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Unmanned Sea Surface Vehicle Technology Development

ABSTRACT

The utility and effectiveness of unmanned vehicle systems is clearly recognized by DoD and the military services. Currently, most unmanned surface vehicles (USVs) are based on existing, manned boats that have been adapted or converted to be unmanned. These craft were designed to meet certain human-based factors; therefore, their performance in terms of speed, seakeeping, payload capability, endurance, towing capacity, and adaptability to various naval missions is not optimized. The Unmanned Sea Surface Vehicle (USSV) S&T program is focused on the development of technologies to extend the capabilities of USVs for naval missions. The approach focuses on *purpose-built* USSVs, rather than converted, manned craft, autonomous control of these vehicles, and launch and recovery. Two USSVs have been designed and constructed: the *USSV-High Tow Force* (*USSV-HTF*), which is optimized for payload fraction, endurance and high towing capacity, and the *USSV-High Speed* (*USSV-HS*), a hydrofoil, which provides high speed in a sea state. Also, progress has been made toward autonomous launch and recovery and toward a greater degree of vehicle autonomy. The technology development described in this paper will help to optimize the mission capabilities of USVs and help to maximize the combat effectiveness of the Littoral Combat Ship (LCS).

INTRODUCTION

Deployment of unmanned surface vehicles by the U.S. Navy is scheduled to begin in 2007 as the first engineering development models are delivered for use on the first two Littoral Combat Ships (LCS), *Freedom* and *Independence*. These USVs will be required to meet demanding performance requirements. USVs are expected to make a significant contribution to LCS' combat capability due to their ability to perform high-risk littoral missions with low risk to personnel, ability to carry large, heavy, power-intensive payloads into the operational area and remain on-station for relatively long periods of time.

The deployment of USVs for naval missions represents a new paradigm in naval warfare and requires technology development in several areas including hull/mechanical/electrical, launch and recovery and autonomy. Until the inception of the USSV program, almost all existing USVs were based on platforms optimized for manned operations, such as rigid hull inflatable boats (RHIBs), which had been converted to be unmanned. Such platforms are not optimized to missions required by LCS and do not possess the capabilities necessary for LCS missions. In particular RHIBS have insufficient seakeeping, payload, endurance and towing capacity. In addition, launch and recovery of manned craft in a seaway is a manpower-intensive, hazardous operation; extending this to launch and recovery of unmanned craft is a very significant challenge. Achieving a degree of autonomous control that will reduce operator workload on LCS and will allow operation in complex, rapidly changing environments is another key technical challenge.

In 2003, Naval Surface Warfare Center, Carderock Division and the Office of Naval Research recognized these technology gaps and stood up the Unmanned Sea Surface Vehicle (USSV) program to address them. The objectives of the USSV program are three-fold:

1. To demonstrate improved operational capability of USVs by optimizing the vehicle's performance for selected missions,
2. To advance the level of autonomy for USVs and groups of USVs,
3. To develop the technology necessary for launch and recovery of USVs from a host ship.

This paper describes the advances made in the USSV program toward each of these objectives.

USV REQUIREMENTS DETERMINATION

At the inception of the USSV program, a requirements analysis was performed by Johns Hopkins University/Applied Physics Lab with the objectives of (1) extending the LCS analysis of multiple concepts OPSITS to develop operational tasks and functions for USVs deployed from LCS and (2) assess the impact on USV characteristics and key design factors. The USV characteristics and capabilities defined by this requirements analysis were used in a subsequent USV trade study performed by NSWC-Carderock Division (Sokol, 2004). The primary capabilities examined in the trade study were speed in a seaway, endurance, range, mission performance in a seaway, payload modularity and mission adaptability, within the constraints of a craft that would fit onboard LCS: no greater than 40' length and 22,500 lbs full load displacement (NAVSEA, 2006). Seven design concepts addressing four mission areas (mine influence, antisubmarine warfare, surface warfare and intelligence, surveillance and reconnaissance (ISR)) were generated. To address the desire of the LCS Program Office for a minimum number of USV designs, preferably one, similarities in hullform size and shape, powering requirements and overall vehicle capabilities were identified and the number of design concepts was distilled to two. These encompass the major capabilities necessary to cover all of the LCS mission areas.

UNMANNED SEA SURFACE VEHICLE DESIGNS

The nomenclature adapted in the USSV program for the two USSV designs is indicative of the optimized function of the craft: *Unmanned Sea Surface Vehicle – High Tow Force (USSV-HTF)* and *Unmanned Sea Surface Vehicle – High Speed (USSV-HS)*. The *USSV-HTF* was designed by NSWC-Carderock and is optimized for high payload fraction, high towing loads, and to maintain mission capability through sea state 4. The *USSV-HTF* is shown in Figure 1 and its principal characteristics in Table 1. *USSV-HS* was designed by NSWC-Carderock and Maritime Applied Physics Corporation. It is optimized for high speed in a seaway. It is projected to be capable of speeds of greater than 40 kts through sea state 4. It attains this capability via a hydrofoil design, as shown in Figure 2. The hydrofoil struts are retractable to facilitate launch and recovery. The principal characteristics of *USSV-HS* are shown in Table 1. This vessel has a smaller payload fraction than *USSV-HTF* due to the weight of the foils and struts, the additional structure required for the hydrofoil design and the mechanisms associated with the retractable struts. The *USSV-HTF* and *USSV-HS* are designed to use common powerplants, common control systems and common launch and recovery systems on the host ship.

Figure 1. *USSV-High Tow Force*

Figure 2. *USSV-High Speed*

Table 1. Principal characteristics of the USSVs.

	USSV-HTF	*USSV-HS*
Length	39’	35’
Beam	9’6”	10’
Full Load Displacement	18,000 lbs	20,500 lbs
Lightship Displacement	9,050 lbs	15,000 lbs
Top Speed	25 kts	> 40 kts
Cruise Speed	21 kts	35 kts
Propulsion	Twin diesel	Twin diesel
Hullform	Semi-planing monohull	Hydrofoil

USSV-HTF and *USSV-HS* were both built by Maritime Applied Physics Corporation in Baltimore, MD. The *USSV-HTF* was launched in early 2005 and the *USSV-HS* in early 2006. Since the launch of the USSVs, one of the key in-water tests was a tow test of *USSV-HTF* performed at the Naval Undersea Warfare (NUWC) facility at Seneca Lake, NY in February 2005. In this test the tow force versus speed characteristics of the *USSV-HTF* were measured. The test used a tow drogue and the *USSV-HTF* was in a full load condition. The tests were performed in calm water. The test results demonstrated that the *USSV-HTF’s* tow capacity well-exceeds that of RHIBs and is capable of towing a bare cable mine influence system, with margin to spare. The results of the Lake Seneca tow test provide validation of the premise that purpose-built USSVs will provide better mission capability than manned craft adapted for unmanned missions.

Table 2 summarizes the benefits of a purpose-built craft for the mine influence mission. This table shows the enhanced performance that is realized in the *USSV-HTF* compared to an 11 meter RHIB-based USV. Although this result is not surprising, it supports the hypothesized level of gains in operational capability when the craft design is focused on the mission or set of missions.

Table 2. Comparison of *USSV-HTF* and 11 m RHIB-USV for Mine Influence Mission

Attribute	**LCS Requirement**	***USSV-HTF***	**11 m RHIB**
Seakeeping	SS 3-4	SS 3-4	SS2
Endurance (Towing)	6 hrs	20 hrs	4 hrs
Tow Force	1800 lbs @ 20 kts in SS4	3400 lbs @ 20 kts in SS0	1800 lbs @ 20 kts in SS0

Additional testing of the USSVs is planned and will include experimentation with payloads, including a bare cable mine influence sweep payload on *USSV-HTF* and an electronic warfare package on *USSV-HS*.

Recently, the *USSV-HTF* design has transitioned into a new Technology Transition Initiative (TTI) Program (funded by the Office of the Secretary of Defense and PMS420) entitled "Unmanned Sea Surface Vehicles for Littoral Combat Ship Missions". The objective of this program is to transition the technology developed in the ONR USSV program into the LCS Mission Modules program. In the TTI program, a new USSV will be designed and built and will be deployed on the LCS as an engineering development model. It is anticipated that this new USSV will look very much like the existing *USSV-HTF*.

USSV AUTONOMY

In the ONR USSV Program, three approaches to autonomous control have been pursued. The first approach leverages an existing, government-owned navigation charting system developed by SPAWAR Charleston called COGENT (Common Geospatial Navigational Toolkit) and the Tactical Control System (TCS) developed by Naval Air Systems Command. By employing systems currently in Fleet service, command and control of USSVs is enabled with minimal logistics impact on the host vessels. This system enables waypoint navigation of the USSV, as well as avoidance of fixed, known obstacles that appear on COGENT's navigational charts.

The second approach to USSV autonomy enables the USSV to replan its mission in response to unplanned contingencies. NASA/Jet Propulsion Lab is adapting the autonomous control system used on the MARS ROVER for use on the USSV (Huntsberger, 2004). This system uses a deterministic approach to allow the USSV to replan its mission in response to a change in its situational awareness. The third approach also enables the USSV to autonomously replan its mission, but uses an emergent rather than a deterministic approach. Johns Hopkins University/Applied Physics Lab is implementing a physics-based model in which each object of concern in the battlespace is assigned a potential, the amplitude and functional dependence of which is determined by the desired behavior of the USSV (Chalmers, 2004). At any given time, the potentials are summed and the force on the USSV and its path are computed. This approach leverages work that JHU/APL did with unmanned ground and aerial vehicles that was funded by the Army. While a more far-term approach than the JPL approach, it offers the potential advantages of the ability to deal with more complex mission scenarios.

AUTOMATED LAUNCH AND RECOVERY OF USSVs

Sustained operation of USVs deployed from LCS requires repeated launch and recovery of the USVs. Currently, USV recovery requires manual intervention, is manpower intensive, and represents significant operational and safety risk to LCS personnel. These concerns can be mitigated by making the launch and recovery of USVs an automated operation. The recovery of USVs is the most challenging aspect and is therefore the part that the USSV Program has focused on. Autonomous recovery may be thought of in three phases: (1) alignment of the USV with the recovery mechanism on the host ship, (2) autonomous latching of the USV to the recovery apparatus on the host ship and (3) autonomous hoisting of the USV on-board the host ship. All three have been addressed in the USSV Program.

In 2005 a tow body/latch system developed in the USSV Program by NSWC-Carderock was tested in the Patuxent River and Chesapeake Bay, in up to sea state 2 and at speeds of 6-12 knots. The latch was mounted on the bow of *USSV-HTF* and a MK-V Special Operations Craft operated the tow body. The rate of successful latches was measured at various speeds and in various sea states. Below 8 kts, a 100% successful latching rate was achieved. Above 8 kts, the successful latching was achieved, but the success rate was found to more strongly depend on the distance of the USSV behind the host craft. To realize autonomous alignment of the *USSV-HTF* with the tow body, a precision radar transponder was integrated into the system. Signals from the RF transponder are processed by the USSV's control system, allowing it to successfully align itself with the tow body. This was followed by autonomous latching, as described above.

In 2006, launch and recovery experimentation progressed from the tow body to the more challenging environment of a stern ramp on a host ship. Two launch and recovery experiments were conducted aboard *FSF Sea Fighter*, an ONR prototype craft which possesses a stern ramp. The first experiment, in April 2006, demonstrated autonomous approach and alignment of a 7 m RHIB equipped with the USSV control system to the base of the *Sea Fighter's* stern ramp. Figure 3 shows the USV engaged in the approach and alignment to the stern ramp. 14 successful approaches out of 17 attempts were accomplished in sea state 3 at a *Sea Fighter* speed of 5 knots. The second test took place in August 2006 and demonstrated successful approach, alignment and latching of the 7 meter USV to the *Sea Fighter's* stern ramp. The conditions during this test were high sea state 1 and the *Sea Fighter's* speed was again 5 knots. Thus, the most difficult aspects of the autonomous recovery process have been demonstrated in these experiments.

In the near future, underway refueling of a USSV from a host ship will be addressed. Underway refueling will have the benefits of reduced turnaround time due to avoidance of a complete USV launch and recovery cycle and of freeing up the LCS' stern ramp for other operations. The tow body described previously will be used to deploy a fuel hose. Technology for accomplishing autonomous alignment and latching of a fuel receptacle on the USSV to the fuel hose on the tow body will be developed in the USSV program.

Figure 3. USV making an autonomous approach and alignment to Sea Fighter's stern ramp (foreground), April 2006.

OTHER USSV TECHNOLOGY DEVELOPMENT

In addition to the work described above, supporting technology for USVs is being developed in the SBIR program. For example, hybrid-electric USVs are being developed. This will provide the capability for high density power for USV payloads and for quiet operation on battery power. As well, the application of technology for scavenging energy from the environment to USVs is being investigated. Autonomous, robotic systems for launch and recovery of small unmanned vehicles from USSVs are also being developed. This would extend the range of the small vehicles by preserving their batteries or fuel for the mission rather than using them for transit. This requires development of robotic systems to launch, recover and perform on-board handling of these vehicles. A health monitoring system is being developed for on-board diagnostics, prognostics and self-maintenance. This will increase the level of self-awareness and autonomy of these vehicles. A system to sense and mitigate craft motion and the use of advanced materials that would provide weight savings or blast protection are other areas of investigation in the SBIR program.

SUMMARY

With the launch of the first Littoral Combat Ship in 2007 and the reliance of LCS on its offboard vehicles, including USVs, for a substantial part of its combat capability, we are embarking on a new paradigm in naval warfare. The technology development described in this paper will help to optimize the mission capabilities of USVs and help to maximize the combat effectiveness of LCS.

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