iv) The Hydrofoil Point Designs have ***excellent speed in high sea states*** and ***superior seakeeping*** capability compared to conventional monohulls. They were not, however, required by the ONST to carry helicopters. The Hydrofoil Point Designs, therefore, are best suited to operate in areas where air assets are available from other sources.

(v) The high-speed maneuverability of the Hydrofoil Point Designs is far superior to that of a comparable monohull. This attribute can be a significant advantage in many tactical situations.

(vi) The Hydrofoils, and to a lesser extent the SES, because of their relatively smaller size compared to a monohull, are potentially less detectable and targetable. However, the SES and Hydrofoil Point Designs, because of their smaller size, carry less combat-system related payload and offer less general-purpose capability than do conventional modern ASW vessels. The ratio of payload to full-load weight at approximately 10% for the four SES and two Hydrofoil Point Designs is, however, similar to that of conventional ships.

(vii) The specific Point Designs examined should not necessarily be regarded as direct replacements for conventional ASW ships, rather they should be considered to be superior in carrying out certain tasks, and as complementary to conventional vessels for executing other tasks.

(viii) It may be pertinent to trade-off certain performance requirements, such as speed or range, in favor of increased weapon payload for the particular ANVs examined by SWG/6. This could result in an increase in the towed array size and/or increased surface warfare capability. This may improve or broaden the scope of the mission capabilities of the Point Designs and increase their usefulness as naval vessels. A more thorough examination of the likely roles in particular scenarios needs to be carried out in order to make a more quantitative assessment of these trade-offs.

(b) **Objective: Cost**

(i) The ***annual life-cycle cost*** of the SES Point Designs is, on the average, ***close to that of an FFG*** 7-class frigate. The investment cost, with payload, for the SES is, on the average, 64% of the cost for an FFG 7.

(ii) The ***annual life-cycle cost*** of the US and Canadian Hydrofoils is *86% and 62%* respectively, of the cost ***of an FFG*** *7.* The investment cost of the US and Canadian Hydrofoils, with payload, is 75% and 49%, respectively, of the cost of an FFG 7.

(iii) The investment cost and life-cycle ***cost per ton of military payload for the SES and Hydrofoils is significantly higher than that for current Navy monohulls:***

- The average platform investment ***cost per ton of payload*** for the SES Point Designs is ***65% greater than for the FFG 7***

- The platform investment ***cost per ton of payload*** for the US and Canadian Hydrofoils ***is 400% and 260% greater than for the FFG 7.***

(iv) ***However,*** since sprint-and-search ASW operations allow for a smaller number of escorts, ***the cost of a complete escort force can be substantially lower for these high-speed ANVs.***

(c) **Objective: Technical Feasibility**

(i) Within the scope of pre-feasibility design investigations, it has been determined that ***it is feasible to produce SES or Hydrofoil lead ships*** that essentially meet the performance targets set by the ONSTs, within less than 12 years. The development of SES or Hydrofoil ships, however, ***entails greater development and schedule risk*** than the development of conventional monohulls. Where risks have been identified ***solutions have been suggested or development needs have been identified***, many of which are ***already being pursued by the SWG/6 nations.***

(ii) For the SES these needs include the development of large air cushion seals having acceptable life in the open ocean, and an improved understanding of seakeeping and underwater signatures.

(iii) For the Hydrofoil these needs include the development of foilborne mechanical power transmissions, an improved understanding of underwater signatures and, for the U.S. Hydrofoil, the development of a large foil/strut steering system.

(iv) These and other development items listed in the report should be given priority during the next phase of design. ***None are considered to pose a very high risk*** and all are believed to be resolvable with reasonable investments of time and money. In particular, the whole question of ***ASW effectiveness is intimately tied to sonar performance*** in the projected environment, and the military value of high-speed ANVs in terms of ASW capability cannot be separated from the ***need to develop ASW sensors*** which are compatible with the proposed ANV operating cycles and the post-year-2000 threat.

7.2.2 SWATH Point Design

(a) **Objective: Military Value**

(i) The chief attribute of the SWATH Point Design is its ***superior seakeeping,*** which ensures that all personnel and embarked systems can work efficiently. This superior seakeeping performance is partly attributable to its large displacement. The maximum calm-water speed of the SWATH Point Design is 25 knots. Its maximum sustained speed in average North-Atlantic weather is 22 knots. Designing the SWATH to much higher speeds was found to require excessive propulsive power.

(ii) The SWATH, using its inherent seakeeping and enhanced helicopter carrying capability (four helos), can provide ASW coverage for protected forces at SOAs of 22 knots and below with a potential operability level of 100% in Northern North-Atlantic Winter conditions (the helicopters can only operate for about 70% of the time under these conditions due to the limitations imposed by the high winds associated with high sea states). This is significantly higher than the 50% operability level of the baseline DD 963. The SWATH can embark four helicopters, which may not be practical for even a comparable monohull. The ratio of payload to full-load weight for the CA SWATH is, however, just below 6% compared to the typical 10% for a comparative monohull. This could be improved by trading off fuel for payload.

(iii) The SWATH Point Design is best suited for specific ASW applications for which its unequalled operability is particularly advantageous. An example of this is the long-duration, low-speed ASW patrol required in the Greenland-Iceland-UK gap. Submarines could wait for the frequent heavy weather before traversing this area so that the very high operability of the SWATH could provide ***a critical edge which is not currently available with existing NATO forces.*** The selection of a SWATH by the U.S. Navy, as a second hullform for the T-AGOS class of ocean surveillance ship, substantiates this conclusion.

(b) **Objective: Cost**

(i) The ***life-cycle cost*** of the SWATH Point Design is close to that of a DD 963 Spruance-Class destroyer.

(ii) The ***investment cost***, less payload cost, for the SWATH is 12% less than the same cost for a DD 963.

(iii) The platform ***investment cost per ton of payload*** for the SWATH Point Design is 29% greater than for a DD 963.

(c) **Objective: Technical Feasibility**

(i) The SWATH Point Design was assessed to be ***technically feasible with minimum development needs*** for an initial operational capability within less than 12 years.

(ii) The particular design produced by SWG/6 was unique in that it required development of advanced electric propulsion machinery and intercooled regenerative gas turbines. These developments offer performance advantages but do not necessarily represent a generic need for future SWATH development.

7.3 Recommendations

It is recommended that:

1. The results of the SWG/6 study be forwarded to the MNCs for consideration in their development of future concepts and military requirements.

2. The NNAG encourage nations to continue near-term research and development, either nationally or collaboratively, to minimize risk, particularly in the following areas:

   SES

   - Advanced (Future Threat) ASW Sonar Systems for High-Speed Ships
   - Bow and Stern Seals
   - On-Cushion Seakeeping and Ride Control
   - On-Cushion Stability for High-L/B Hullforms*
   - Underwater Radiated Noise

   Hydrofoil

   - Advanced (Future Threat) ASW Sonar Systems for High-Speed Ships
   - Mechanical Foilborne Transmission (Z-Drive)
   - Foil/Strut Steering Systems*
   - Foil-System Structural Design
   - Underwater Radiated Noise

SWATH

- Advanced Electric Propulsion Machinery*
- Intercooled Regenerative Gas Turbines*
- Stabilizer Steering*
- Resistance
- Underwater Radiated Noise

Items shown in the above list without an asterisk are considered to be generically applicable to ASW SES, Hydrofoil or SWATH development in general. The other items listed with an asterisk are applicable to only the particular point designs examined by SWG/6.

3. The area of most critical development, "High Speed Sonar" be addressed by NNAG-IEG 2.

4. The nations be urged to pursue their individual efforts in ANV development, ***using the firm base of both data and concepts established by the SWG/6 effort.***

5. Nations desiring to enter into feasibility studies based on the designs establish minimum acceptable criteria in the following areas. These are areas which tend to drive displacement and cost:

- Speed in High Sea State
- Allowable Ship Signature (Especially Underwater Acoustic Signature)
- Number of Helicopters Required
- Expendable Items Load Out (Including Ordnance)
- Ship Service Life

8. REFERENCES

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ALL APPENDICES ARE CONTAINED IN VOLUME III.