Evaluation of "Spot-and-Sweep" Blasting as a Cost Effective method of Underwater and Outer Hull Surface Preparation

Prepared for:

National Shipbuilding Research Program
Surface Preparation and Coatings Panel (SPC)

Submitted by:

Gordon Kuljian, Consultant
Stephen Cogswell, BAE Systems Southeast Shipyards
John Odwazny, Chariot Robotics
J. Peter Ault, P.E., Elzly Technology Corporation

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EXECUTIVE SUMMARY

The current U.S. Navy underwater hull surface preparation strategy is to completely remove the coating systems after an 8-year service life. This is accomplished through abrasive blasting or ultra-high water-jetting (UHPWJ) and is the only strategy approved under NAVSEA Standard Item 009-32 (preservation). Surface preparation in the commercial arena (general cargo fleet, tankers, bulkers, and cruise liners) generally consists of repairing the system at 36-60 month intervals by removing only loose or delaminated coating, applying primer to exposed steel, adding additional anti-corrosive as needed and applying full antifouling coats. Such a practice is termed "spot-and-sweep blasting".

This project examined using commercially available high speed semi-automated robots in conjunction with ultra-high pressure water-jetting (UHPWJ). This process of high speed spot-and-sweep surface preparation is being used now and for the past several years in yards throughout Europe, the Middle East, Japan, Singapore, and the Caribbean. The concept is approximately 5%-10% of the anti-corrosive coating breaks down periodically and therefore it is redundant and unnecessary to completely remove 90%-95% of intact coating to bare metal, as is the current requirement in Standard Item 009-32, each time–the coating system is renewed. As a precursor to the NSRP SPC tasking, Chariot Robotics arranged a pro bono demonstration at BAE Systems Norfolk Ship Repair in August 2010 on the underwater hull of USS ARLEIGH BURKE (DDG-51) that was witnessed by over 30 Government and contractor personnel.

The approach to this project was to demonstrate the benefits and successfully implement the spot and sweep process using real time dry-dockings of U.S. Navy assets. Additional monitoring of simple metrics such as the condition of underwater hull paint prior to blasting, production rates of surface preparation, effect on coating adhesion (pre and post blasting) and resultant coating thickness would also be accomplished.

Performance of the spot-and-sweep technique was demonstrated by the sub-contractor, Chariot Robotics LLC (Palm City, FL) on the following vessels:

USS KLAKRING (FFG-42) – February 2011, spot/sweep of entire underwater hull and freeboard
BERTHING BARGE (APL-65) – July 2011, spot/sweep of 2000 ft^2, WJ-2 of remaining U/W hull
USS RODNEY M. DAVIS (FFG-60) – February 2011, spot/sweep of 2000 ft^2 underwater hull
USNS ALAN SHEPARD (T-AKE-3) – May, 2012 spot/sweep of 75000 ft^2 underwater hull

In all cases the spot-and-sweep was deemed a success by all observers and by the principal investigator of this project. Reasons for this success included:

- Increased productivity using the spot-and-sweep technique over traditional surface preparation methods due to the robotic nature of the machinery
- Increased coating adhesion of the remaining coating system
- Decreased time-in-dock resulting in decreased costs and increased operational readiness
- Minimal impact to adjacent trades performing routine overhaul work (other trades may actually benefit from reduced interference from surface preparation activities)
- Decreased environmental impact as compared to abrasive blasting cleanup and disposal

A simple cost analysis is presented showing that millions of dollars per year can be saved by incorporating a spot-and-sweep philosophy as part of routine Fleet maintenance. Finally, the report presents draft verbiage to be presented at SSRAC for acceptance into FY-14 version of 009-32. Verbiage

is necessary for Shipbuilding Specialists, Quality Assurance, Quality Control and others involved in the inspection of spot-and-sweep surfaces to make the Objective Quality Evidence manageable.

ACKNOWLEDGEMENTS

The help and assistance of several individuals was received during this project which contributed to its successful completion. The project could not have been a success without the help of the NSRP Surface Preparation and Coatings (SPC) Panel participants and their collaborative effort to reduce cost and maintain quality.

Other individuals and activities that helped the investigators in coordinating shipboard demonstrations include:

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Mr. John Odwazny, Chariot Robotics, LLC, Palm City, FL
Mr. Paul Ralph and Mr. Steven Johnson, YYK Enterprises, National City, CA
Mr. Mark Ingle, Naval Sea Systems Command, Washington D.C.
Mr. Stephen Cogswell, BAE Systems Southeast Shipyards, Jacksonville, FL
Mr. Dave Ciscon, The Columbia Group, Alexandria, VA
Mr. Mark Edmonds, Vigor Shipyards, Seattle, WA
Mr. Terrence J. Mead, Puget Sound Naval Shipyard, Code 250VP
The command of USS ARLEIGH BURKE (DDG-51)
The command of USS KLAKRING (FFG-42)
The command of USS RODNEY M. DAVIS (FFG-60)
NAVSEA Southeast Regional Maintenance Center
NAVSEA Northwest Regional Maintenance Center
NAVSEA Southwest Regional Maintenance Center
Puget Sound Naval Shipyard & IMF Code 400

The authors would also like to thank all active participants at SPC Panel meetings held in the following cities, for their insight and input.

Maplewood, MN	May 2012
Orlando, FL	February 2012
Newport News, VA	October 2011
Marinette, WI	June 2011
MEGARUST Norfolk, VA	June 2011
Las Vegas, NV	February 2011

Finally, the authors would like to thank all active participants in the CWP-356 Partial Blast/CWP-367 NSRP Spot and Sweep Blasting monthly conference calls for their insight and input.

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CONCLUSIONS

1. Most importantly, the spot-and-sweep method of underwater hull and freeboard maintenance surface preparation can lead to significant cost savings for the United States Navy and Military Sealift Command ships. This study estimated nearly $ 10 million can be saved for dry docked U.S Navy CRUDES, Amphibious, CVN, and SSBN hulls in calendar year 2012 by employing the spot and sweep methodology for underwater hull and freeboard maintenance surface preparation.

2. The spot-and-sweep method of underwater hull and freeboard maintenance surface preparation can result in significant reduction of the surface preparation portion of the schedule. This study estimated more than 1,000 days of surface preparation schedule can be eliminated for dry docked U.S. Navy CRUDES, Amphibious, CVN, and SSBN hulls in calendar year 2012 by employing spot and sweep methodology for underwater hull and freeboard maintenance surface preparation. This schedule reduction can improve the productivity of other trades and may reduce the overall time in dock. The potential savings from the schedule reduction could be far greater than the savings associated with the surface preparation activity.

3. Based on the demonstration projects held, spot-and-sweep water-jetting of underwater hull coating systems can be a viable cost-saving alternative to full removal. Such a method can make a significant impact on dry docking maintenance costs for aging surface combatants such as the FFG-7 and CG-47 class fleet. With multiple ship de-activations scheduled in the next decade, there is every reason to seriously consider the spot-and-sweep method for these platforms.

4. Production runs of spot-and-sweep water-jetting removal were measured for this program and ranged from 1120 – 2545 ft^2 /hour. This method can be up to ten times faster than traditional abrasive blast removal to a SSPC-SP-10 condition, thereby saving time in dock and increasing the ship's operational readiness.

5. Adhesion of the tightly adhering existing coating is not adversely affected by the spot-and-sweep method even when using pressures in excess of 20,000 psi.

6. Remaining coating dry film thickness readings can vary significantly. It is therefore recommended to use wet film thickness readings for subsequent coating application.

7. Chariot Robotics has demonstrated that their "sweeping head" technology is capable of being readily adjusted to greatly reduce visible "swirl marks" that are inherent to most robotic water-jet machinery.

8. During the spot-and-sweep process all water and paint effluent was vacuum extracted directly into a tank placed on the dry dock floor. This was in stark contrast of having to remove large volumes of spent abrasive from a dry dock floor.

RECOMMENDATIONS

1. Modify as required and adopt the draft verbiage for OQE contained in this report into the latest change to NAVSEA Standard Item 009-32 after submission to the July 2012 SSRAC committee meetings.

2. Add SPOT-AND-SWEEP BLASTING as an alternate surface preparation method to Table 1 Line 1 of NAVSEA Standard Item 009-32 for Underwater Hull (up to 7 years' service life and up to 12 years' service life)

3. Add SPOT-AND-SWEEP BLASTING as an alternate surface preparation method to Table 2, Line 1 for exterior vertical surfaces above the boottop (with exception of well deck and areas to receive non-skid).

4. Continue to evaluate and monitor performance of ships underwater hulls that have been prepared and coated using the spot-and-sweep method via high production UHPWJ.

5. Maintain an accurate database of hulls preserved using the spot-and-sweep method so that the performance of this cost saving measure can be tracked.

6. The integrity of the subject hull coating system must be evaluated prior to electing spot-and-sweep. We recommend 5% general coating breakdown as the upper limit of defects before a full SSPC SP-10 or SSPC SP-12 WJ2L be used as the surface preparation specification.

7. The Military Sealift Command should continue to encourage the spot-and-sweep methodology for dry dockings of their ships.

PROJECT OBJECTIVES AND METHODOLOGY

The main objective of the project is to introduce an alternate technology and method for preparing the outer hull surfaces, primarily the underwater hull, to the U.S. Navy, its shipyards, private shipyards, and all contractors who perform outer hull preparation on U.S. Navy vessels. The present project proposed that the U.S. Navy examine the worldwide commercial practice of "spot and sweep" for underwater hull surface preparation. The NSRP Surface Preparation and Coatings (SPC) panel project provided an excellent means to demonstrate this spot and sweep technology on the underwater hulls and freeboard areas of four U.S. Navy platforms.

The specific project goals and objectives were:

(1) Demonstrate to the U.S. Navy and Maintenance and Repair community the equipment and technology available to perform the high production spot and sweep methodology of surface preparation by way of actual performance on U.S. Navy platforms in dry dock.
(2) Identify equipment, costs and support services required for this method of removal.
(3) Establish initial coating evaluation procedures, QC procedures, and evaluation metrics for this commercially accepted cost-effective surface preparation method.
(4) Draft verbiage for a SSRAC Proposal for U.S. Navy Implementation in 009-32 FY14

Our approach to this project included four interrelated tasks:

<u>Task 1 – Review Production Data and Methods</u>. We briefly reviewed all related underwater and freeboard hull surface preparation methods incorporated by regional shipyards and their sub-contractors. In addition, we reviewed commercial shipyard practices world-wide to provide comparison data to the NSRP panel. We presented our analysis of the technical literature at the first NSRP SPC panel meeting in February 2011, after project approval.

<u>Task 2 – Accomplish Surface Preparation on Multiple Platforms in Dry Dock.</u> We arranged multiple dry dock demonstrations of the UHPWJ spot-and-sweep process, commercially deemed the "Ultrasweep™" Process on U.S. Navy ships. The first demonstration was performed pro-bono on USS ARLEIGH BURKE (DDG-51) at BAE Systems Norfolk Ship Repair in August 2010. Once the project was awarded, the second demonstration was full coating removal on the underwater hull and freeboard of the USS KLAKRING (FFG-42) at BAE Systems Southeast Shipyards in February 2011. The third demonstration was conducted at Naval Base San Diego on APL-65 Berthing Barge. The last demonstration was conducted at Vigor Shipyards in Seattle, WA on USS RODNEY M DAVIS (FFG-60). Finally, as the project was concluding the process was demonstrated in full production on USNS ALAN SHEPARD (T-AKE-3) at BAE Systems San Francisco Ship Repair.

In all cases the host shipyard, or general contractor, provided the ship platform, utilities, rigging and general dry dock support. They interfaced with the local contractual requirements, RMC and Ships Command. Chariot Robotics provided manpower, equipment, and worked alongside shipyard personnel to accomplish spot-and-sweep blasting for the NSRP demonstrations. The project documented pre and post treatment hull coating condition, removal productivity, and assessed effectiveness of the method.

<u>Task 3 – Presentation of Findings</u>. At all SPC panel meetings we presented highlights of the technical effectiveness of the hull removal method on all platform trials performed to-date. The project team also presented any significant data, findings and observations at these meetings. Project representatives

continue to participate in CWP-356 Partial Blast/CWP-367 NSRP Spot and Sweep Blasting monthly conference calls.

Task 4 – Develop QC Methods and SSRAC Proposal. Based on the results of the shipyard trials, we developed a QC procedure to gauge candidate suitability for spot and sweep preparation. The SPC panel of NSRP will submit a proposal to the Standard Specification for Ship Repair and Alteration Committee (SSRAC) for their consideration at the August, 2012 meeting.

BRIEF REVIEW OF PAST RELATED WORK

In 1996 NSRP commissioned a study entitled "*Productivity Study – Hydroblast Removal of Coatings*."[1, 2] This study examined a number of factors concerning water-jetting in various environments, such as shipbuilding and ship maintenance. Open cycle water-jetting (hand lances, or "men-on-guns") were studied, as well as various robotic or automated equipment available at the time. Full removal, selective stripping, and spot and sweeping were all studied as part of an effort which looked at water-jetting over nine ship visits, including new construction, U.S. Navy ship dry docking maintenance, and even off-shore ballast tank work. The following information was gathered for each scenario:

- Production rates of equipment and workers
- Chloride and conductivity removal efficiency
- Adhesion of existing coating
- Surface profile created (for selective removal and sweeping)
- Blasting efficiency (trigger time/total blasting time)

Related to spot and sweep blasting, much of the work was performed on USS DULUTH (LPD-6) while dry docked for routine maintenance. The entire underwater hull was spot-and-sweep blasted by men-on-guns, as well as several ballast tanks. The sweep blast was intended to stress the coating system leaving only tightly adherent paint as well as create a clean profile in the existing coating. Corroded areas were spot blasted to bare metal. All coating removal was performed using open cycle hand-held lances.

For the ballast tanks, the scope of work was to spot blast to bare metal all corroded areas and sweep blast all other areas to remove staining and provide a clean profiled surface for subsequent coating application. The tank observed had a two coat MIL-PRF-23236 epoxy system, averaging 9.8 mils DFT. Production rates ranged between 90ft^2/hour/gun and 236 ft^2/hour/gun with an average of 171 ft^2/hour/gun. The pump equipment operated between 18,000 psi and 20,000 psi at a flow rate of 8 gpm. The nozzle on the lance contained 2 jewels and was hydraulically spun at 4800 rpm.

Other data was collected during the removal of damaged shop primer on the outer hull of the chemical tanker during new construction. The blasters were to sweep blast the entire painted surfaces and remove any damaged areas down to bare metal (i.e. charred areas from internal welding, areas damaged by scraping and handling, erection joints). The shop primer ranged from 0.5 to 2.0 mils. Production rates ranged between 146 ft^2/hour/gun and 365 ft^2/hour/gun with an overall average of 198 ft^2/hour/gun. The pump equipment operated at 40,000 psi with a flow rate of 5.5 gpm. The nozzle on the lance contained 5 jewels.

Production rates from the internal tanks of an offshore platform were also observed. The coating system for the tanks consisted of only two coats: epoxy primer (~1 mil), epoxy top-coat (~10 mils). The average production rate for the spot and sweep blast inside of the tanks was 157 ft^2/hour/gun. The UHP pump equipment operated between 18,000 psi and 20,000 psi at a flow rate of 8 gpm. The nozzle on the lance contained 2 jewels and was hydraulically spun at 4800 rpm.

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[1] National Shipbuilding Research Program Project 3-96-4, "Productivity Study – Hydroblast Removal of Coatings", Reference 0520, December 1998

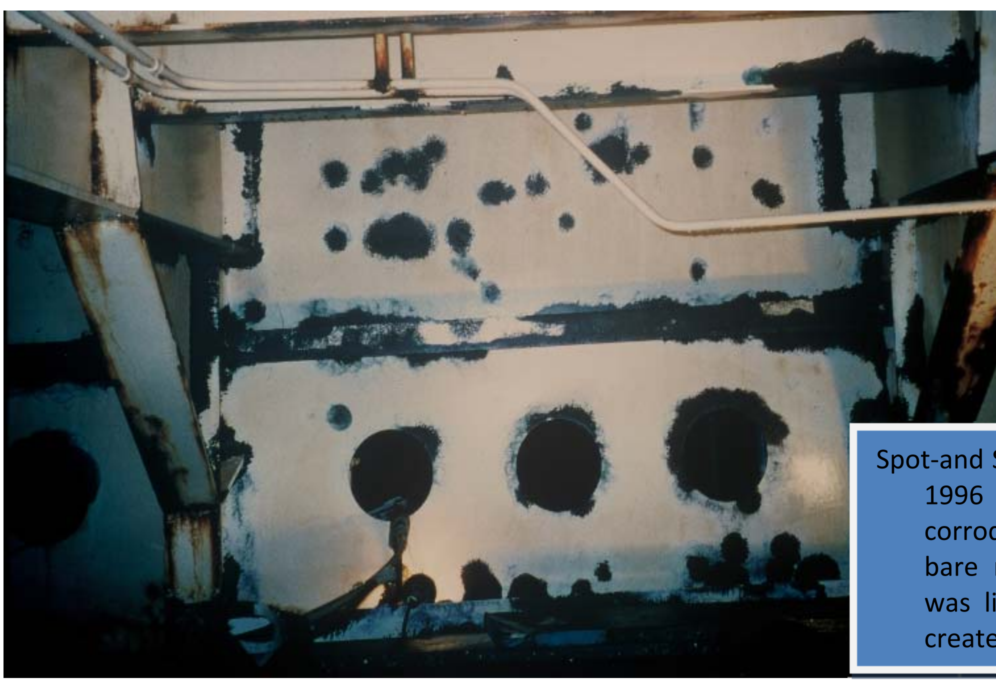
[2] G. Kuljian , D. Melhuish, "Evaluating the Productivity of Waterjetting for Marine Applications", Journal of Protective Coatings and Linings, August 1999 , 36-46

Also note that the production rates for these (three) spot and sweep observations achieved values around the 150 ft^2/hour/gun mark; fairly consistent for three separate scenarios.

On a consistent basis, the study showed that coating adhesion was either equal or better after sweep blasting with high or ultra-high pressure water. Chloride readings were "consistently reduced to under 3 $\mu g/cm^2$, with the majority of readings under 1$\mu g/cm^2$" while substrate conductivity readings were reduced to less than 20 µS/cm for the majority of readings.

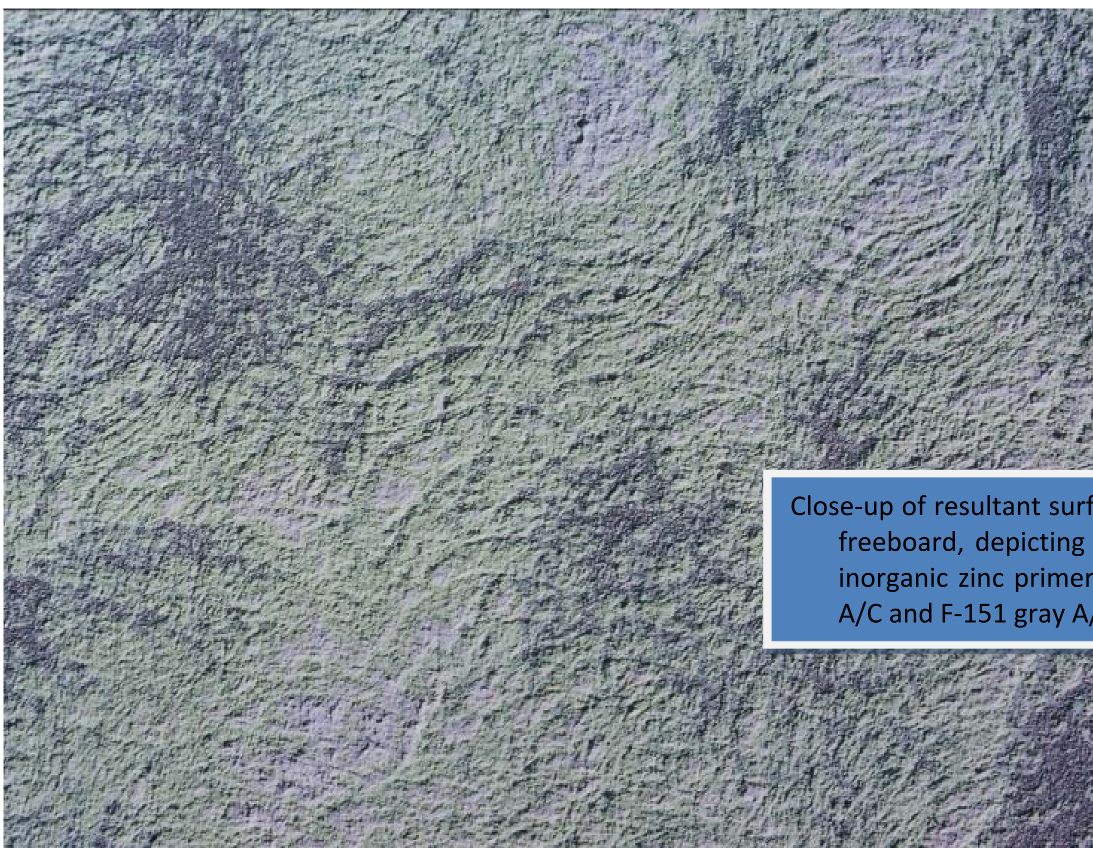
Photographs of related work from the above study are presented below:

Spot-and Sweep of underwater hull from 1996 NSRP study. Note feathering of buff and red A/C to adjoining A/F



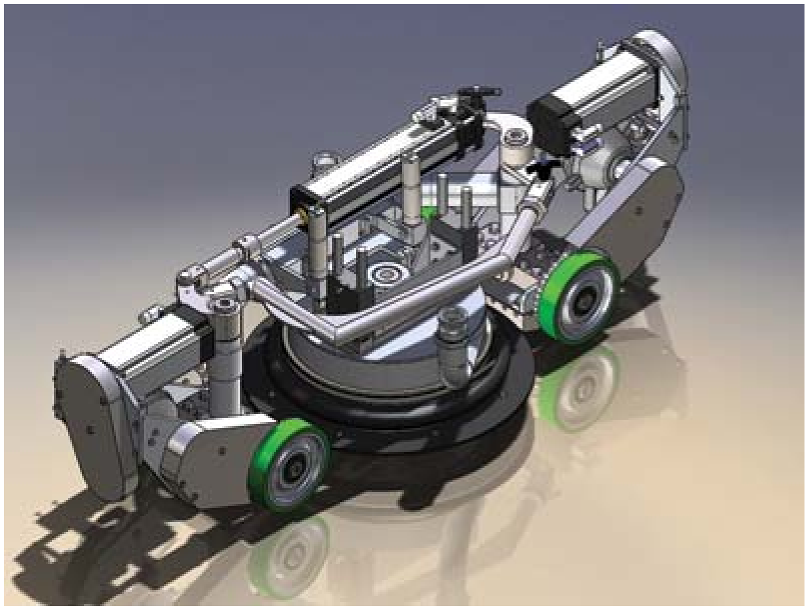
Spot-and Sweep of ballast tank from 1996 NSRP study. Note corroded areas were taken to bare metal and remaining A/C was lightly swept to clean and create a profile.

Men-on-guns sweeping freeboard of LHD-6 during 1996 NSRP Study



Close-up of resultant surface of LHD-6 freeboard, depicting a mixture of inorganic zinc primer, F150 green A/C and F-151 gray A/C.

DESCRIPTION OF THE CHARIOT ROBOTICS SYSTEM



The ENVIROBOT system removes coatings from ferrous surfaces by the means of a remotely operated vehicle that contains rotating Ultra-High Pressure (UHP) water jets. It is the most technically advanced solution in the world for sweeping and removal of coatings on ship's hulls. A rotating spray bar delivers the water in a 15 inch wide cut pattern as the vehicle traverses the work surface. The magnetically-attached vehicle maintains traction to the surface in any orientation, including vertical, horizontal and inverted. The system can completely remove coatings or partially remove coatings, (deemed "selective stripping") depending on the nozzles chosen, the water pressure, proximity of the nozzles to the coated surface and rate of travel. All of the effluent is captured and transferred to a holding tank by the means of a vacuum system. The 4-wheel independent steering make the robot fast and maneuverable, while the high density polyurethane wheels prevent any marring of painted surfaces and provide outstanding traction.

A full description of the ENVIROBOT and all of its components is detailed in Appendix A.

The main components of the Envirobot are the robot, the robot control and power systems, the ultra-high pressure (UHP) pump, and the vacuum. Each unit is designed for transport by land or sea and is configured for immediate setup upon delivery.

A full technical paper devoted to the development of the ENVIROBOT is available.[3] Some applicable specifications of the Chariot Robotics Envirobot system used in this NSRP study follow:

[3] W. Ross, J. Bares, C. Fromme, A Semi-Autonomous Robot for Stripping Paint from Large Vessels, The International Journal of Robotics Research, Vol 22, No 7-8, July-August 2003, pp. 617-626

CHARIOT ROBOTICS ENVIROBOT FEATURES SUMMARY

FEATURE	DESCRIPTION
MAGNETIC AIR GAP	PATENTED, FOCUSED NON-POLAR, NON-MAGNETIC ARRAY
DRIVE WHEELS	SEALED DOUBLE BEARING HUBS, HIGH COMPRESSION NON-MARRING POLYURETHANE
DRIVE MOTORS	AIR AND ELECTRIC DRIVE OPTIONS AVAILABLE
VEHICLE DRIVE	4 WHEEL DRIVE, 4 WHEEL STEER
VEHICLE BRAKES	FAIL SAFE BRAKES ON DRIVE MOTORS
CONTROL	WIRELESS REMOTE CONTROL JOYSTICK
SPEED	0-12 INCHES PER SECOND
HULL CURVATURE CAPABILITY	72 INCH OR LARGER RADIUS OF CURVATURE
ORIENTATION DURING OPERATION	ANY (INCLUDING FLAT-BOTTOM HULL)
MAXIMUM WATER PRESSURE	50,000 PSI
CUTTING JETS	12 JET SELF ROTATING PROPRIETARY SPRAYBAR
JET CUTTING HEIGHT	0-3 INCHES FROM SURFACE USING WIRELESS REMOTE CONTROL
JET MAINTENANCE	HEAD RAISES AND LOCKS FOR EASY ACCESS AND MAINTENANCE
CUTTING WIDTH	15 INCHES
DIMENSIONS	67” x 27” x 22”
VACUUM	100% EFFLUENT CAPTURE
SAFETY	DUAL EMERGENCY E-STOP SWITCHES ON REMOTE JOYSTICK CONTROL AND CONTROL CONTAINER. FALL ARRESTORS SUPPLIED.

DESCRIPTION OF SHIPYARD SERVICES REQUIRED TO OPERATE CHARIOT ROBOTICS SYSTEM

Yard Services Required:

Crane/Forklift Service/Teleboom: Forklift/Telecom support will be required for the robot deployment and positioning. The robot's skid is constructed of steel and is equipped with standard slots for long or short arm forks. The entire unit (robot magnetically attached to the skid) is raised and positioned adjacent to the ship hull, and the robot is driven off the ramp onto the hull. Forklift service is not required again until the robot needs to be driven off the hull after job completion or for re-positioning to another location on the hull.

Dock Arm, Crane, or High Reach: Intermittent use required to install and move fall arrestors on the vessel's deck may be required depending on the vessel's configuration. Typical U.S. Navy ships have either deck mounted equipment to which the fall arrestors are attached, or welded on eyelets (boatswain's eyes to which the arrestors were clipped.

Water: Access in the work area to 15 gpm - 65 psi potable water for the robotic units UHP pump (uninterrupted supply).

Fuel: Diesel fuel for UHP pump or generator depending on shore power availability.

Vacuum tank: A vacuum tank is necessary for the duration of the job for containment of removed paint and waste water. Chariot Robotics generally operates the robotic system using an 18'-20' Baker Vacuum Tank, which is periodically drained or vacuumed out, depending on the location. Some shipyards have dry docks outfitted with drains which divert water directly to a shipyard wastewater treatment plant or to another collection site, such as a wingwall tank in a floating dry dock.

Lighting: Adequate lighting as required to operate the robotic equipment during evening hours.

Shore Power: No shore power is required; however, the system is capable of operating with shore side power (440 - 480v, 60Hz, 3 phase power) in the event the yard does not desire to run the onboard generator.

Yard Air: Access to yard air of 105 psi and 5.0 cfm is not required unless there is a problem with the system's air compressor.

PROJECT DEMONSTRATIONS

This section describes the actual shipyard demonstrations for this NSRP SPC panel project. These were coordinated by the project team and various shipyards that were performing dry docking availabilities on vessels as either full or partial boat demonstrations.

The demonstrations were used to evaluate the effectiveness of the Chariot Robotics ENVIROBOT in a spot-and-sweep mode of coating removal. Again, the philosophy of the spot-and-sweep coating removal is to only remove loose paint and corrosion products to bare metal keeping tightly adhering in-tact anti-corrosive layers in place. The Chariot Robotics system is optimized on a case-by-case basis for each scenario to deliver a traversing speed, rotational spray bar speed, stand-off distance to the hull, and operating pressure that will only remove loose and damaged coatings leaving well adhered coatings on the hull.

The condition of each hull must be evaluated by an experienced coating assessor to determine if it is a viable candidate for spot-and-sweep removal and subsequent coating. In other words, if a coating system is so full of defects, it may be more prudent to remove all of the coating to bare metal. Conversely if only 3-5% of the coating is damaged, then this method of hull coating removal will only remove the damaged coating leaving the remaining 95-97% (for this example) of tightly adhering anti-corrosive. This translates to significant savings through increases in production, decreased manpower requirements, and decreased time-in-dock.

Demonstration summaries follow for the following vessels:

USS ARLEIGH BURKE (DDG-51)	BAE SYSTEMS NORFOLK SHIP REPAIR	AUG 2010
USS KLAKRING (FFG-42)	BAE SYSTEMS SOUTHEAST SHIPYARDS	FEB 2012
APL-65 BERTHING BARGE	NAVAL BASE SAN DIEGO	JUN 2011
USS RODNEY M DAVIS (FFG-60)	VIGOR SHIPYARDS SEATTLE WA	FEB 2012
USNS ALAN SHEPARD (T-AKE 3)	BAE SYSTEMS SAN FRANCISCO	MAY 2012

PROJECT DEMONSTRATION – USS ARLEIGH BURKE (DDG-51)

TECHNOLOGY DEMONSTRATION DATE: 6 AUGUST 2010

LOCATION: BAE SYSTEMS NORFOLK SHIP REPAIR

CONTRACTOR: BAE SYSTEMS NORFOLK SHIP REPAIR

SUB-CONTRACTOR: CHARIOT ROBOTICS, LLC

PROJECT SUMMARY:

This demonstration was performed by Chariot Robotics LLC at BAE Systems Norfolk Ship Repair at the request of NAVSEA 04XP for the office of the Chief of Naval Operations (CNO). Approximately thirty coating professionals were in attendance for the presentation and demonstration of underwater hull spot and sweep blasting, as well as full coating removal on ARLEIGH BURKE (DDG-51) while in dry dock. Attendees from government shipyards (east coast and west coast), local Norfolk shipyards, local Norfolk area painting contractors, NAVSEA, NSWC and NAVSEA/NSWC/NRL support contractors all participated.

The existing coating system was estimated to be approximately 10 years old, and consisted of a typical 5 coat MIL-PRF-24647 underwater hull system. The coating condition showed typical accelerated wear (via cavitation) on the rudders and struts and approximately 1%-3% scattered localized breakdown on the remainder of underwater hull area.

The area reserved for the demonstration was on the forward port area of the underwater hull just aft of the forward ICCP dielectric shield and forward of the first emitter belt. The first portion of the demo used the Ultrasweep® process to remove the coating system down to the first coat of red anticorrosive primer. This process was explained in the preliminary brief by Chariot Robotics as a process they are using on commercial vessels to save schedule and costs while providing a smooth surface ready to accept a new underwater hull coating system. The robot demonstrated the removal of all anti-fouling layers, including most of the topcoat of epoxy (white), while leaving the intact red epoxy primer and taking any failed red primer and/or corrosion to a bare substrate SSPC WJ-2 condition. The robot moved with ease over a surface area of 30 x 40 feet. The travel speed was then slowed down increasing the dwell time on the surface to remove all coatings to the bare substrate (condition WJ-2) in an area of approximately 300 ft^2. This showed the audience that by simply slowing down the traverse speed, a full WJ-2 is easily achieved.

PROJECT DEMONSTRATION – USS KLAKRING (FFG-42)

TECHNOLOGY DEMONSTRATION DATE: 11-16 FEBRUARY 2011

LOCATION: BAE SYSTEMS SOUTHEAST SHIPYARDS

CONTRACTOR: BAE SYSTEMS SOUTHEAST SHIPYARDS

SUB-CONTRACTOR: CHARIOT ROBOTICS, LLC

PROJECT SUMMARY:

USS KLAKRING was available for this demonstration during her Dry dock Selected Restricted Availability (DSA) at BAE Systems Southeast Shipyards. The demonstration was originally envisioned to be a one day hull stripping event, however after observing the productivity, this evolved into receiving NAVSEA's concurrence to use KLAKRING as a full ship platform to demonstrate the spot-and-sweep technology. The original work package for the shipyard involved complete removal of freeboard and underwater hull coatings and recoat according to NAVSEA Standard Item 009-32. After coordinating with NAVSEA and Southeast Regional Maintenance Center, Chariot was separately contracted to spot-and-sweep all freeboard and underwater hull areas.

The underwater hull of USS KLAKRING was last preserved in November 2002. The existing coating system was in typical condition of a hull that had approximately 8 ½ years' service life. It was in generally good condition, showing fewer than 3% scattered coating breakdown. At the time of arrival, the hull had been pressure washed, showing a mixture of approximately 50% red anti-fouling and 50% black anti-fouling. Tooke gage readings verified the standard MIL-PRF-24647 A/C and A/F system and confirmed that the topcoat of red antifouling had ablated away over time yielding the remaining two layers. Depending upon location coating thickness readings varied greatly. As a general rule, coatings were applied much thicker than required on KLAKRING, especially on the freeboard. SERMC personnel reported that DFTs on the freeboard exceed the 60 mil capacity on their gage and were estimated in 85-100 mil range. Readings were as follows:

DESCRIPTION	LOCATION 1	LOCATION 2
TOOKE GAGE	2' aft of sonar dome at keel (Port)	At Stem (Starboard)
1st coat (red epoxy)	10 mils	15 mils
2nd coat (white epoxy)	5 mils	6 mils
3rd coat (red A/F)	5 mils	10 mils
4th coat (black A/F)	2 mils	2 mils
DFT GAGE (Elcometer 456)	LOCATION 1	LOCATION 2
Number of readings	30	10
Average thickness (mils)	26.5	42.7
High reading (mils)	30.6	45.4
Low reading (mils)	22.4	39.0
Standard deviation (mils)	2.14	2.27

Production

Approximately 31,000 ft^2 of combined underwater hull and freeboard hull coating system were prepared using a combination of systems. Chariot Robotics, using the Envirobot, accomplished approximately 26,000 ft^2 of surface preparation while FLOW International Hydro Cats were used for the remaining 5,000 ft^2. All perimeters and appendages were cut-in with UHP hand lances.

The Chariot Robotics equipment arrived on 10 February 2011 following the 8 Feb 2011 dry docking of the ship. Equipment included one 20' shipping container, one on-site vacuum box rental, and the UHP pump and robot. Hull stripping began on 11 February with two shifts working, 2 men per shift. Due to the rather tight configurations of the FFG class vessel, BAE personnel commenced cut in work with UHP open cycle gun lancing equipment. Cut in work included the following areas: rudder, struts, skeg, two feet down the hull from the fantail flight deck edge, and around hull discharges including seachests, bilge keel, and fin stabilizers.

The robot's parameters were optimized within 30 minutes and production commenced. The goal of the demonstration stripping event was to leave as much intact epoxy anti-corrosive while removing to bare metal any unsound paint and corroded areas. In addition, all anti-fouling paint was removed as a result of the pressures involved. As is the case with most modern MIL-PRF-24647 coatings, the primer layer is red and the topcoat epoxy is gray. As seen below, the resulting surface can vary quite dramatically depending on the current paint condition. In areas where the hull coating is well adhered with little or no defect a mixture of red and gray A/C remains. In areas where the hull coating adhesion is compromised a mixture of bare steel, red, and gray A/C remains.

Although the original scope of work for this project included only underwater hull coatings the investigators wished to demonstrate, where feasible, the spot-and-sweep concept on the freeboard. USS KLAKRING presented this opportunity. With a 30 year old ship freeboard hull coating thicknesses often exceeded 80 mils. The excess weight of multiple cosmetic coats of MIL-PRF-24635 alkyd can reduce ship fuel efficiency and negatively impact appearance. It is of great benefit to the ship if all excess coating can be removed while retaining intact anti-corrosive. For this reason the robot removed the excess freeboard hull coating down to the remaining intact anti-corrosive.

A quick production run of the Ultrasweep spot and sweep technique was observed on the forward starboard outer hull just under the hull number and down to the keel. This demonstration involved a mixture of both freeboard and underwater hull spot and sweep blasting. Approximately 1400 ft^2 of hull coating was stripped in 75 minutes. This equates to a spot and sweep stripping rate of 1120 ft^2/hour.

Coating Adhesion

Random coating adhesion tests were performed via ASTM D4541, Standard Test Method for Pull-Off Strength of Coatings using Portable Adhesion Testers.[4] The model used was a Positector AT-Manual Hydraulic Pump type pull-off gage. Coating pull-off strength measured on the retained coating after the spot-and-sweeping measured as follows:

AREA MEASURED	PULL OFF STRENGTH (PSI)
SINGLE COAT A/C REMAINING	1356
TWO COATS A/C REMAINING	1007
TWO COATS A/C REMAINING	2030

[4] ASTM D-610/ SSPC VIS-2, Standard method of Evaluating Degree of Rusting on Painted Steel Surfaces

Typical Condition of Resulting Surface

After the spot-and-sweep blasting over 90% of the coating remained on the hull. Of this ninety percent, a relative mixture of red (primer layer only) and white (primer and top layer) epoxy remained on the hull. As can be seen from close-up photos, these remaining layers are well adhered and well profiled. The remaining ten percent of the hull on KLAKRING was removed to bare metal (SSPC-SP-12-WJ-2) via virtue of the ultra-high pressure water impacting on a marginally adhered and degraded surface. Other areas making up this ten percent included a 1500 ft^2 section prepared to SP-12-WJ2L on the aft starboard side along with cut-in areas prepared to a SP-12-WJ2L via men on guns.

Looking forward from skeg. Note general mixture of white and red epoxy and spot bare metal areas. This is typical of the spot-and-sweep method.

Chariot Robotics Envirobot deployed on port mid-ship hull performing spot-and-sweep preparation on KLAKRING.

Chariot Robotics Envirobot beginning production run of starboard bow

Chariot Robotics Envirobot after completing production run on the starboard bow.

Comments on USS KLAKRING demonstration

1. SERMC, NAVSEA and shipyard personnel worked together to develop the Objective Quality Evidence (OQE) criteria as to how the spot-and-swept surface could be objectively evaluated for QA personnel. Such evidence is presented in the Economic Analysis section of this report and forms the basis for verbiage to be presented to the SSRAC Committee for inclusion into NAVSEA Standard Item 009-32 at their next meeting.
2. The KLAKRING proved to be an ideal candidate to demonstrate the merits of the spot-and sweep technology in that its outer hull coating systems showed minimal breakdown to bare metal and associated corrosion.
3. High tensile pull-off data after the coating system had been swept lends confidence to the notion that the retained coating is in a robust condition for over-coating.
4. No edge lifting of retained coatings was observed after the two subsequent coats of anti-corrosive were applied. This confirms that the retained coating was properly feathered and well adhered to accept subsequent top coats. The criterion for inspecting this condition is in the proposed 009-32 language.
5. The KLAKRING demonstration showed that the spot-and-sweep equipment can be mobilized and set up in a contractor's dry dock in one day. The equipment was set up mid ship and supported the blast from stern to bow. The equipment footprint included one 8-foot by 20-foot shipping container, an 8-foot by 10-foot UHP pump, and an 8-foot by 15-foot vacuum container/collection vessel.
6. The FLOW Hydro Cats were able to achieve a surface condition which met the specification, demonstrating that a combination of equipment can be used to accomplish the spot and sweep process evaluated by this project.

PROJECT DEMONSTRATION – APL-65 BERTHING BARGE

TECHNOLOGY DEMONSTRATION DATE: 18-20 JULY 2011

LOCATION: GRAVING DOCK, NAVAL STATION SAN DIEGO

CONTRACTOR: C&N UNIVERSE

SUB-CONTRACTOR: YYK ENTERPRISES AND CHARIOT ROBOTICS, LLC

PROJECT SUMMARY:

The APL-65 berthing barge is owned and maintained by the U.S. Navy's Commander Pacific Fleet Berthing and Messing Program. It is used to house ship's force and provide messing and office space while a ship is undergoing a major upkeep period or overhaul. The barge measures 269' in length and 69' breadth and was placed into service in December 2000. During the summer of 2011this barge was dry docked and overhauled in the graving dock at the Naval Station San Diego. Its underwater hull and freeboard coating systems were due to be replaced thus presenting an ideal opportunity to demonstrate the Chariot Robotics spot-and-sweep technique. The coating contractor, YYK Enterprises (National City, CA) had sub-contracted Chariot Robotics to water-jet all accessible underwater hull surfaces to a SSPC SP-12 WJ2 removal to bare metal, while providing cut-in services themselves with open cycle hand lancing. YYK agreed to allow Chariot Robotics to perform the spot-and-sweep demonstration on an easily accessible area knowing later that the "demo area" would be blasted to the specified SP-12 WJ2 condition.

Initial Condition of Coating System Upon inspection it was evident that this 10+ year old underwater hull coating system was severely degraded. On the port side, approximately 40% of the coatings system showed evidence of broken blisters with corrosion. After pressure washing minor waterline grass remained along with a large band of heavy corrosion at the waterline weld. Heavy corrosion with widespread coating breakdown was evident on approximately 30 percent of the stern diagonal. Coating condition on the flat under-belly of the barge was slightly better; however there was a heavy distribution of calcareous shell basal plates remaining which had to be hand scraped. Sacrificial cathodic protection was intact on the ship in the form of 24 pound zinc anodes. Forty anodes were mounted to the side shell forward-starboard, and forty were mounted port-aft, with an additional eleven anodes mounted on faces of each rudder. A survey showed the total dry film thickness of the coating as follows:

LOCATION	# RDNGS	AVG. DFT (mils)	LOW	HIGH	STD DEV
STBD MDSHIP	15	18.2	12.7	27.1	3.9
STBD SKEG FACE	15	22.32	11.6	34.6	7.1
MIDSHIP CNTRLINE FLATBOTTOM	15	21.4	17.7	26.7	2.9
FWD CNTRLINE FLATBOTTOM	15	38.4	26.1	48.6	7.1

Production and Sequencing

Prior to production water-jetting that portion of the graving dock encompassing the barge was encased in plastic sheeting, including the docking blocks. A large vacuum box was placed in the dry dock floor and was emptied two times per day by the local tank cleaning contractor. While the top four feet of the freeboard were inaccessible due to protruding bumpers, the robot did have unfettered access to the balance of the wetted hull. This area was prepared to a SSPC-SP-12-WJ2L condition by YYK using the open cycle "men-on-guns" approach of ultra-high pressure water-jetting. After prepping an area, the painting contractor spray-applied a primer layer of the MIL-PRF-24647 anti-corrosive system to avoid any subsequent flash rusting that may develop on the surface. The open cycle water-jetting was observed to cut at an average rate of 48 ft^2/hour using the two man approach which is consistent with similar work observed in the 1996 NSRP report.[5]

The Chariot Robotics robot prepared the following areas to an SSPC-SP-12 finish:
7/18/11-Entire starboard freeboard during night shift (approximately 3000 ft^2)
7/19/11-Port side and majority of flat bottom during day and night shift (approximately 15,600 ft^2)
7/20/11-Pick-up of some flat-bottom areas and spot-and-sweep demonstration (approximately 7900 ft^2)
7/21/11-Stern and remaining flat-bottom areas (approximately 2500 ft^2)

The bow section of the underwater hull was reserved to demonstrate the spot-and-sweep technique. The candidate area measured 72' wide and 35' high. The A/C-A/F system showed a relatively equal mixture of red and black anti-fouling visible. There was a heavy concentration of blistered coating detailing a mixture of ruptured and un-ruptured blisters. Overall, 40% of the candidate areas were blistered with much localized distribution. The upper areas of the test zone exhibited heavy corrosion undercutting and rust tubercles throughout the entire coating system.

Process Optimization and Demonstration Runs

In order to optimize parameters, the Chariot Robotics system started at 40,000 psi with a 9 gallon per minute (GPM) flow rate with the spray bar in the DOWN position. This removed all traces of A/F with only minor spots of red and gray A/C remaining. The pressure was then turned down to 25,000 psi with the spray bar in the UP position. This removed all A/F and approximately 50% of the gray A/C as well as any poorly adhered coating. Next the spray bar was put in the DOWN position at the same 25K psi pressure and all failed coatings were stripped leaving well adhered coating. Finally the pressure was raised slightly to 30,000 psi (at the same 9.0 GPM flow rate) with the cutting head in the UP position. This yielded a surface which showed approximately 25% bare metal, with the remaining 75% a mixture of red and gray anti-corrosive. This entire optimization procedure took approximately 10 minutes.

With the system optimized, the remaining area was spot-and-sweep prepared. When the preparation was complete, the area showed approximately 40% bare metal with the remaining 60% a mixture of red and gray primer. Tensile adhesion buttons were placed on the remaining coating. DFT and surface conductivity measurements were then taken. All spot and sweeping was timed and measured at an average of 2545 ft^2/hour.

Other data includes: A random dry film thickness survey was taken of the bow coating prior to the demonstration. Results were relatively consistent with a U.S. Navy underwater hull MIL-PRF-24647 coating system and are presented in the following table.

[5] National Shipbuilding Research Program Project 3-96-4, "Productivity Study – Hydroblast Removal of Coatings", Reference 0520, December 1998

BEFORE STRIPPING	# RDNGS	AVG DFT (MILS)	HIGH	LOW	STD DEV
PORT BOW	10	17.8	20.9	13.7	2.0
CNTR BOW	10	22.2	25.8	18.7	2.6
STBD BOW	10	28.5	21.3	15.0	1.7
AFTER STRIPPING	# RDNGS	AVG DFT (MILS)	HIGH	LOW	STD DEV
CNTR BOW	10	10.7	13.3	8.7	1.0

Tensile adhesion of the existing coating was determined prior to and after the spot-and-sweep run of the coating. Tests were run per ASTM D4541, *Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers*. The model used was a Positector AT-Manual Hydraulic Pump type pull-off gage, with abrasive blasted aluminum dollies. Results are as follows:

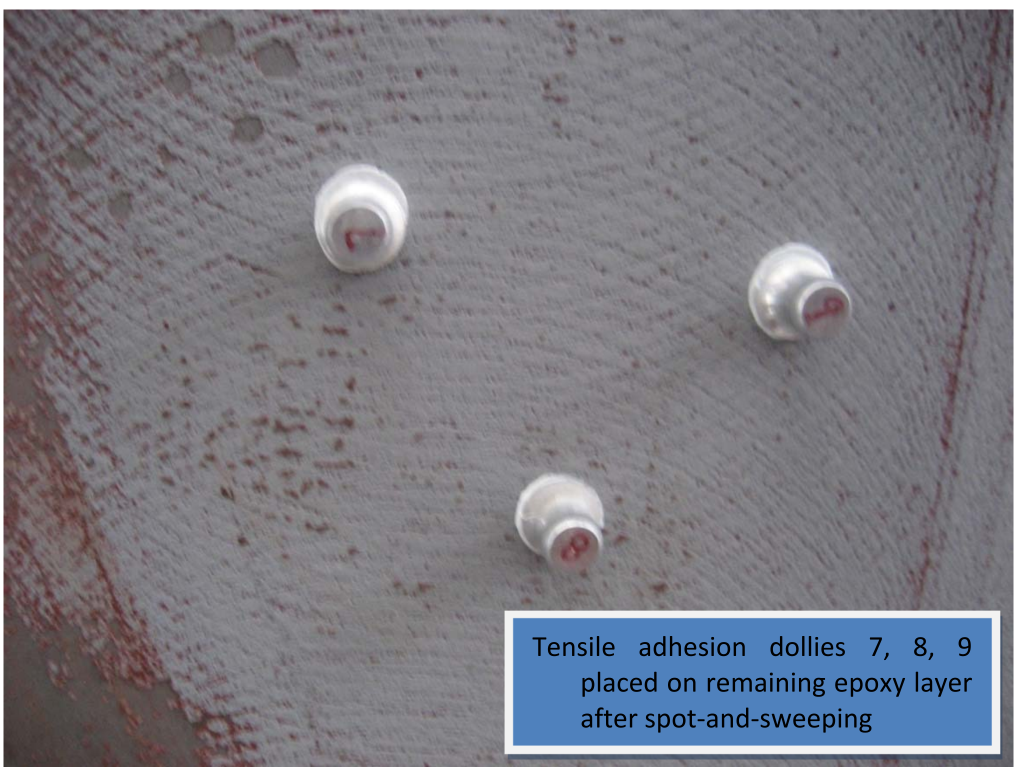
BEFORE STRIPPING	PSI AT FAILURE	MODE OF FAILURE
BUTTON 4	1531	100%GRAY A/C TO GLUE
BUTTON 5	1943	100% GRAY A/C TO GLUE
BUTTON 6	474	BLACK SHOWING
AVERAGES	1316 psi	
AFTER STRIPPING		
BUTTON 7	630	100% RED TO STEEL
BUTTON 8	2015	30% RED TO GRAY 70% GREY TO GLUE
BUTTON 9	2200	100% COHESIVE W/IN RED
AVERAGES	1615 psi	

After data was collected, the bow demonstration was subsequently water-jetted down to a SSPC-WJ-2 condition by the Chariot Robotics robot in order to meet the original contracted specifications of the APL-65 dry-docking.

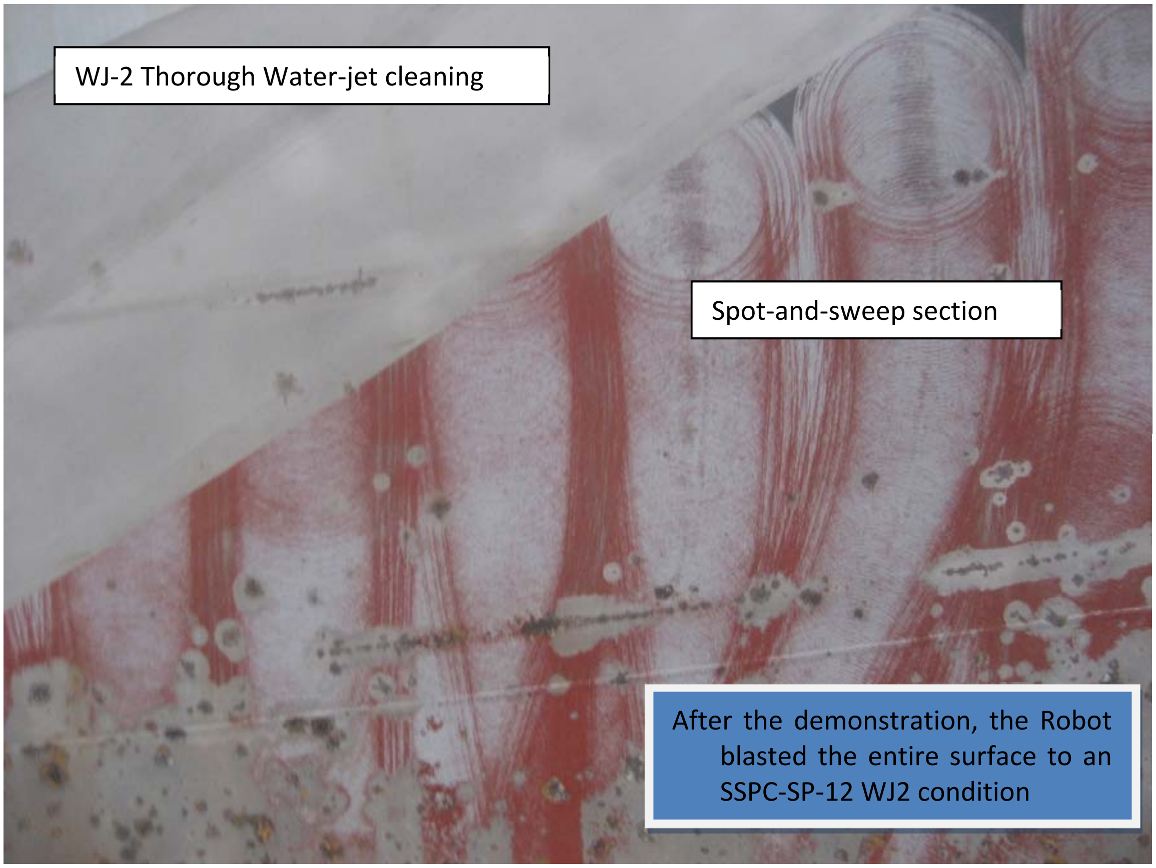
APL 65 in graving dock prior to lining the dock floor with plastic sheeting.

Port side looking aft showing band of hard fouling at waterline, and typical paint degradation. Note bumpers along top of freeboard. These areas were prepared with open cycle UHPWJ.

Robot sweeping bow section. Notice mixture of bare steel, red, and gray epoxy primer remaining.



Tensile adhesion dollies 7, 8, 9 placed on remaining epoxy layer after spot-and-sweeping



Comments on APL-65 berthing barge demonstration

This demonstration yielded some very valuable information.

1. The degraded condition of the underwater hull coating on APL-65, coupled with the rather high amount of bare metal resulting from the spot-and-sweep process showed that such conditions of underwater hull coating ARE NOT good candidates for the spot-and-sweep process. Experience to-date has shown that approximately 5% widespread and general coating degradation seems to be the upper limit beyond which a general coating removal may be more prudent. Such a determination can be made by consulting various resources.[6, 7]
2. High tensile pull-off data after the coating system had been swept lends confidence to the notion that the retained coating is in a robust condition for over-coating. In other words, when the process parameters are optimized, the resultant coating that remains is of high adhesion to the hull.
3. The APL-65 demonstration showed that the spot-and-sweep equipment can be mobilized and set up in a Government dry dock in one day. Furthermore, the underwater hull and freeboard of an APL-65 type berthing barge can be spot-and-swept and ultimately stripped to a WJ-2 condition in just a few days.

[6] Charles and Lydia Frenzel, Book of Spots, Pocket Edition, ©2000
[7] ASTM D-4541, Standard Test Method for Pull-Off Strength of Coatings using Portable Adhesion Testers

PROJECT DEMONSTRATION – FFG-60 USS RODNEY M. DAVIS

TECHNOLOGY DEMONSTRATION DATE: 6-8 FEBRUARY 2012

LOCATION: PUGET SOUND COMMERCE CENTER, SEATTLE WA

CONTRACTOR: VIGOR SHIPYARDS, INC (formerly Todd Pacific Shipyards)

SUB-CONTRACTOR: CHARIOT ROBOTICS, LLC

PROJECT SUMMARY:

USS RODNEY M. DAVIS is another FFG-7 class Frigate, home-ported in Everett, WA and was in dry dock at Vigor Shipyards for a DSRA in early February 2012. Unlike KLAKRING's whole ship availability, only a small section on DAVIS's starboard bow was available for demonstrating the technology for NSRP personnel. Upon arrival the forward zone, both port and starboard from the stem to just forward of the forward Prairie Masker emitter belt (at Frame 177), was blasted to an SSPC SP-10 Near White Metal Blast. The shipyard saved two areas in this zone on the starboard side for the Spot and Sweep demonstration.

Initial Condition of Coating System

Upon arrival in the dry dock and according to on site Vigor personnel, the ship had been pressure washed with a 5000 psi freshwater wash down. The anti-fouling (A/F) layer was worn down to a mixture of red 1st coat A/F and black mid-coat A/F. Anti-Corrosive (A/C) breakdown on the port side was confined to mostly around discharges, leading edge of the fin stabilizers, sea-chests and around all emitter belts. Both faces of the rudder exhibited over 15% bare metal and other coating breakdown. Isolated bands of corrosion pits were randomly dispersed along the waterline in the test locations. The pits were mostly ¼" to 3/8" in diameter and measured 0.010" to 0.020" in depth, as determined by a pit depth gage. Other than the localized coating breakdown mentioned the combined underwater hull system appeared in serviceable shape. According to the on-site Port Engineer, the underwater hull of the DAVIS was last preserved in early 2003, making the current coating system approximately 9 years old.

A Tooke gage reading taken forward of Frame 177 Starboard confirmed the standard MIL-PRF-24647 underwater hull system. The reading was taken over an area with black A/F exposed. The system appeared to be:

TOOKE	RED A/C	GRAY A/C	RED A/F	BLACK A/F	RED A/F
READING 1	10 mils	7 mils	13 mils	10 mils	----
READING 2	10 mils	10 mils	13 mils	10 mils	---

Three sets of DFT readings were taken on the starboard side just forward of the retractable Auxiliary Propulsion Unit (APU). DFT's were as follows:

LOCATION	# RDNGS	AVG. DFT	HIGH	LOW	STD. DEV.
1	20	35.1	38.7	31.6	2.5
2	20	32.2	40.0	25.2	5.1
3	20	30.6	38.5	26.2	2.5

Tensile adhesion of the current system was assessed. The location chosen was at approximately Frame 100 above the APU on the starboard side. The A/F coating was sanded away to sound A/C and 3 tensile adhesion dollies were adhered according to ASTM D4541. Results follow.

BEFORE STRIPPING	PSI AT FAILURE	MODE OF FAILURE
BUTTON 1	**---**	**OPERATOR ERROR**
BUTTON 2	**743**	**100% GRAY A/C TO GLUE**
BUTTON 3	**2085**	**100% GRAY A/C TO GLUE**
AVERAGES	1414 psi	

Process Optimization and Demonstration Runs

Chariot Robotics provided their patented “sweeping head” for this demonstration, as opposed to their “cutting head” provided for other demonstrations. The chief difference is that the sweeping spray bar has 4 bars with 16 sets of jewels, while the cutting head uses two bars with 12 jewels. The angle of the jewels is key to the rotational speed attained. As such the cutting head rotates at approximately 1200-2000 rpm. The sweeping head rotates at approximately 4000 rpm, thereby greatly reducing the visible “swirl marks” that are inherent with most robotic water-jet machinery.

The forward patch measured approximately 870 ft^2, and was located under the anchor housing at the starboard stem. Fall arrestors were placed forward and aft of the test zone and were easily attached to welded-on boatswain clips on the freeboard. After all jewels were observed to be clean and ready the robot was deployed on the hull. System parameter check-out began at 1100 AM and after a brief 15 minute power outage the system checked out and optimization was complete.

Approximately fifteen attendees from various departments within Vigor Shipyards, Puget Sound Naval Shipyard and IMF, and the US Coast Guard, attended the demonstration. Two separate production runs were made and the average spot-and-sweeping rate was 2100 ft^2/hour. The robot stripped an area which left approximately 60% of the gray A/C and 40% of red A/C showing. Less than 5% of the area had scattered areas of bare metal showing. Directly beneath the anchor housing was one large area to bare metal where it was evident that prior touch-up had been made with a white epoxy. Operating pressure for this portion of the demonstration was maintained in the 22,000-24,000 psi range.

The second demonstration run took place shortly after lunch and averaged only 700ft^2/hour with an operating pressure of only 21,000 psi.

The inspection criteria (draft language for the 009-32 SSRAC proposal) were provided to inspectors from PSNS Code 250 and the local RMC inspector. These inspectors evaluated the prepared surface and found the criteria to be satisfactory for completion of a G-point inspection**.**

Condition of Remaining Coating

Resulting DFT’s after sweeping yielded the following:

LOCATION	# RDNGS	AVG. DFT	HIGH	LOW	STD. DEV.
GRAY A/C	10	15.9	19.0	12.2	1.8
RED A/C	10	5.0	8.8	2.7	1.9

A random conductivity check of bare metal resulting from the spot and sweep process was taken using a Horiba B-173 portable conductivity check. Sample extraction was conducted according to ISO 8502-9.[8] After correcting for the conductivity of the extraction fluid, the conductivity was 9 micro-Siemen/cm, far below the acceptable limit of 30 micro-Siemen/cm as required by 009-32.

Resulting tensile adhesion data was as follows:

OVER GRAY A/C	PSI AT FAILURE	MODE OF FAILURE
BUTTON 1	1694	100% COHESIVE W/IN GLUE
BUTTON 2	522	50% COHESIVE W/IN GLUE 50% GLUE TO GRAY A/C
BUTTON 3	2646	100% COHESIVE W/IN GLUE
AVERAGES	1621 psi	
OVER RED A/C		
BUTTON 4	2863	90%COHESIVE W/IN GLUE 10% COHESIVE IN RED A/C
BUTTON 5	2382	80% COHESIVE W/IN GLUE 10% GREY TO GLUE 10% RED A/C TO STEEL
BUTTON 6	1323	80% COHESIVE W/IN GLUE 20% ADHESIVE TO GREY
AVERAGES	1615 psi	

Additional dry film thickness readings were taken on both the forward and aft demonstration patches to further characterize the thickness of the remaining anti-corrosive coating, prior to the test patch removal by Vigor Shipyards. Results follow:

FORWARD PATCH	# RDNGS	AVG. DFT	HIGH	LOW	STD. DEV.
GRAY A/C	20	16.5	19.8	11.3	2.2
RED A/C	20	8.5	15.6	1.2	3.4
RED/GRAY A/CMIX	20	5.7	9.4	1.8	2.6
AFT PATCH	# RDNGS	AVG. DFT	HIGH	LOW	STD. DEV.
GRAY A/C	20	23.2	30.9	16.0	4.0
RED/GRAY A/C MIX	20	12.9	20.4	4.5	4.3
GRAY A/C	20	28.4	36.1	20.3	5.7
RED A/C	20	8.2	21.4	0.7	5.6
RED/GRAY A/C MIX	20	16.9	25.7	12.2	3.8

The above data shows some interesting trends. With regard to coating adhesion, a slight increase in coating adhesion occurred on the anti-corrosive layer after water-jetting compared to before water-jetting. This is consistent with other demonstration projects performed in this program and is consistent with

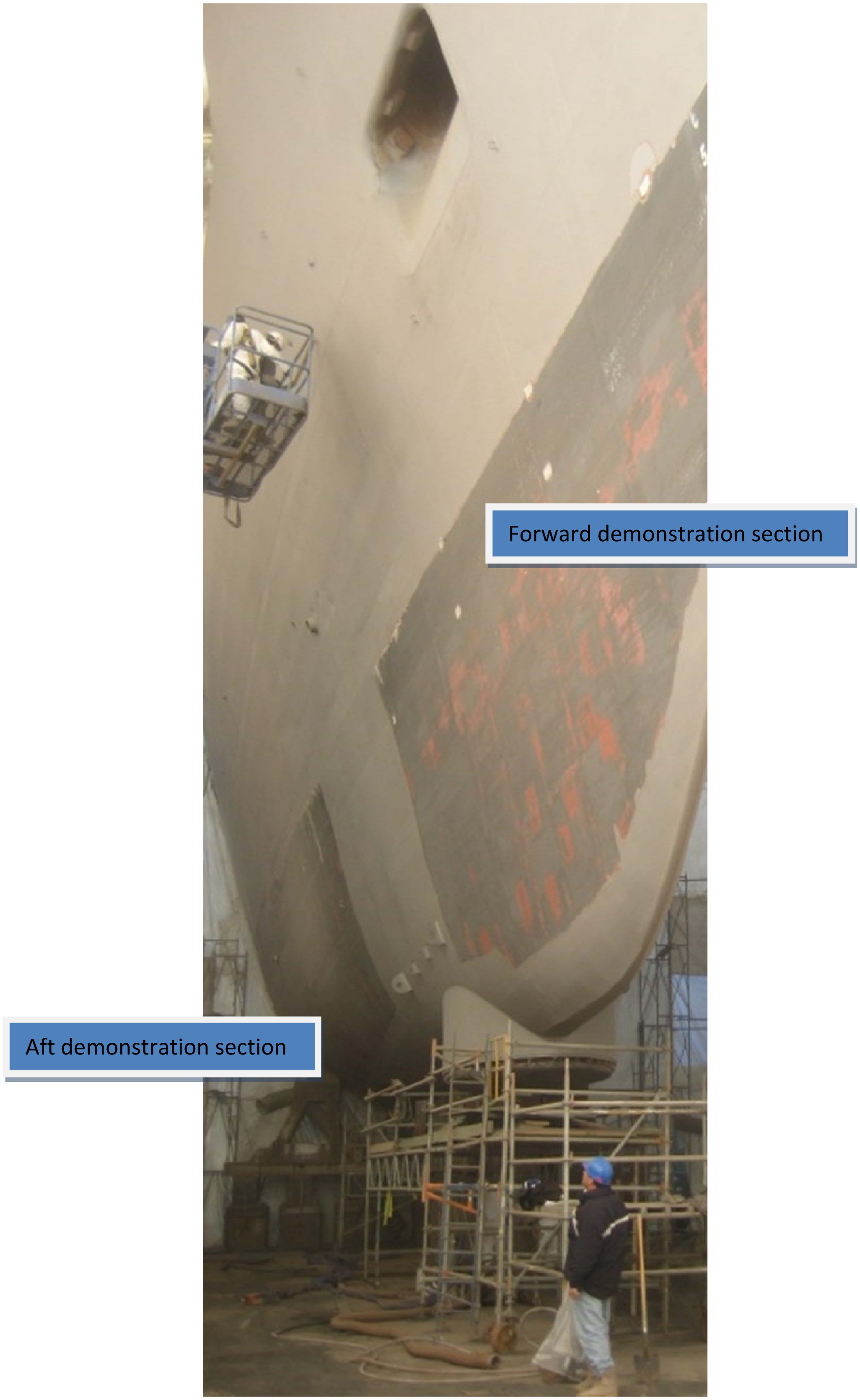
[8] ISO-8502-9, Tests for the Assessment of surface cleanliness -- Part 9: Field method for the Conductometric Determination of Water-soluble Salts.

before and after sweep blasting of epoxy ballast tank coatings seen in the 1996 NSRP study on water-jetting productivity.[9]

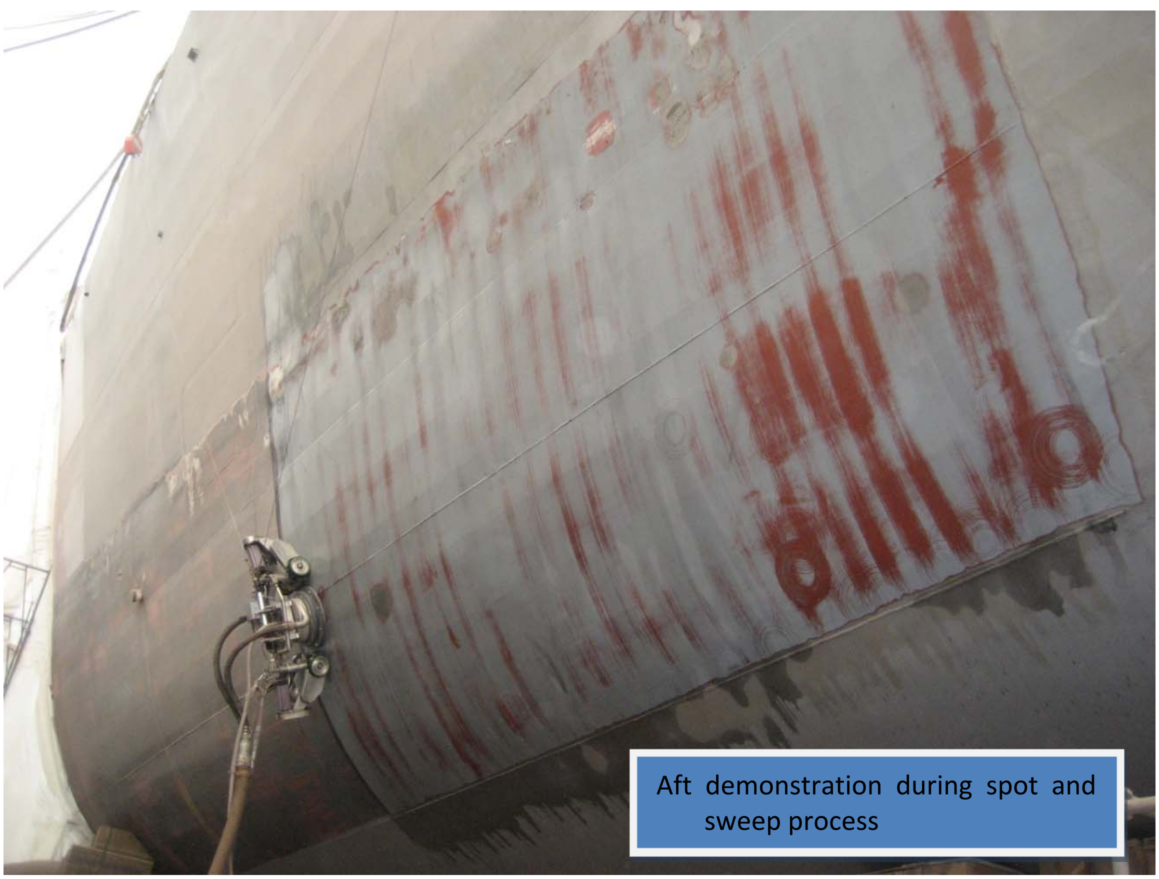
An examination of the "high" and "low" DFT's on individual data sets shows there is clearly a wide range in individual coating thickness that remains on the hull. This is crucial in devising a coating protocol for vessels which undergo a spot-and-sweep approach. For example, in one of the data sets where only red A/C is showing, thicknesses range from under 1.0 mil to over 21 mils. The important data, in the investigator's opinion, is the high degree of tensile coating adhesion of this remaining coating.

Initial condition of underwater hull coating on RODNEY DAVIS

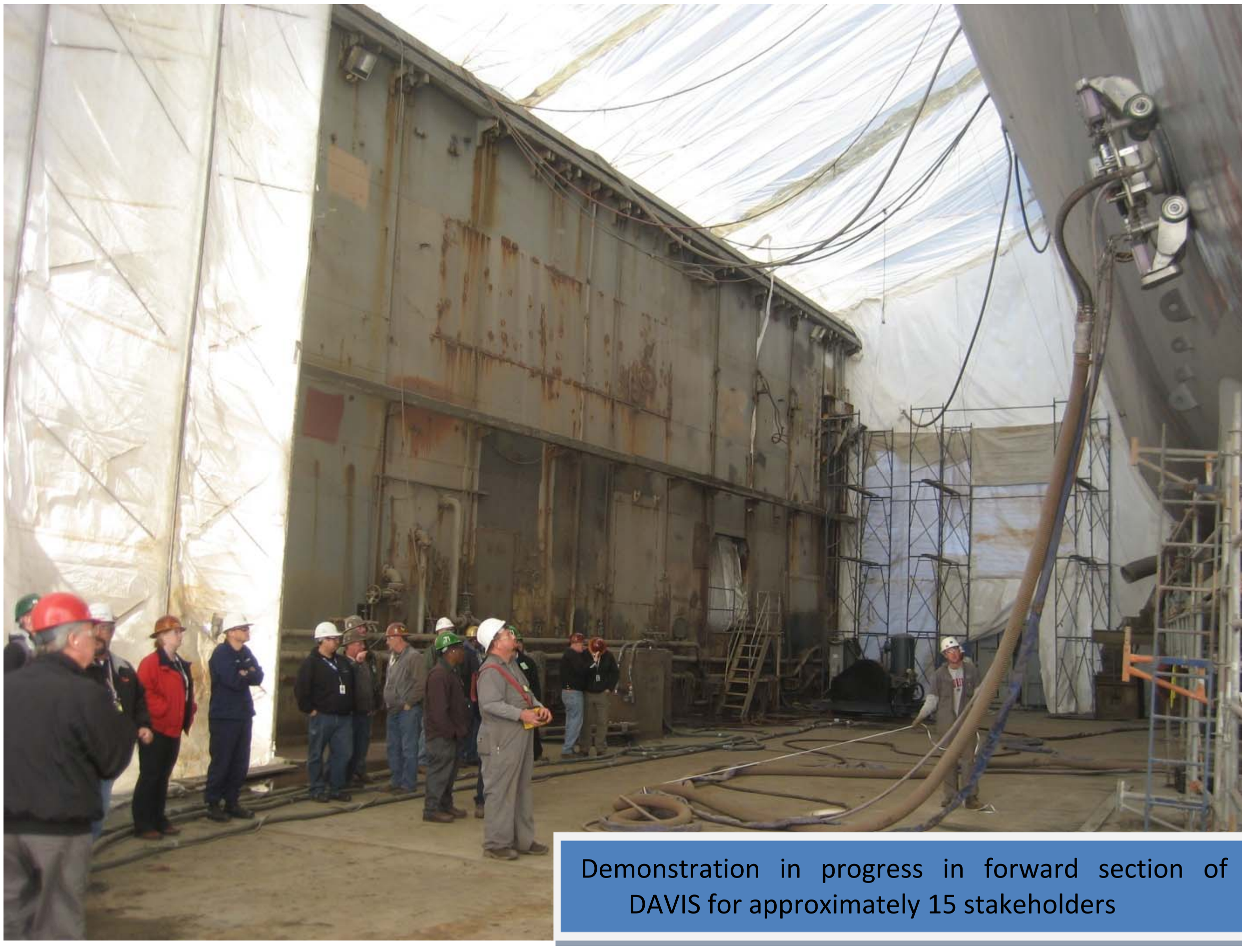
[9] National Shipbuilding Research Program Project 3-96-4, "Productivity Study – Hydroblast Removal of Coatings", Reference 0520, December 1998


Forward demonstration section
Aft demonstration section

Forward demonstration section completed



Aft demonstration during spot and sweep process



Demonstration in progress in forward section of DAVIS for approximately 15 stakeholders

Comments on USS RODNEY M. DAVIS demonstration

This demonstration yielded some very valuable information.

1. USS RODNEY M. DAVIS proved to be an ideal candidate to demonstrate the merits of the spot-and sweep technology in that it's outer hull coating systems showed minimal breakdown to bare metal and associated corrosion.
2. High tensile pull-off data after the coating system had been swept lends confidence to the notion that the retained coating is in a robust condition for over coating on this vessel.
3. USS RODNEY M. DAVIS demonstration showed that the spot-and-sweep equipment can be mobilized and set up in a contractor's dry dock in one day, optimized and be ready for production runs less than 30 minutes thereafter.

USNS ALAN SHEPARD (T-AKE 3)

PRODUCTION DATE: MAY 2012

LOCATION: BAE SAN FRANCISCO SHIP REPAIR, SAN FRANCISCO, CA

CONTRACTOR: BAE SAN FRANCISCO SHIP REPAIR

SUB-CONTRACTOR: CHARIOT ROBOTICS, LLC

PROJECT SUMMARY:

At the end of the NSRP SPC project, the spot and sweep technique was employed during a dry docking availability of USNS ALAN SHEPARD (T-AKE 3, Military Sea Lift Command, MSC) at BAE SAN FRANCISCO SHIP REPAIR. It was beyond the scope of the present project to collect data on this effort, but photos from the work are shown below.

The specified work included spot and sweep of the underwater hull. At approximately 2 months, MSC dry dockings tend to be much shorter than those of the U.S. Navy. The spot-and-sweeping of MSC hulls is commonplace, especially at such locations as BAE San Francisco Drydock where Chariot Robotics has performed full removal and spot-and-sweep removal on nearly a dozen MSC hulls in the past 4 years. MSC hulls present an enormous amount of unobstructed surface area, allowing for the merits of the spot-and-sweep methodology to be manifested, as opposed to the traditional method of full blast removal.

Underwater hull of MSC ship Alan Shepard T-AKE-3. 75,000 ft^2 of underwater hull coating was spot-and-sweep blasted in 4 days, 2 shifts per day. Finish depicted is intact red and white epoxy, with some spots to bare metal.

Large unobstructed freeboards and underwater hulls on MSC ships such as USNS Bob Hope seen here are quite amenable to the spot-and-sweep approach.

PROCESS USED FOR SPOT AND SWEEP BLASTING DEMONSTRATIONS

Following is the proposed "draft" language to be included with the 009-32 proposal to NAVSEA Standard Specification for Ship Repair and Alteration Committee (SSRAC). It will be submitted for approval in August, 2012. The following language is substantially identical to that which was used as an aid by QC personnel in being able to objectively determine the quality of the resultant surface after the spot-and-sweep process and to apply the subsequent anti-corrosive and anti-fouling coating system over the retained coating system. In addition, guidance is provided on how to QC the subsequent in-process coating application for thickness when a varying thickness of retained A/C may or may not already be in place.

PROCESS FOR SPOT AND SWEEP BLAST DEMONSTRATION

1. The spot and sweep process performed by the Chariot Robotics unit (or equivalent) may be used for all areas of the underwater hull and freeboard on approved surface ships. For areas not prepared using a Chariot Robotics unit (or equivalent): An Ultra High Pressure (UHP) lance or abrasive blasting may be used to create either a SSPC SP-12 WJ- 4/M surface or a SSPC SP-7 surface. SSPC SP-3 Power Tool Cleaning may be authorized for feathering in the spot and sweep surface as required.

2. The contractor shall inspect the existing coating on the hull and shall determine the sequence of the epoxy coatings currently on the hull prior to blasting. The anticipated sequence is red primer followed by gray epoxy tie coat. The contractor shall note these colors for use in NAVSEA inspection of the hull prior to application of the first coat of epoxy primer.

3. The Chariot Robotics unit (or equivalent) shall be set up to accomplish the following:

   (a) Remove all rust and fouling from areas of bare metal to create a SSPC-SP12 WJ-2M surface condition in accordance with specified NAVSEA Standard Item 009-32, FY 12 Change 1 processes.
   (b) Remove all antifouling coating and ~~remove~~ approximately 1/2 of the thickness of the current epoxy tie coat thickness from the underwater hull area.
   (c) Remove all silicone alkyd, regardless of coating thickness along with approximately 1/2 of the thickness of the current epoxy topcoat from the freeboard area.
   (d) Smoothly feather or transition from areas of bare metal to the retained epoxy primer/tie coat. Areas of sharp or "step" transition between bare metal and paint shall be noted by the NAVSEA representative for detailed inspection.

4. Upon completion of standard zones or work areas, in accordance with current standard contractual requirements, the contractor shall inform the NAVSEA representative when they are ready to apply the first coat of primer to the zone or work area. NAVSEA representative shall conduct all standard data reviews and inspections on bare metal areas in accordance with specified Standard Item 009-32 requirements. Areas of retained paint shall be visually inspected and shall satisfy the following:

   (a) There shall be no more than two colors of paint visible in any area of retained coating. Inspectors shall observe the red primer adjacent to any bare metal areas and then continue observations into the bulk of the retained epoxy. Gray epoxy may be retained on top of the red primer, but any visual evidence of additional coats of red or black paint on top of the gray shall be cause for closer inspection. Closer inspection shall be conducted from a minimum distance of 3 feet. Upon closer inspection, a solvent-wipe test with a white rag shall be conducted using the clean-up solvent from the anti-fouling coating. If the solvent wipe test shows color transfer onto the rag, the area shall be rejected. Rejected areas shall be cleaned again until no color transfers to the rag.

(b) There will be no areas of sharp transition or steps between bare metal and paint. Any such areas shall be inspected and tested with a dull putty knife to determine adhesion. If the paint flakes or can be dislodged, the area shall be rejected and cleaned again to remove the loose paint.

(c) Measurements of existing DFT shall be recorded for historical purposes in accordance with SSPC PA-2.

5. Upon approval of the surface preparation, the contractor shall apply one coat of AC primer, in accordance with established Standard Item 009-32 requirements to all areas in the zone or work area (i.e., bare metal and retained epoxy primer) to achieve the specified 5-7 mil dry film thickness. The contractor is not obligated to apply a thin or varied primer thickness when traversing areas between bare metal and retained epoxy. Again following standard practices, SUPSHIP shall inspect the zone or work area coating thickness. Because the coating thickness retained will vary notably, DFT readings shall be taken and recorded; however high DFT readings shall not be means for rejection and such readings shall only be taken for documentation purposes. In place of DFT readings for determining proper coating thickness, WFT readings shall be taken and recorded on each coat to confirm proper coating thickness (i.e. follow the 009-32 requirement for taking WFT readings in place of DFT readings for accept/reject criteria). All other QA requirements of 009-32 shall be accomplished.

6. Once the primer has cured to overcoat, the surface area shall be inspected for edge lifting of the remaining epoxy that was over coated. This inspection shall be conducted at a maximum distance of 15 feet. The curing epoxy primer will lift any loose edges of the existing coating that may not have been visible during the initial surface preparation inspection. These areas shall be prepared in accordance with SSPC-SP-3 and primed.

7. For underwater hull areas, apply second or tie coat of epoxy, along with the first coat of antifouling in accordance with Standard Item 009-32 requirements (using WFT readings).

8. For underwater hull areas, apply complete antifouling system in accordance with Standard Item 009-32 requirements and note final coating thickness. Again, use WFT readings in place of DFT readings for determining proper coating application, with DFT readings being recorded for documentation purposes.

9. For freeboard areas, apply second coat of epoxy followed by the topcoat in accordance with Standard Item 009-32 requirements (using WFT readings).

10. The contractor and NAVSEA representative shall retain time, cost, or productivity metrics ~~to~~ for reporting to NAVSEA. This information will be used to provide supporting data for any future Standard Item 009-32 proposal to incorporate spot and sweep processes.

ECONOMIC ANALYSIS OF APPLICABLE FLEET HULLS USING THE SPOT-AND-SWEEP APPROACH TO SHIP SURFACE PREPARATION

A simple economic analysis is presented for the following hull classes, for which the authors and appropriate NAVSEA directorates feel the system presented is most applicable. The analysis will show potential Fleet Savings ***by year***, using Calendar year 2012 Fleet maintenance data.

From the most recent posting on the US Navy's official website (www.navy.mil)[10] the following numbers of ships are in each of the ship classes listed. These form the basis for this economic analysis. Additionally, we have listed the approximate square footage of underwater hull area, and freeboard hull area for each ship class. Note that underwater hull area does not include rudders, struts, stabilizers, and other inaccessible areas to robotic crawlers. Freeboard area does not include painted surfaces of life boat stowage and catwalks as found on CVN and various carrier amphibious assault classes.

CLASS	SHIPS IN CLASS	U/W HULL AREA (ft^2)	FREEBOARD AREA (ft^2)
FFG-7	26	15,000	15,000
CG-47	22	24,000	24,000
DDG-51	61	22,000	22,000
CVN	11	180,000	175,000
LSD-41	12	46,000	46,000
LPD-17	6	17,000	46,000
LHA	1	118,000	118,000
LHD	8	118,000	118,000
SSBN	14	77,000	N/A

According to the latest Fleet Ship Maintenance Availability Schedules[11] for Calendar Year 2012, the following numbers of ships by class will be in dry dock for extended maintenance periods. Such availabilities include DSRA's, EDSRA's, DPMA, DPIA, EDPMA, etc.

CLASS	NUMBER DRY-DOCKING AVAILS CALANDER YEAR 2012
FFG-7	4
CG-47	5
DDG-51	13
CVN	4
LHD	1
LSD-41	4
SSBN	2

[10] www.navy.mil/our_ships.asp

[11] Private communication G. Kuljian, NSWC Carderock, CNO Maintenance Availability Schedules of 21 May 2012

The potental savings of the spot and sweep process versus full removal include (1) a reduction in surface preparation activity costs (labor, operating costs, waste disposal, etc) and (2) a reduction in schedule associated with surface preparation activities. Appendix B contains the detailed savings calculation for each ship class. Each area of savings is discussed further below.

Surface Preparation Cost Savings

For the surface preparation cost savings, the analysis assumes that the overall cost of surface preparation may be reduced by $3.00 per square foot by moving from a complete removal to spot and sweep approach. This number was assumed based on the percentage cost reduction observed during the study and applying it to a baseline cost of surface preparation for an underwater hull or freeboard of a U.S. Navy ship, ~~is~~ currently assumed to be $9.00 per square foot (inclusive of prep work, blasting, and treatment/removal of waste as well as any applied overhead).[12] This analysis assumes that all other costs related to surface preparation and painting (e.g., support costs & coating application) remain the same for either scenario. Finally, the analysis assumes that the existing coatings are "typical" U.S. Navy underwater hull or freeboard systems (e.g. MIL-PRF-24647 or MIL-PRF-24635).

The surface preparation cost savings for each class of ship is simply the surface area (underwater hull, freeboard or both) times $3.00 per square foot of savings. Appendix B contains the assumed surface areas for each ship class. The following table summarizes the savings per ship.

Surface Preparation Cost Savings per Ship			
Class	**Freeboard**	**Underwater Hull**	**Total**
FFG-7	$ 45,000	$ 45,000	$ 90,000
CG-47	$ 72,000	$ 72,000	$ 144,000
DDG-51	$ 66,000	$ 66,000	$ 132,000
CVN	$540,000	$540,000	$1,080,000
LHD	$354,000	$354,000	$ 708,000
LSD-41	$138,000	$138,000	$ 276,000
SSBN	$ 0	$ 231,000	$ 231,000

Based on calculations outlined for each of the effected ship classes for Calendar Year 2012, an overall surface preparation cost savings of nearly $10 million per year is possible if the U.S. Navy adopts a spot and sweep methodology for hull surface preparation. The following table shows the savings breakdown for freeboard and underwater hull by ship class for the number of dry docking availabilities presented above.

[12] Based on discussions of full coating removal by hydroblasting during various meetings of the Navy "Global War on Corrosion Working Group."

Annual Navy Surface Preparation Cost Savings				
Class	**CY12 AVAILS**	**Freeboard**	**Underwater Hull**	**Total**
FFG-7	4	$180,000	$180,000	$360,000
CG-47	5	$360,000	$360,000	$720,000
DDG-51	13	$858,000	$858,000	$1,716,000
CVN	4	$2,160,000	$2,160,000	$4,320,000
LHD	1	$354,000	$354,000	$708,000
LSD-41	4	$552,000	$552,000	$1,104,000
SSBN	2	$0	$462,000	$462,000
Total Potential Navy Savings		**$4,464,000**	**$4,926,000**	**$9,390,000**

Surface Preparation Schedule Reduction

To accurately define the cost impact of schedule reduction depends on a multitude of factors which are predominately outside the control of the painting team. However, the reduction in surface preparation schedule undoubtedly has the potential to significantly contribute to cost savings. For example, the schedule reduction could lead to reduced time in dry dock or reduced interference with other trades. Obviously, there are many availability specific variables which impact the actual savings.

The following tables summarize the results of calculations for schedule reduction which are presented in Appendix B. The data in Appendix B is sufficient to allow the reader to adjust the assumptions as they see fit. For purposes of this analysis, we have assumed production rates and daily hours at full production. Obviously, these parameters would need to be adjusted for any specific situation. For example, the production hours per day may be impacted by the number of production units used, the work plan, other trades working on the ship, complexity of the ship, number of shifts, availability of equipment, etc. Similarly, production rates may be impacted by the skill of the operator, complexity of the ship, interference from other trades or activities, etc.

For this analysis we used abrasive blasting to an SSPC SP-10 condition as the baseline process and compared those rates to the production rates observed using the Chariot Robots Envirobot® technology. The following assumptions were made for the analysis presented herein:

Assumptions for Economic Analysis	Spot and Sweep	SSPC SP-10
Production Rate (square feet per "nozzle hour")	1,200	175
Productivity (nozzle-hours of full production per day)	7	12

The number of production days in the schedule is simply the square footage divided by the product of production rate and productivity. So to complete 15,000 square feet of surface preparation would require 1.79 days: i.e 15,000/(1,200 x 7). For the analysis, partial days were rounded up to the next whole number (2 days in this case).

As a matter of comparison, in the previously referenced NSRP study, [13] spot and sweep for outer hull with men-on-guns ranged from 150-350 ft^2/hr/gun with an average of 198 ft^2/hr/gun. Bare metal WJ2 with robotics (Hammelman Dockmaster) ranged from 162 to 792, averaging 471 ft^2/hr. A Hydrocat on one

[13] National Shipbuilding Research Program Project 3-96-4, "Productivity Study – Hydroblast Removal of Coatings", Reference 0520, December 1998

occasion was observed removing the freeboard system at rate of 280 ft^2/hr. Outside of the NSRP study, one robotic system manufacturer has reported full WJ-2 production rates on exterior hulls as high 550-700 ft^2/hr. Any of these rates and a range of assumed productivity assumptions could be made in the following analysis to suit an individual shipyard's experience.

The following table summarizes the surface preparation schedule reduction per ship.

Surface Preparation Schedule Reduction per Ship			
Class	**Freeboard**	**Underwater Hull**	**Total Days**
FFG-7	6	6	12
CG-47	9	9	18
DDG-51	8	8	16
CVN	64	64	128
LHD	42	42	84
LSD-41	16	16	32
SSBN	0	27	27

The following table projects a total annual schedule reduction for the Navy based on the CY 2012 availabilities outlined above. If we assume that each day of schedule reduction has a value of $25,000, an additional $28 million in annual savings is possible.

Annual Potential Days of Schedule Savings				
Class	**CY12 AVAILS**	**Freeboard**	**Underwater Hull**	**Total**
FFG-7	4	24	24	48
CG-47	5	45	45	90
DDG-51	13	104	104	208
CVN	4	256	256	512
LHD	1	42	42	84
LSD-41	4	64	64	128
SSBN	2	-	54	54
Total Potential Navy Savings		**535**	**589**	**1,124**

On a yearly basis, the above tables present some rather remarkable cost savings just by switching from a full blast of the underwater hull (or freeboard) to a spot-and-sweep methodology. It is reasonable to conclude that the U.S. Navy could save millions, if not tens of millions of dollars, per year by employing the spot and sweep methodology for preparing a ship's hull for a new coat of paint. The calculations assume that for each ship in each class that is dry docked its underwater hull is scheduled to be repainted. That is not always the case based on ship underwater hull paint condition or money in the budget for that particular evolution.

Similar calculations can be made for Military Sealift Command (MSC) ships. A brief query of the MSC Fleet Ship Maintenance Availability Schedules show that for calendar year 2012 there are 16 different dry docking events, and for calendar year 2013, there are 18 such events. MSC ship classes dry docked in years 2012 and 2013 include T-AKE, T-AOE, T-AO, T-AH, and T-ARS.

APPENDIX A

SPECIFICATIONS OF CHARIOT ROBOTICS SYSTEM

SYSTEM SPECIFICATION

ENVIROBOT®
Ultra High Pressure
Robotic Surface Preparation System

Project:	ENVIROBOT UHP
Customer:	
Date:	May 14, 2012
Configurations:	20' Container with Internal Electric UHP (see enclosed Drawing 1650001) Power: 380/3/50

Table of Contents

1. INTRODUCTION

The ENVIROBOT system removes coatings from ferrous surfaces by the means of a remotely operated vehicle that contains rotating Ultra-High Pressure (UHP) water jets. A rotating spray bar delivers the water in a wide cut pattern as the vehicle traverses the work surface. The magnetic vehicle maintains traction to the surface in any orientation, including vertical, horizontal and inverted. The system can completely remove coatings or partially remove coatings, depending on the nozzles chosen, the water pressure, proximity of the nozzles to the coated surface and rate of travel. All of the effluent is captured and transferred to a holding tank by the means of a vacuum system. The self-contained coating removal system provides unprecedented performance and reliability.

This specification covers all of the ENVIROBOT system components including the vehicle, vehicle control and power systems, vacuum, UHP pump, spares kits and training. Each unit is designed for transport by land or sea and is configured for immediate setup upon delivery. The inclusive documentation package and testing procedures are also described.

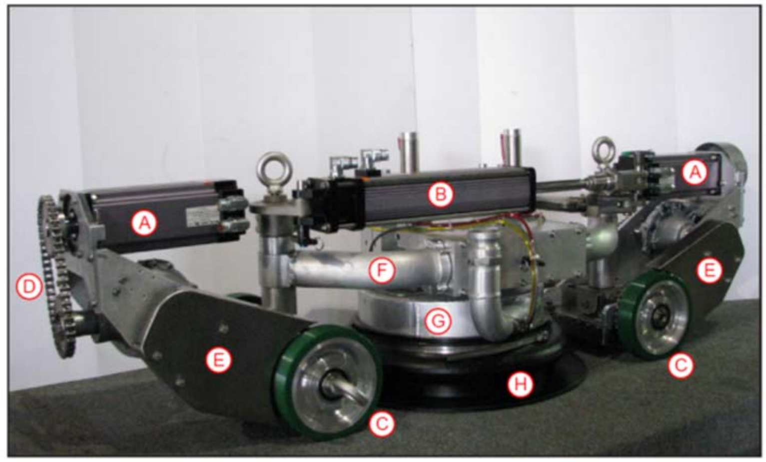
New features that have been added to the latest generation robot include:

- 350' Tether (107 m)
- Independently selectable LED head lights on each end
- Rotational speed sensor on the spray bar
- Larger vacuum hoses on the shroud
- Simplified rotor mount that provides rapid access

EQUIPMENT DESCRIPTION

A. VEHICLE

i. Vehicle Platform



(A) Sealed Electric Servo Drive Motors
(B) Steering Servo Motor
(C) High Traction Wheels
(D) Primary Drive Chain and Sprockets
(E) Independent Wheel Drive Chain, Sprockets and Chain Guards
(F) Chassis
(G) Floating Head and Suspension
(H) Flexible Shroud Bellow Seal

The semi-autonomous robotic vehicle has four wheel drive and steering. Each pair of wheels is driven by a normally-braked servo motor via a limited-slip differential. Power transmission is accomplished with all stainless steel sprockets and non-corrosive chain. An electric linear actuator is used for steering both axles simultaneously. A pair of magnets provides a large attractive force to the substrate which results in substantial wheel traction. Lightweight and corrosion resistant materials are used throughout the platform assembly including aluminum for the frame, stainless steel for rotary components and titanium for the axles. Safety covers are placed over all rotary components (one is removed in the photo for illustration purposes). Control features include cruise control for speed and straight-line steering.

ii. Vehicle Payload

For UHP applications a shroud assembly is installed at the center of the vehicle platform. The assembly contains a shroud that envelopes all of the UHP components in order to capture the effluent. Two durable skids are located at the bottom of the shroud. The skids are in continuous contact (at the operator’s discretion) with the substrate and subsequently provide accurate control of the relative distance between the spray bar and the substrate. A flexible, semi-permeable polymer seal surrounds the shroud. The amount of force that is applied on the seal is pneumatically controlled. The spray bar mechanism, including a high-speed passive rotary joint, is mounted at the center of the shroud and is controlled with a second pneumatic function. Both the shroud and the spray bar can be raised during transits of high speed or in rough areas. The distance from the jets to the target is changed by adding shims to the spray bar linear actuator brackets. The shroud also contains multiple vacuum ports for attachment to the vacuum system. The entire assembly is hinged for rapid access to the wet components during maintenance intervals.

iii. Vehicle Controls

The Robot Control Panel (RCP) receives power from the Power Distribution Panel (PDP), switches it on, cleans it, and routes it to the robot motor controllers. The motor controllers constantly monitor the status of the incoming power, the integrity of the circuits and the power demand of the motors. If any activity falls outside of pre-determined limits, the controller aborts the mission, isolates power to the suspect components and sends a fault code to the operator. Low voltage DC is created within the RCP for operating various solenoids, the Programmable Logic Controller (PLC) and the fault indicators. The PLC receives all commands and routes the resultant action to the required components. A touch screen interface is provided on the outside of the RCP enclosure for monitoring and controlling critical functions. The RCP has a built-in environmental control system for cooling and dehumidifying the contents and contains all control connections for the robot, both electrical and pneumatic. The enclosure is rated to NEMA 12.

A wireless Robot Control Box (RCB) provides all of the controls for the system in a lightweight ergonomic package that can be hand-held by the operator or secured with a neck strap. A key switch is provided for security purposes. Indicator lights are used to monitor the quality of the wireless communications with the RCP and the condition of the RCB batteries. The antenna for the receiver is mounted external to the container. Emergency stop actuators are provided in three locations; the RCB, external to the container and on the RCP.

The RCB controls include:

- Strip / Sweep Select
- Strip speed control
- Sweep speed control
- Steer trim
- Emergency Stop
- Run / Off
- Cruise / Free speed select
- Seal On / Off
- UHP On / Off
- Center / Center Bypass
- Raise / Lower Spray Bar
- Vacuum On / Off / Speed
- Vehicle Direction Joystick
- LED Front/Off/Back

iv. Vehicle Tether & Hoses

The vehicle is connected to the support components with electrical cables as well as various fluid conductors such as air, water and vacuum. A support saddle is available for extremely high applications when the weight of the tether assembly would be excessive.

The tether consists of 6 electrical cables (power and feedback cables for each motor), and 3 pneumatic tubes to control the shroud functions. The tether is sheathed in a protective cover and secured with grips at the vehicle and control box terminations. All components are color coded for ease of installation. The tether enters the container via a small port for connection to the RCP. The UHP supply hose is provided in short sections for ease of transport and handling. Each section is provided with integrated armor and rapid connection devices. Each joint is restrained by grips. The vacuum hose has a smooth bore and a lightweight external strength member. Standard cam and groove connectors are used for industrial compatibility.

v. Vehicle Power

The ENVIROBOT systems will be configured to operate at the voltage specified on the Purchase Order. Shore power is brought in to the Power Distribution Panel (PDP) via a large tunnel sealed to the wall of the container. The PDP then monitors the quality of the 3 phase power and distributes it to the RCP and to a small transformer for supplying power in the container. The PDP provides standard safety devices such as circuit breakers and phase balance monitors. Alarms, indicators and timers are located on the front panel of the NEMA 12 enclosure.

A small air compressor is in the container with a reservoir that has a burst disc and a mechanical pressure gauge. The air is routed from the reservoir to the RCP and to the UHP dump valve. The air control for the dump valve is electrically actuated via the PLC located within the RCP. A regulator is provided within the RCP for controlling the pneumatic shroud seal force.

B. CONTAINER

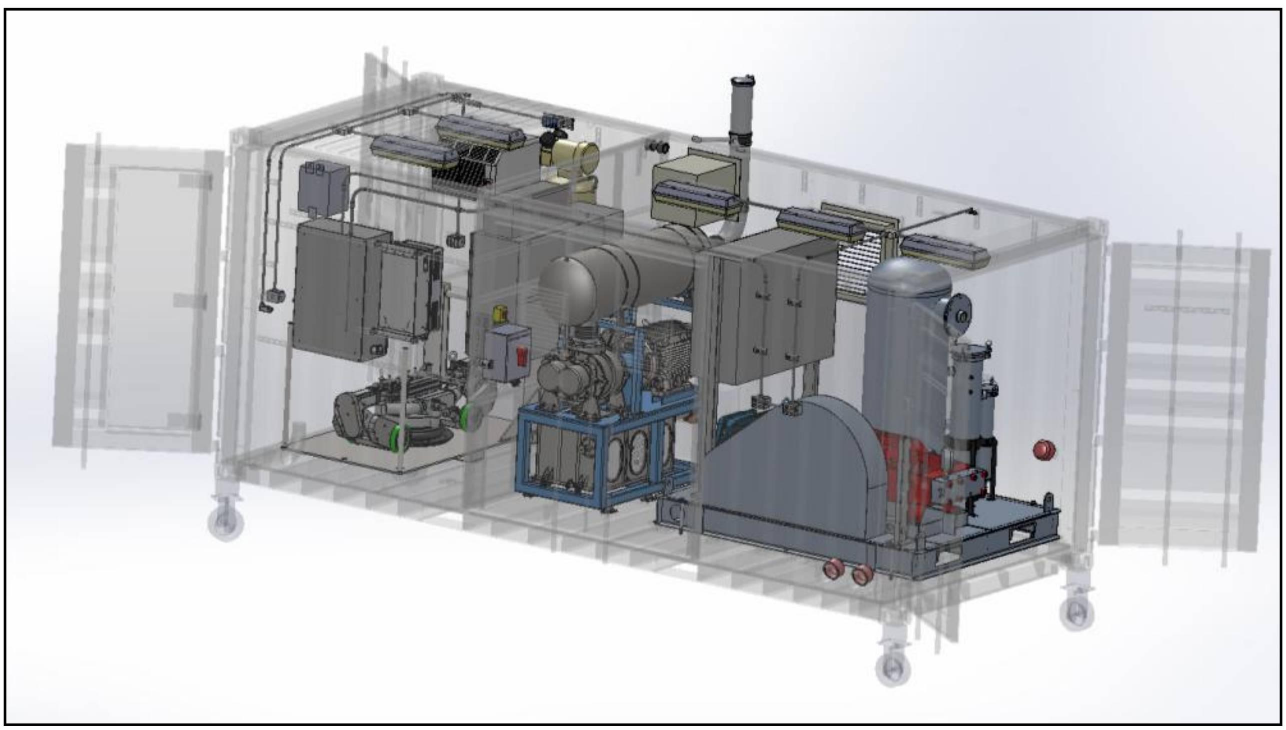
The container is an ISO general purpose dry cargo container. It will have dual locking openings on both ends and standard connection corners at all eight corners. Fork lift pockets are included. Vent and access panels are also provided where thermal control or maintenance access is required. All bulkhead connections are fitted inside of wells in order to protect connectors from impact and weather conditions. Threaded lugs are provided on the outside of the container for earth grounding. Standard placards are provided for shipping markings.

Example of Control Room

A “Control Room” environment is created behind a bulkhead in the container with an HVAC system. This maintains air quality and allows operation of the PDP and RCP in most operating environments. The control room is also configured as a small work area with a work bench. A “man-door” is included in one of the dual openings in the Control Room.

An "Equipment Room" is located on the opposite side of the bulkhead and contains the vacuum system and the electric UHP pump. Forced air cooling system(s) are provided. All components are shock mounted for increased vibration tolerance and noise reduction.

Fixtures in the containers include overhead lighting and power receptacles. Paint schemes can be tailored to the customer’s preference. Tie downs are provided within each room for securing items during storage. The vehicle and the vehicle launch skid can be located within the control room during transport. The photograph on page 9 illustrates the vehicle on the launch skid ready for placement in to the container for shipment.



20' Container Configuration

C. Ultra High Pressure PUMP

Electric UHP Pump in 20' Container

The triplex bare-shaft UHP pump is self-cooling with an external drain for the discharge of the cooling water. A mechanical gauge is located on the pump for monitoring the downstream pressure. A remote and a local start/stop feature are provided. Two burst discs are provided such that the ultimate pressure cannot exceed the working pressure by more than 12%. The pressure developed by the pump is contingent on the types and quantity of jets on the spray bar and the speed of the electric motor. A downstream dump (or bypass) valve can be manually or remotely activated from the Robot Control Box to reduce the downstream pressure to zero. An emergency stop function is also provided on the RCB which will stop the motor rotation.

Power for the UHP pump electric motor is provided by a separate power feed through a small port in the container. Additional ports are provided for the water supply hose, low pressure drain hose and the high pressure UHP hose. The water supplied to the UHP pump must meet the cleanliness, pressure and flow requirements as listed below. High levels of contamination will reduce the life-expectancy of the pump seals and water jets.

D. VACUUM SYSTEM

The vacuum blower provides air flow that moves the removed coatings and UHP water from the vehicle to the customer furnished separator tank. The mixture of coating debris, water and air separates in the tank and the vacuum air is then routed in to the vacuum system in the Envirobot container where a secondary water separator and strainer are provided to protect the blower. During robot operations, the speed of the electric motor as well as an On/Off control is provided to the robot operator on the RCB. The blower motor also stops when any of the three Emergency Stop buttons are pressed. A vacuum gauge and a discharge thermometer are located on the vacuum system. In addition an automatic safety relief valve, water sensor and temperature sensor are provided for emergency back-up. Power for the electric motor is provided to the motor controller in the Robot Control Room from the PDP.

E. RIGGING

Three commercial fall arrestors are placed above the robot in order to arrest the robot in the unlikely event of a fall during vertical operations. The rigging is periodically shifted as work progresses.

A steel launch skid is provided for launching the vehicle onto the substrate in either a vertical or horizontal orientation with the aid of a small fork lift. The skid is also used for transporting the vehicle in the container or for relocating the vehicle during maintenance.

**Vehicle on Launch Skid
Ready for Transport**

F. EQUIPMENT SPECIFICATIONS

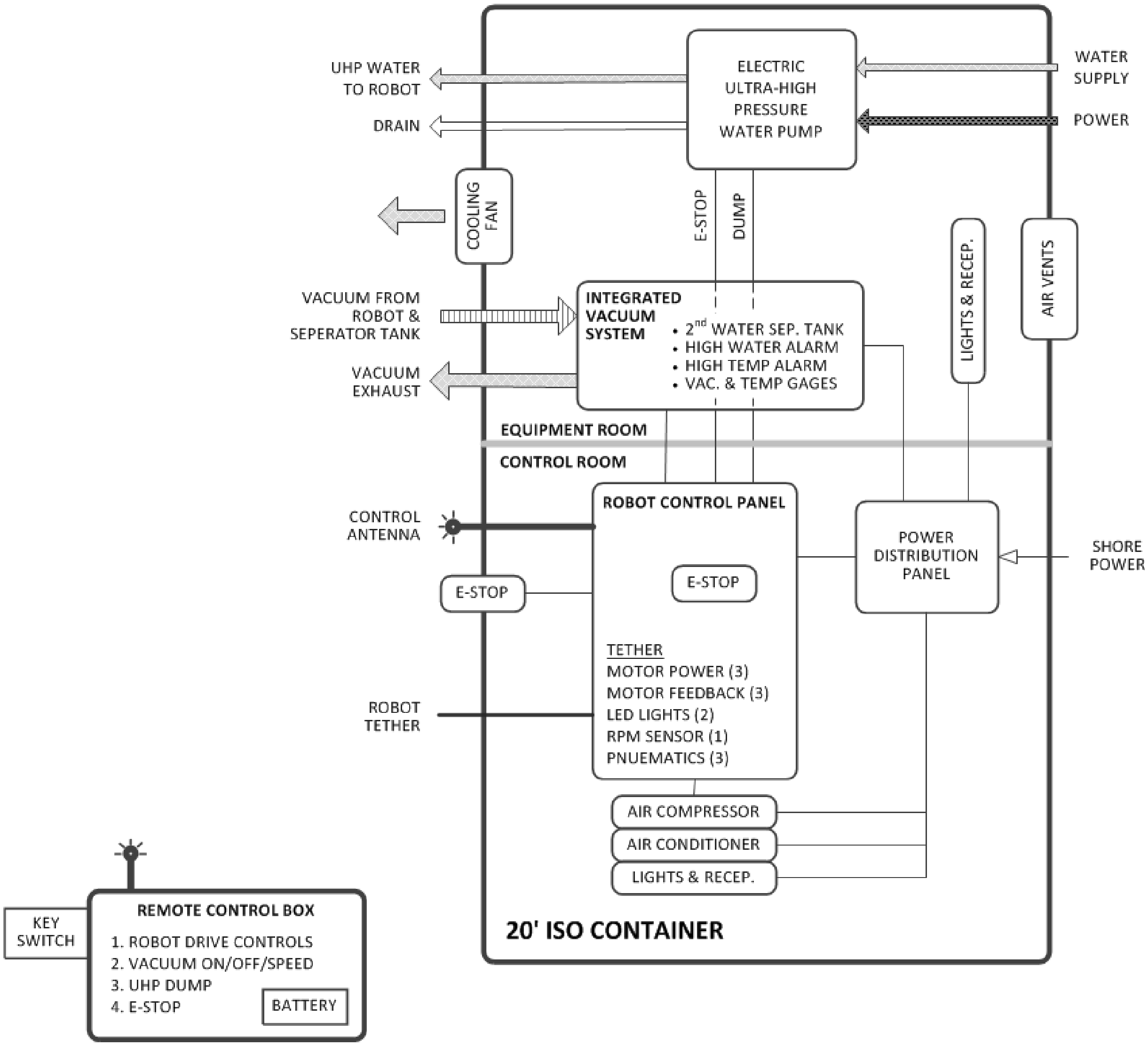
SYSTEM PERFORMANCE	
Operating Cycle	Rated for continuous operation
Environmental Conditions	35 – 125 deg F
Complete Package Dimensions	19’ 10 ½” x 8’ x 8’ 6” (L x W x H)
Overall Weight (lbs. nominal)	19,000
UHP ROBOT VEHICLE	
Dimensions (LxWxH)	70 x 27 x 21 inches
Weight	500 lbs
Drive Method	4 Wheel-drive and Steering, Fail-safe Brakes
Wheel Treads	Poly-Urethane, non-marking
Attachment Method	Focused, non-polar, non-electric Magnetic Array (Patented)
Operating Orientation	Any (including flat bottom inverted)
Ground Clearance	0.50 in (13 mm)
Maximum Vertical Excursion	90% of Tether length with Auxiliary Tether Support
Turning Radius (Curb to Curb)	Left Turn: 45 Inches
	Right Turn: 65 Inches
Hull or Tank Curvature	72 inches Minimum Radius
Cutting Width	15 Inches
Cutting Nozzle Height	Adjustable, 0.6 – 3.5 inches
Spray Configuration	Multiple options of bars and nozzles
Spray Bar Rotation Speed	2500 – 3000 rpm
Effluent Capture	95-100% of removed coating on all surfaces
Onboard Vacuum Hoses	2.5 in diameter (64 mm)
Safety	Fall Arresters (3), Emergency Stops (3)
ROBOT CONTROL PANEL (RCP)	
Voltage Input	380 Volts, 3 Phase AC, 50 Hz
Motor Feedback	Low Voltage AC from 3 Motor Resolvers
Voltage Outputs	Low Voltage DC to operate Solenoids (VAC on/off, UHP Dump, E-Stop)
	400 Volt PWM for 3 Robot Motors
Pneumatic System Pressure	120 PSI from Storage Tank
Pneumatic Functions	Shroud Seal (40-60 psi), Spray Bar Up/Down (120 psi)
Instrumentation	Motor fault indicators located inside provide automatic protection
Local Control	Master Power on/off
	Touch Screen Interface
	External Emergency Stop Button (secures power to entire system)
Enclosure	NEMA 12, with connectors for tether components
	3500 BTU Environmental Control System (HVAC)

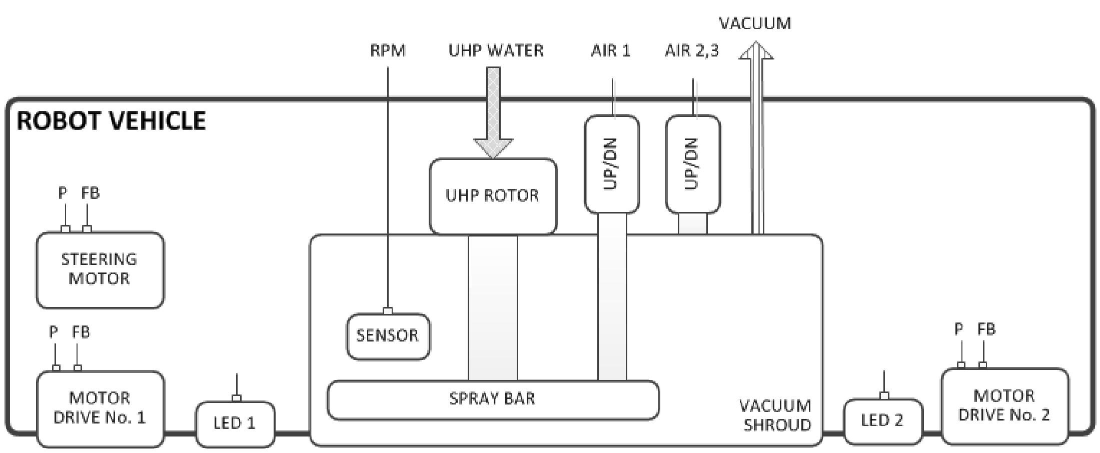
ROBOT CONTROL BOX (RCB)	
Type	Wireless, 458 MHz (user selectable), 500’ Maximum Range
Power	Rechargeable Battery (or 3 X AA)
Control Functions	Automatic or Manual Speed Control
	Steering, with Automatic Centering and Trim
	Spray Bar Height, Seal Up/Down
	Vacuum On/Off & Speed Control, UHP Pressure On/Off
	Emergency Stop
TETHER	
Length	**350’ Nominal**
Components	Air Control Lines (3 each)
	Actuator Power Cables (3 each)
	Actuator Feedback (3), Light Cables (2) & RPM Sensor Cable (1)
	4” Vacuum Hose
	8mm UHP Hose (104,000 PSI Burst Pressure) with M14 Female Swivel fittings (7/8-14 threads, 58 deg Cone)
POWER DISTRIBUTION PANEL (PDP)	
Power Service Required	380 VAC, 3 Phase, 50 Hz, 200 Peak Amps
Distribution Panel	Power source selection (if applicable), Circuit protection and isolation of Power to Control Box, Vacuum System & Utilities
Instrumentation/Safety	Breaker Closed & Fault Indicators
	Automatic Fault Interruption (voltage, phase or frequency imbalance)
Enclosure	NEMA 12
CONTAINER	
Type	20' Dry Freight ISO Cargo Container
Access Doors	Both ends have standard double doors and 2’ man-door @ end, 20' containers have an additional 6’ door on side
Openings	Air flow is provided via louvered panels on both sides of the container
External Controls	External Emergency Stop Control
Connections	Vacuum from Robot, Electrical Ground Lugs
Access Ports	Control Room: Power to PDP, Tether, Control Antenna Equip. Room: Vacuum Connect & Vacuum Exhaust Water Supply / Output, Electrical power to Pump
	Note: Power cables to Control Room and Electric UHP are not provided
Environmental Control	Control room has HVAC, container is not insulated
Aux Power & Lighting	380 VAC, 50 Hz Receptacles for general use (Type/Style ?) Marine grade overhead fluorescent lights
Storage	Robot and tether are stored/shipped in the Control Room
Accessories	Casters for the container are not provided

ELECTRIC ULTRA-HIGH PRESSURE WATER PUMP (UHP)	
Water Pump & Motor Type	3 Cylinder Triplex Reciprocating Piston Pump, 300 hp TEFC Motor
Power Service Required	380 VAC, 3 Phase, 50 Hz, 600 Amps
Dimensions (LxWxH)	93 x 71 x 79 inches
Weight	7,000 lbs
Water Flow	12 GPM Maximum (Nominal)
Water Pressure	40,000 PSI (2,750 bar)
Configuration	Skid mounted with Fork Pockets & Lift eyes
Drive Transfer	V-Belts
Electric Motor Controls	Soft Start, remote E-Stop
Reservoir	40 Gallons
Instrumentation	Mechanical Pressure Gauge
Control	Remotely operated, air powered bypass valve used to reduce pump output pressure to less than 500 psi
Boost Pump	Charges water pressure to filters and pump, electric motor, controlled from Main Control Panel
	Operating Pressure: 25 - 35 psi
	Actuation Pressure: 70 psi maximum
Filters	5 micron primary filter, 1 micron secondary filter
Safety	Test Certifications, 2 Burst Discs (50,000 psi), low water shut down
UHP WATER SUPPLY REQUIREMENTS	
Type	Drinkable, potable water
Pressure, Flow	20 – 125 psi, 12 – 15 gpm
Temperature	Less than 86°F (30°C)
Particle Size	Not to Exceed 10 micron
Mineral Content	50 – 100 mg/l
VACUUM	
Power	50 bhp, 380 VAC, 3 Phase, 50 Hz (Powered from Control Room supply)
Dimensions (LxWxH)	76 x 30 x 73 inches
Weight	2,550 lbs
Flow	1,320 Cubic Feet per Minute @ 2050 RPM
Pressure	10 – 12 mmHg, Nominal (Blower Maximum Allowable: 15 inHg)
Blower	Bi-Lobed, Constant Displacement
Drive	Direct, via Jaw Coupling, Max indicated run-out ±0.015 in (0.4 mm)
Sound Control	Discharge Silencer, fully Vibration Isolated
Filter	Suction Strainer & water separator
Instrumentation	Safety Relief Valve, Vacuum & Temperature Gauges High Water/Temp Alarms
Controls	Remote On / Off & Speed
Speed Parameters	RCB Settings: Start 1600 rpm, Maximum 2050 rpm
	RCP Settings: Start 1600 rpm (adjustable on Touchscreen)
	Blower Maximum Allowable: 2050 rpm
	Blower Minimum Allowable: 900 rpm
Discharge Temperature	Blower Maximum Allowable Temperature: 275°F

G. CONFIGURATION DIAGRAM

20' Container with Internal Electric UHP





2. DOCUMENTATION

Documents will be delivered to the client in electronic format (Adobe PDF) in English. Delivered documents will include:

- Operation / Maintenance manual
- Block diagrams and schematics
- Training materials

3. TESTING AND COMMISSIONING

Each component or subsystem will be tested under full load until all operating parameters are verified to operate within specification. After verification, final assembly will commence which will be followed by the entire system being tested under the same success criteria. Factory Acceptance Testing will include the use of each ENVIROBOT system in the removal of a coating from a vertical test substrate at the factory in Palm City, Florida.

APPENDIX B

SPECIFIC SHIP CLASS COST SAVINGS SPREADSHEETS

FFG-7 OLIVER HAZARD PERRY CLASS		
Assumptions		
Underwater Hull Surface Area	15,000	square feet
Freeboard Surface Area	15,000	square feet
Production Rate for Spot and Sweep	1,200	square feet per hour
Productivity of Spot and Sweep (hours full production per day)	7	nozzle hours per day
Production Rate for SSPC SP-10	175	square feet per nozzle-hour
Productivity of SSPC SP-10 (hours full production per day)	12	nozzle hours per day
Surface Preparation Cost Savings	$ 3.00	dollars per square foot
Assumed number of dockings in CY-12	4	ships
Surface Preparation Cost Savings	**Freeboard**	**Underwater Hull**
Cost Savings per FFG (surface area time cost savings)	$ 45,000	$ 45,000
CY 2012 Potential Cost Savings	$ 180,000	$ 180,000
Production Schedule Savings	**Freeboard**	**Underwater Hull**
Days Required for Spot and Sweep	1.79	1.79
Days required for SSPC SP-10	7.14	7.14
Total Days Spot and Sweep	2	2
Total Days for SSPC SP-10	8	8
Production days saved for Spot and Sweep	**6**	**6**
Total Potential Savings for FFG-7 Class in CY 2012	**Freeboard**	**Underwater Hull**
Cost Savings	**$ 180,000**	**$ 180,000**
Production Schedule Savings	**24**	**24**
Total Potential Surface Preparation Cost Savings for FFG-7 Class in CY2012		**$ 360,000**
Total Potential Schedule Reduction for FFG-7 Class in CY2012		**48**

CG-47 TICONDEROGA CLASS		
Assumptions		
Underwater Hull Surface Area	24,000	square feet
Freeboard Surface Area	24,000	square feet
Production Rate for Spot and Sweep	1,200	square feet per hour
Productivity of Spot and Sweep (hours full production per day)	7	nozzle hours per day
Production Rate for SSPC SP-10	175	square feet per nozzle-hour
Productivity of SSPC SP-10 (hours full production per day)	12	nozzle hours per day
Surface Preparation Cost Savings	$ 3.00	dollars per square foot
Assumed number of dockings in CY-12	5	ships
Surface Preparation Cost Savings	**Freeboard**	**Underwater Hull**
Cost Savings per FFG (surface area time cost savings)	$ 72,000	$ 72,000
CY 2012 Potential Cost Savings	$ 360,000	$ 360,000
Production Schedule Savings	**Freeboard**	**Underwater Hull**
Days Required for Spot and Sweep	2.86	2.86
Days required for SSPC SP-10	11.43	11.43
Total Days Spot and Sweep	3	3
Total Days for SSPC SP-10	12	12
Production days saved for Spot and Sweep	**9**	**9**
Total Potential Savings for CG-47 Class in CY 2012	**Freeboard**	**Underwater Hull**
Cost Savings	**$ 360,000**	**$ 360,000**
Production Schedule Savings	**45**	**45**
Total Potential Surface Preparation Cost Savings for CG-47 Class in CY2012		**$ 720,000**
Total Potential Schedule Reduction for CG-47 Class in CY2012		**90**

DDG-51 ARLEIGH BURKE CLASS		
Assumptions		
Underwater Hull Surface Area	22,000	square feet
Freeboard Surface Area	22,000	square feet
Production Rate for Spot and Sweep	1,200	square feet per hour
Productivity of Spot and Sweep (hours full production per day)	7	nozzle hours per day
Production Rate for SSPC SP-10	175	square feet per nozzle-hour
Productivity of SSPC SP-10 (hours full production per day)	12	nozzle hours per day
Surface Preparation Cost Savings	$ 3.00	dollars per square foot
Assumed number of dockings in CY-12	13	ships
Surface Preparation Cost Savings	**Freeboard**	**Underwater Hull**
Cost Savings per FFG (surface area time cost savings)	$ 66,000	$ 66,000
CY 2012 Potential Cost Savings	$ 858,000	$ 858,000
Production Schedule Savings	**Freeboard**	**Underwater Hull**
Days Required for Spot and Sweep	2.62	2.62
Days required for SSPC SP-10	10.48	10.48
Total Days Spot and Sweep	3	3
Total Days for SSPC SP-10	11	11
Production days saved for Spot and Sweep	**8**	**8**
Total Potential Savings for DDG-51 Class in CY 2012	**Freeboard**	**Underwater Hull**
Cost Savings	**$ 858,000**	**$ 858,000**
Production Schedule Savings	**104**	**104**
Total Potential Surface Preparation Cost Savings for DDG-51 Class in CY2012		**$ 1,716,000**
Total Potential Schedule Reduction for DDG-51 Class in CY2012		**208**

CVN NIMITZ CLASS		
Assumptions		
Underwater Hull Surface Area	180,000	square feet
Freeboard Surface Area	180,000	square feet
Production Rate for Spot and Sweep	1,200	square feet per hour
Productivity of Spot and Sweep (hours full production per day)	7	nozzle hours per day
Production Rate for SSPC SP-10	175	square feet per nozzle-hour
Productivity of SSPC SP-10 (hours full production per day)	12	nozzle hours per day
Surface Preparation Cost Savings	$ 3.00	dollars per square foot
Assumed number of dockings in CY-12	4	ships
Surface Preparation Cost Savings	**Freeboard**	**Underwater Hull**
Cost Savings per FFG (surface area time cost savings)	$ 540,000	$ 540,000
CY 2012 Potential Cost Savings	$ 2,160,000	$ 2,160,000
Production Schedule Savings	**Freeboard**	**Underwater Hull**
Days Required for Spot and Sweep	21.43	21.43
Days required for SSPC SP-10	85.71	85.71
Total Days Spot and Sweep	22	22
Total Days for SSPC SP-10	86	86
Production days saved for Spot and Sweep	**64**	**64**
Total Potential Savings for CVN Class in CY 2012	**Freeboard**	**Underwater Hull**
Cost Savings	**$ 2,160,000**	**$ 2,160,000**
Production Schedule Savings	**256**	**256**
Total Potential Surface Preparation Cost Savings for CVN Class in CY2012		**$ 4,320,000**
Total Potential Schedule Reduction for CVN Class in CY2012		**512**

LHD CLASS AMPHIB ASSAULT		
Assumptions		
Underwater Hull Surface Area	118,000	square feet
Freeboard Surface Area	118,000	square feet
Production Rate for Spot and Sweep	1,200	square feet per hour
Productivity of Spot and Sweep (hours full production per day)	7	nozzle hours per day
Production Rate for SSPC SP-10	175	square feet per nozzle-hour
Productivity of SSPC SP-10 (hours full production per day)	12	nozzle hours per day
Surface Preparation Cost Savings	$ 3.00	dollars per square foot
Assumed number of dockings in CY-12	1	ships
Surface Preparation Cost Savings	**Freeboard**	**Underwater Hull**
Cost Savings per FFG (surface area time cost savings)	$ 354,000	$ 354,000
CY 2012 Potential Cost Savings	$ 354,000	$ 354,000
Production Schedule Savings	**Freeboard**	**Underwater Hull**
Days Required for Spot and Sweep	14.05	14.05
Days required for SSPC SP-10	56.19	56.19
Total Days Spot and Sweep	15	15
Total Days for SSPC SP-10	57	57
Production days saved for Spot and Sweep	**42**	**42**
Total Potential Savings for LHD Class in CY 2012	**Freeboard**	**Underwater Hull**
Cost Savings	**$ 354,000**	**$ 354,000**
Production Schedule Savings	**42**	**42**
Total Potential Surface Preparation Cost Savings for LHD Class in CY2012		**$ 708,000**
Total Potential Schedule Reduction for LHD Class in CY2012		**84**

LSD-41 CLASS AMPHIB ASSAULT		
Assumptions		
Underwater Hull Surface Area	46,000	square feet
Freeboard Surface Area	46,000	square feet
Production Rate for Spot and Sweep	1,200	square feet per hour
Productivity of Spot and Sweep (hours full production per day)	7	nozzle hours per day
Production Rate for SSPC SP-10	175	square feet per nozzle-hour
Productivity of SSPC SP-10 (hours full production per day)	12	nozzle hours per day
Surface Preparation Cost Savings	$ 3.00	dollars per square foot
Assumed number of dockings in CY-12	4	ships
Surface Preparation Cost Savings	**Freeboard**	**Underwater Hull**
Cost Savings per FFG (surface area time cost savings)	$ 138,000	$ 138,000
CY 2012 Potential Cost Savings	$ 552,000	$ 552,000
Production Schedule Savings	**Freeboard**	**Underwater Hull**
Days Required for Spot and Sweep	5.48	5.48
Days required for SSPC SP-10	21.90	21.90
Total Days Spot and Sweep	6	6
Total Days for SSPC SP-10	22	22
Production days saved for Spot and Sweep	**16**	**16**
Total Potential Savings for LSD-41 Class in CY 2012	**Freeboard**	**Underwater Hull**
Cost Savings	**$ 552,000**	**$ 552,000**
Production Schedule Savings	**64**	**64**
Total Potential Surface Preparation Cost Savings for LSD-41 Class in CY2012		**$ 1,104,000**
Total Potential Schedule Reduction for LSD-41 Class in CY2012		**128**

SSBN OHIO CLASS		
Assumptions		
Underwater Hull Surface Area	77,000	square feet
Freeboard Surface Area	N/A	square feet
Production Rate for Spot and Sweep	1,200	square feet per hour
Productivity of Spot and Sweep (hours full production per day)	7	nozzle hours per day
Production Rate for SSPC SP-10	175	square feet per nozzle-hour
Productivity of SSPC SP-10 (hours full production per day)	12	nozzle hours per day
Surface Preparation Cost Savings	$ 3.00	dollars per square foot
Assumed number of dockings in CY-12	2	ships
Surface Preparation Cost Savings	**Freeboard**	**Underwater Hull**
Cost Savings per FFG (surface area time cost savings)	N/A	$ 231,000
CY 2012 Potential Cost Savings	N/A	$ 462,000
Production Schedule Savings	**Freeboard**	**Underwater Hull**
Days Required for Spot and Sweep	N/A	9.17
Days required for SSPC SP-10	N/A	36.67
Total Days Spot and Sweep	N/A	10
Total Days for SSPC SP-10	N/A	37
Production days saved for Spot and Sweep	**N/A**	**27**
Total Potential Savings for SSBN Class in CY 2012	**Freeboard**	**Underwater Hull**
Cost Savings	**N/A**	**$ 462,000**
Production Schedule Savings	**N/A**	**54**
Total Potential Surface Preparation Cost Savings for SSBN Class in CY2012		**$ 462,000**
Total Potential Schedule Reduction for SSBN Class in CY2012		**54**