

Unmanned Surface Vehicles – A Survey

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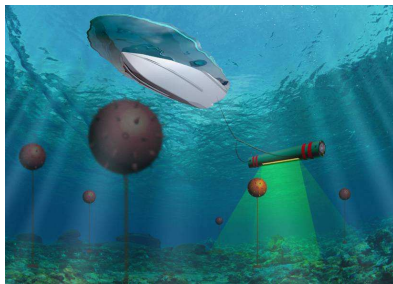
Abstract

The survey of marine Unmanned Surface Vehicles (USVs) covers both actually built and projected USVs. Most USV developments are found in the USA. USVs remain so far limited to small to medium vessels with limited autonomy.

1. Introduction

While unmanned [water] surface vehicles (USV) date back at least to World War II, it is only in the 1990s that a large proliferation of projects appears, *Corfield and Young (2006)*. This is in part due to the technological progress, but also driven by a paradigm shift of the US Navy with a much stronger focus on littoral warfare and anti-terrorism missions. Successful missions of USVs in the second Gulf war have increased interest within the US Navy in USVs and several modern navies followed suit. Potential USV missions could range from small torpedo-size data gatherers to large unmanned ships. Carderock Laboratory has used the following grouping:

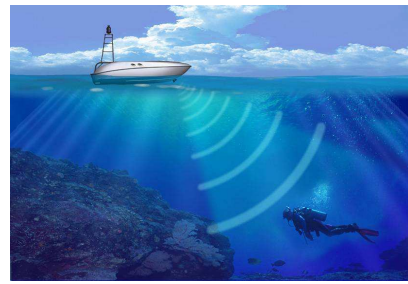
- Small (<1 t)
- Medium (< 100 t)
- Large (< 1000 t)
- Extra large (> 1000 t)



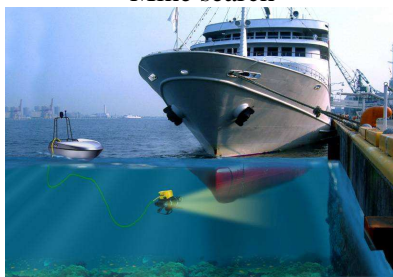
Mine search



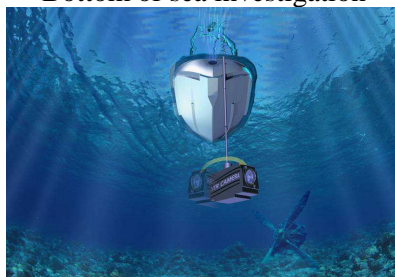
Bottom of sea investigation



Suspicious divers search



Search bottom of ship with ROV



Search with underwater camera



Target boat

Applications for USVs, source: Yamaha

So far, all USVs have small or medium size. Most USVs are about the size of recreational watercraft, i.e. 2 to 15 m long with displacements of 1.5 to 10 t. Some can operate at more than 35 knots in calm water. Current R&D efforts aim at improving existing technical challenges to have USVs widely accepted:

- Affordable over-the-horizon (OTH) communications to extend the range that USVs can operate from host ship or base
- Safe, reliable USV launch and recovery
- Greater USV autonomy

- Increased reliability and survivability

In addition to technical challenges, civil and navy regulatory authorities have yet to develop maritime procedures and protocols that define how unmanned vessels operate and interact with other maritime traffic.

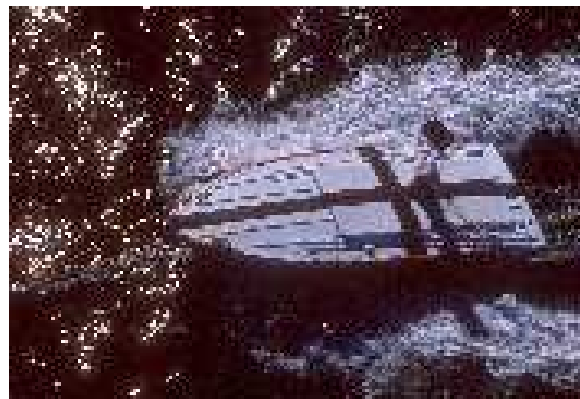
This survey builds on various printed sources and internet information, particularly on *Portmann et al. (2000)*, <http://www.globalatlantic.com/unmanned.html>, and a market overview prepared in 2003 by Moiré Inc., www.moireinc.com/USVMarket.pdf.

2. Historic background

World War II saw the first experimentation with USVs. Canadians developed the COMOX torpedo concept in 1944 as a pre-Normandy invasion USV designed to lay smoke during the invasion - as a substitute for aircraft. COMOX was designated a torpedo because it could only be programmed to traverse a fixed course. Although COMOX was not deployed, a vehicle was constructed and a successful test was completed. Meanwhile, the US Navy developed and demonstrated several types of "Demolition Rocket Craft" intended for mine and obstacle clearance in the surf zone. The "Porcupine," "Bob-Sled," and "Woofus 120" were variants of converted landing craft that carried numbers of mine clearing rockets in different configurations. Unmanned operation was part of the concept, although it is unknown which, if any, of these vehicles were demonstrated as USVs.



Mobile Ship Target (MST)



QST 33



QST-35/35A SEPTAR



High Speed Maneuverable Seaborne Target (HSMST)

Unmanned target drones

Post-war applications of USVs expanded, with the USN using drone boats to collect radioactive water samples after atomic bomb blasts Able and Baker on Bikini Atoll in 1946. The 1950s-era US Navy Mine Defense Laboratory's project DRONE constructed and tested a remotely operated minesweeping boat in 1954. By the 1960s, the Navy was using target drone boats based on remote-controlled "aviation rescue" boats for missile firing practice, and the Ryan Firefish target drone boat was used for de-

stroyer gunnery training. Similar to UAVs, target drone USV development and use has continued and evolved over the years. Today, the Navy operates a number of USVs as target drones, including the Mobile Ship Target (MST), the QST-33 and QST-35/35A SEPTAR Targets, and the High Speed Manueverable Seaborne Target (HSMST).



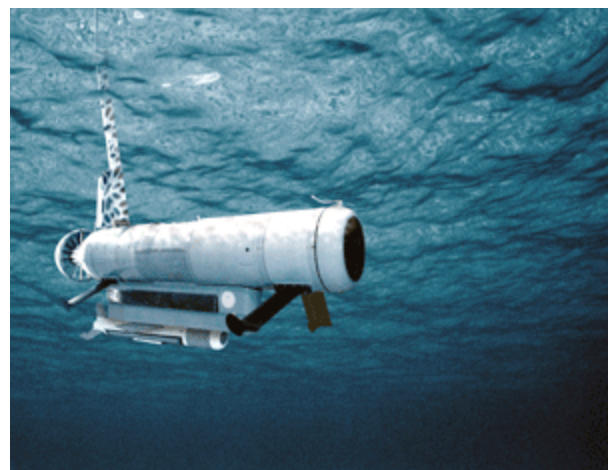
STANFLEX – drone



German Troika

Interest in USVs as minesweeping drones and for other dangerous missions continued to grow after the 1950s for obvious reasons, and further US Navy development included the small "Drone Boat" - a 15ft USV for unmanned munitions deployment - that was quickly developed and deployed to the fleet in ten vehicle kits in 1965 during the Vietnam War. Larger Minesweeping Drone (MSD) USVs were also developed and deployed in Vietnam in the late 1960s.

The value of unmanned minesweeping systems was recognized by a number of countries, and systems were developed and deployed. Examples include Denmark's STANFLEX, Germany's Troika Groups (one manned control ship operating three drones), Netherlands drones, the UK's RIM drones, Sweden's SAM II ACV drones (SAM = Self-propelled Acoustic/magnetic Mine sweeper), and Japan's SAM ACV drones operated from Hatsushima Class MCM ships.



Remote Mine-hunting System (RMS)

By the 1990s, the Navy developed and tested more sophisticated USV mine sweeping systems, *Brown (2004)*, *Palmer and Brizzola (2004)*, including the R/C DYADS, the MOSS, and finally ALISS - which demonstrated a remotely operated simultaneous acoustic and magnetic influence sweep capability. One mine-hunting USV now in development by the Navy is the Remote Mine-hunting System (RMS), an air-breathing submersible that tows mine-hunting sensors and is deployed and operated organically from surface combatants. RMS, a descendant of the Dolphin, an earlier Canadian remotely operated mine-hunting vehicle, *Young et al. (2006)*, can be considered one of the first examples of truly autonomous USVs.

3. Developments in USA after 1990

Navy interests in USVs for reconnaissance and surveillance missions emerged in the late 1990s, with the development of the Autonomous Search and Hydrographic Vehicle (ASH), later called the Owl, and the Roboski. The Roboski, initially developed as Shipboard Deployed Surface Target (SDST) as a jet-ski type target for ship self-defense training, now also serves as a reconnaissance vehicle test-bed. By the early 2000s, several concepts for stealthy USV sensor platforms have been proposed and are under consideration by the surface fleet. One of the most visible interests is in USVs that could serve as unmanned force multipliers for a number of littoral combat missions.



Roboski



Owl MK II, 1998



Owl MK II

Navtec Inc developed in the late 1990s a USV for the Office of Naval Research (ONR) under the name Owl MK II. The Owl is a Jet Ski chassis equipped with a modified low-profile hull for increased stealth and payload capability. One version with side scan sonar and a video camera has been in operational use in the Persian Gulf. Science Application International Corporation (SAIC) offer also a small USV for port security. This Unmanned Harbor Security Vehicle (UHSV) is an advanced version of the Owl MK II.



Unmanned Harbor Security Vehicle (UHSV)



SSC San Diego USV

The robotics group at the US Space and Naval Warfare Systems Center in San Diego developed an USV test-bed as versatile platform for rapid prototyping and testing of new concepts, *Ebken et al. (2005)*, <http://www.nosc.mil/robots/surface/usv/usv.html>. The USV is based on the Bombardier SeaDoo Challenger 2000 powered by a Mercury 250-hp OptiMax fuel-injected V-6. According to their website, the military community has expressed strong interest in the use of USVs for a variety of roles, including force protection, surveillance, mine warfare, anti-submarine warfare, riverine operations, and special forces operations. This project focuses on developing and transitioning technologies that will enable the USV community to deliver systems with increased capability and autonomy. Much of the USV technology developed at SSC San Diego can be transitioned to other USVs with minimal effort. The team is part of the consortium for the development of the SPARTAN USV.

The SPARTAN was developed as an Advanced Concept Technology Demonstration (ACTD). The French navy and the Singapore navy joined the SPARTAN program of the US Navy in 2003. The SPARTAN USV is a modular, reconfigurable, multi-mission, high-speed, semi-autonomous USV capable of carrying payloads of 1.5 and 2.5 t for 7 m and 11 m craft, respectively, with approximately 8 hours of autonomy, *Maguer et al. (2005)*. The SPARTAN USV saw active service during the US military operations Iraqi Freedom and Enduring Freedom. Commercial production is expected for the year 2007. The Freedom Sentinel is a rigid hull inflatable 11 m test-bed operated by NAVSEA Panama City.



SPARTAN



Freedom Sentinel

The US Navy started several new USV programs in 2003. The Office of Naval Research (ONR) provided funding to the US Naval Facilities Engineering Support Center (NFESC) to develop a small USV sea target called Sea Fox, first demonstrated in June 2003. The NFESC also developed/studied, <http://www.nfesc.navy.mil/amphib/teams/team5/default.asp>:

- Roboraider - USV based on an inflatable platform, a low-cost USV for intelligence, surveillance, and reconnaissance (ISR)
- Roboski (see above)
- Small Weapons Attack Trainer (SWAT) - USV for training on 25mm, 50cal, M-60 and Close-In Weapon System (CIWS) using a jet-ski type platform to tow an expendable target. The system will use a COTS RF control link to command the rudder and throttle.

The Autonomous Undersea Vehicle Fest 2005 featured one USV, presented by Doug Freeman of Naval Surface Warfare center Panama City, which served as carrier for an unmanned underwater vehicle, the RDUST, *Hoffman (2005)*. Radix Marine announced in 2003 plans for the development of a USV 'Odyssey', but no further development was reported. Since 2005, the ONR sponsors the development of the PMS 325 USV Surface Sweep System by NAIAD Inflatables of Newport. This USV is intended to support operation of a littoral combat system ship.



Sea Fox



Roboraider



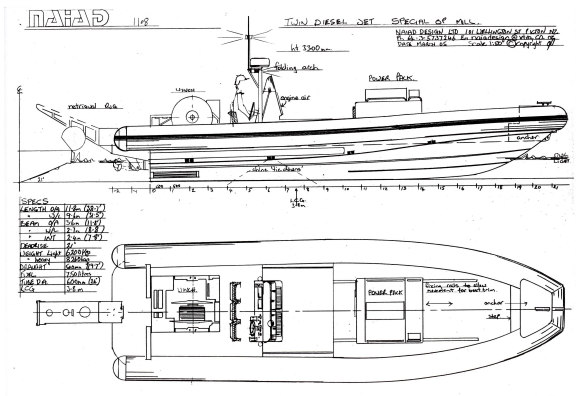
Remotely Piloted Surface Vehicle (RPSV)



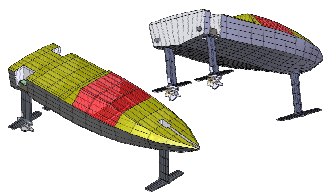
Unmanned water vehicle RDUST on un-manned surface vehicle



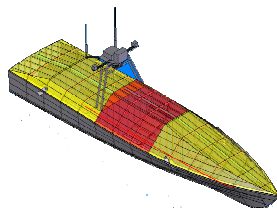
Radix Odyssey



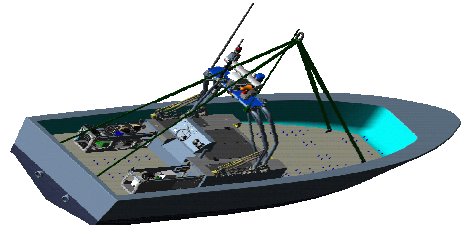
PMS 325 USV Sweep System



USSV-HS



USSV-LS

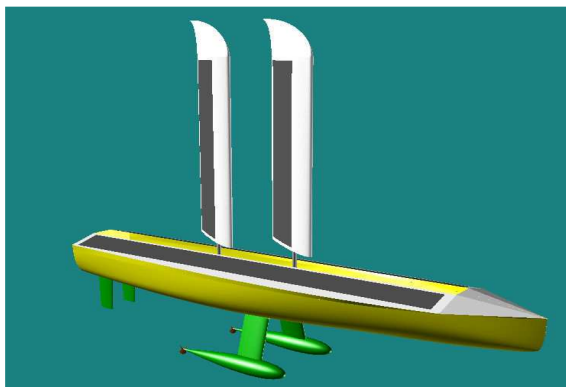


PEO LMW

Two USVs built by Maritime Applied Physics Corporation (MARPC) were tested by the ONR in 2005, *Kennedy (2005)*. The High-Speed Unmanned Sea Surface Vessel is a 10 m hydrofoil with a top speed of more than 40 kn in heavy seas. The Tow Force Unmanned Sea Surface Vessel has just above 20 kn speed, but can tow in excess of 1 t and carry close to 4 t payload and fuel. The Technology Development & Research Institute, www.saiaa.com developed two USVs apparently related in concept to the MARPC USVs, namely the USSV-HS hydrofoil and the USSV-LS larger monohull.

The PEO LMW Unmanned Surface Vehicle (USV) is a mission reconfigurable, high-speed, high endurance, semi-autonomous surface vehicle designed to support focused Navy missions. This USV is equipped with radar (with ARPA), fixed cameras, infra-red sensors, microphone, depth, temperature and wind speed sensors. In addition, for anti-submarine warfare, it will be equipped with acoustic sources and towed array sonar systems. The USV evolved from a US Navy 11m RHIB. Future craft will likely be monohulls, but may not have inflated collars.

The Virginia based company UOV, www.uovehicles.com, developed an autonomous USV relying completely on solar power. The Unmanned Ocean Vehicle (UOV) does not need fuel. It is self-propelled, self-deployable, and provides an inexhaustible supply of electrical power for sensors and communications. Its endurance is thus virtually unlimited, but the vehicle is limited to relatively low speeds. The application appears well suited for data gathering applications as in oceanography and surveillance. The UOV features rigid wing sails covered with solar panels to convert wind energy to propulsive energy. The rigid sails fold on deck in severe weather to prevent damage. The battery storage capacity is sufficient for a week's operation. This provides continuity of power at night and in low wind. Four different models are available, ranging from 5 m to 10 m in length.



UOV: Ocean Cruiser



UOV : Ocean Explorer

4. Developments outside the USA

Besides the USA, several other countries employ and develop USVs. In Japan, Yamaha developed two USVs, the Unmanned Marine Vehicle High-Speed UMV-H and the Unmanned Marine Vehicle Ocean type UMV-O, *Enderle et al. (2004)*. The UMV-H is a deep-V mass-produced hull, equipped with 90 kW to go 40 knots using water-jet propulsion. The boat can be used either manned or unmanned. At a length of 4.44 m, the craft is small enough to be loaded on a small cutter, but large enough to accommodate all necessary equipment and instruments such as under-water cameras (ROV) and sonar equipment. The UMV-O is an ocean-going USV with displacement hull. It is used primarily in applications involving monitoring of bio-geo-chemical, physical parameters of the oceans and atmosphere that put the long-distance capabilities of the vehicle to effective use. The first UMV-O “Kan-Chan” was delivered in 2003 to the Japan Science and Technology Agency.



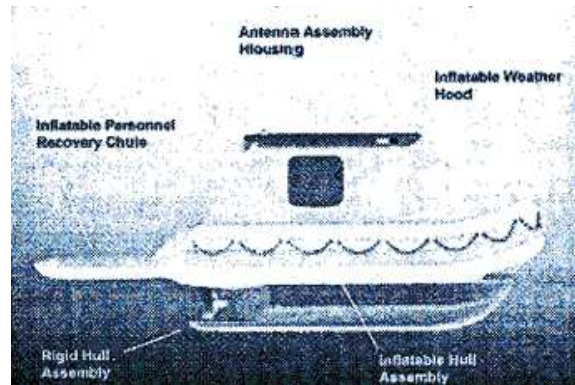
Yamaha UMV-O



Yamaha UMV-H



Canadian Barracuda



Canadian SEAL

The Canadian Barracuda is an unmanned version of an 11 m rigid hull inflated boat (RIB). The Canadian company International Submarine Engineering Ltd (ISE) has been working on USVs for 10 years. They offer a so-called Tactical Controller (TC) Kit. The TC Kit transforms an existing manned boat into a USV which operates via a command link. It is a portable, modular, flexible, expandable package that is based on ACE, ISE's proprietary open architecture control system software. Four USVs have been implemented by ISE, <http://www.ise.bc.ca/USV.html>:

- The Dolphin MK II semi-submersible, <http://www.ise.bc.ca/dolphin.html>, *Young et al. (2006)*, was initially developed for the Canadian Hydrographic Service. In 1985 two Dolphins were delivered to the US Navy for navy payloads, and in 1988 two additional Dolphins were ordered as remote minehunting vehicles. Continued work resulted in 'Dolphin derivatives', *Young et al. (2006)*, including the Canadian 'Dorado', the RMS in the USA (see above), and the French 'Seakeeper' (see below)
- The Seal USV was a demonstrator to Canadian Department of National Defense (DND) for Search and Rescue;
- SARPAL Autonomous Marine Vehicle (AMV) was developed for DND; and
- "The Machine" was a rapidly developed demonstrator for the US Military. ISE integrated the TC Kit into an existing 8 m RIB supplied by ACB Boats of Bellingham, Washington.

The Israeli navy uses the Stingray, <http://www.defense-update.com/products/s/stingray.htm>, to tow targets, a USV somewhat smaller than the Roboski. The Israeli company Rafael offered in 2003 the "Protector", <http://www.rafael.co.il/web/rafnew/products/nav-protector.htm>, an integrated naval combat system, based on unmanned, autonomous, remotely controlled surface vehicles. Highly maneuverable and stealthy, the Protector can conduct a wide spectrum of critical missions, without exposing personnel and capital assets to unnecessary risk. The Republic of Singapore Navy employs the Protector since the year 2005.



Dolphin MK II



Dorado



SASS-6M

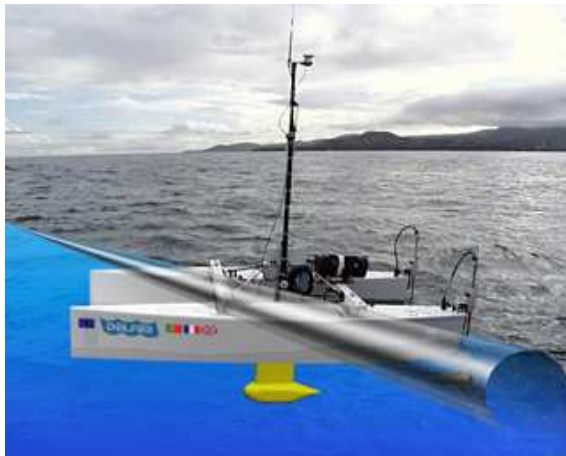


Israeli Stingray



Israeli Protector

The Portuguese Dynamical Systems and Ocean Robotics laboratory, <http://dsor.isr.ist.utl.pt>, has developed several marine robotic vessels, including the DELFIM autonomous surface catamaran and the Caravela autonomous oceanographic vessel with a range of operation of at least 700 nautical miles, *Pascoal et al. (2006)*.



DELFIM



CARAVELA

The University of Plymouth has developed a catamaran USV ‘Springer’ capable of operating in shallow water for measuring water quality and for environmental surveys, *Naeem et al. (2006)*, <http://www.tech.plymouth.ac.uk/sme/springerusv/>. H Scientific (www.h-scientific.com) advertises a Remote Control Automatic System (RCAS) to control unmanned surface vessels. Extent of autonomy and actual applications are unknown. QinetiQ Ltd in the UK has developed an experimental USV system known as the MIMIR, *Corfield (2002)*, *Corfield and Young (2004)*. “The MIMIR EV1 system was designed to investigate the feasibility of using USVs in underwater search and survey roles, the use of USVs within a networked information system and the potential cost/benefits of such systems. The aim was to maximize shallow water access and data acquisition opportunity. The overall MIMIR concept was to use multiple, low-cost, networked USVs operated from a mobile land-based command centre as nodes within a wireless data network”, *Corfield and Young (2006)*. The MIMIR experience was then used to develop SWIMS (Shallow Water Influence Minesweeping System) to support MCM operations in 2003 in the Gulf War, *Ray and Leaney (2004)*. Continued USV work at Qinetiq resulted in the FENRIR family of USVs, intended to deliver small underwater unmanned vehicles (UUVs) and rapidly deployable sensors in navy operations, *Corfield and Young (2006)*. ASV Ltd in the UK developed the Survey Autonomous Semi-Submersible (SASS) vehicle in 2006, *Young et al. (2006)*.



Springer



Basil



MiniVAMP



SeaKeeper



Argonaute



Rodeur



Remote Control Automatic System

The French navy has demonstrated the SeaKeeper, a semi-submersible similar to the Remote Mine-hunting System (RMS). The SeaKeeper is also intended for mine-hunting and port security applications. The drone Argonaute is used by firefighters to chemically analyze ('sniff') the air near containers with unknown content. The French company Sirenha has developed an unmanned jet-ski under the name "Rodeur". The French company ACSA offered in 2005 two USVs, developed originally for

remote surveys of offshore pipelines, <http://www.underwater-gps.com/dpbuoys/dpbuoys.htm>, the Basil and the MiniVAMP (Virtually Anchored Multipurpose Platform), a low-cost version of limited autonomy. In 2004, further developments resulted in the Basil II, with longer autonomy (up to 12 h) and longer range (radio link up to 15 km), equipped with solar panels, battery packs and electric motor.



Basil-II during outfitting



Basil-II with solar panels

In the late 1990s, HDW had reportedly a USV prototype under the name of “Natter” (Naval Training Aid) developed, but developments were not further pursued. The University of Rostock developed in 1995 Rescue Dolphin, a USV to rescue people in distress and in 2000 the Measuring Dolphin, a catamaran USV for oceanographic surveying and measuring purposes, *Majohr and Buch (2006)*. Since 1997, the German company Veers has been active in developing USVs. Initial work focuses on the development of a USV “STIPS” for the German ministry of fishery in two stages. In early 2005, Veers presented the Multi-Mission Surface Vehicle III (MMSV III) or “See-Wiesel”, *Veers and Bertram (2006)*.



STIPS I



STIPS II



MMSV III (See-Wiesel)

5. Final remarks

Miniaturized sensors and electronics, as well as communications equipment allow for the development of small payload packages with significant information gathering capability for almost any USV platform. This includes digital and video cameras, EO/IR sensors, and radars. Although this means that most USV scales can provide some level of "Intelligence, Surveillance, and Reconnaissance" (ISR) capability, larger more complex towed sensors required for a robust mine warfare or anti-submarine warfare capability require significant payload and towing capability, as well as platform stability, and endurance are key factors in determining the utility of USVs for multi-mission applications in the littoral. Generally the larger USV platforms tend to be more stable and offer more mission functionality. An additional consideration for platform stability is the basic design of the USV. Most USVs are adapted from manned surface vessel designs that necessarily have to deal with the fluctuations of the air/water interface to accommodate human occupants. The developers of RMS realized that this limitation need not apply to unmanned systems, and designed the RMS USV to be an air-breathing semi-

submersible, where the entire vehicle except for a snorkel is submerged to improve stealth and platform stability. However, custom-designed USVs have an important drawback.

Any new system brought onboard a combatant competes for very limited and valuable space. One way to mitigate this is to convert existing manned vehicles into dual-purpose vehicles that can function in conventional manned mode or in unmanned mode. Several such projects have been realized over the past decade, often on rigid inflatable boats (RIBs), like the Freedom Sentinel USV of the US Navy. Existing craft can be modified to operate as USVs by the installation of a modular and scalable remote-control kit that allows the craft to be operated either in fully manual mode, in autopilot-augmented mode or in remote-control mode. By doing this the ship not only retains full manual capability but that capability is augmented and extended in an affordable and low-risk manner.

Acknowledgement

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Table I: USVs – Main data (sometimes estimated)

	L [m]	B [m]	T [m]	Displ [t]	V [kn]	Payload [t]
QST-35 Septar	17.00	4.50		19.00	35	10
Roboski SDST	2.70	1.20		0.20	42	0.16
Spartan	7.00	3.00		4.00	>30	0.7
Sea Fox	~5.00			0.64	40	
Yamaha UMV-H	4.44	1.84		0.45	40	
Owl/Ash	2.90	1.50		0.50	45	0.2
11-m RIB	11.00			5.90		
7-m RIB	7.00			1.90		
PMS 325	11.80	3.60	0.5	6.50	24	
USSV-LS	11.90	2.90		8.17	21	4.0
USSV-HS	10.68	3.05	0.56	9.30	45	2.5
Protector	9.00				40	1
Yamaha UMV-H	4.44				40	
Yamaha UMV-O	7.99			3.50	4	
Dolphin MK	7.30	1.00	4.50	2.83	12	
Rodeur	3.50	1.00	<0.50		15	
SeaKeeper	8.30		11.00	7.00	12	
MiniVAMP			0.75	0.06	3	
Basil			2.50	0.40	3	
MMSV	3.30	0.60	0.40	0.28	27	
Ocean Explorer	10.00	2.10		1.40	4-9	0.5
MIMIR	3.00	1.50			4	