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14. ABSTRACT The Hull Bio-Mimetic Underwater Grooming (HullBUG) Vehicle System under development holds the potential to dramatically change current hull cleaning methods and their environmental impacts. Frequent use of the HullBUG, a small autonomous cleaning device, on the hulls of Navy ships in port by applying light cleaning pressure or grooming results in a cost effective solution to the underwater fouling problem. As part of overall HullBUG development the Grooming Tool requires particular attention. This tool and variations of it have been used by Florida Institute of Technology (FIT) during several years of testing activities. FIT was assigned the task to come up with a set of parameters that FIT would want in the next generation tool. SeaRobotics was assigned the task of developing a grooming tool that would address those parameters. After review by Navy and FIT personnel the agreed to design would be built and tested. This report documents that effort.						
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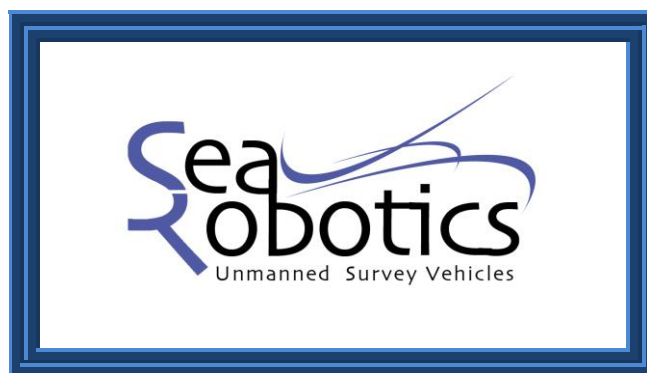
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**HULLBUG TECHNOLOGY DEVELOPMENT FOR
UNDERWATER HULL CLEANING
QUARTERLY REPORT
EMPHASIS ON GROOMING TOOL**

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1/15/14

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I. Contract Information

Contract Number	N00014-09-C-0852
Title of Research	HullBUG Technology Development for Underwater Hull Cleaning
Principal Investigator	Don Darling
Organization	SeaRobotics

II. Technical Section

A. *Technical Objectives*

The Hull Bio-Mimetic Underwater Grooming (HullBUG) Vehicle System under development holds the potential to dramatically change current hull cleaning methods and their environmental impacts. Frequent use of the HullBUG, a small autonomous cleaning device, on the hulls of Navy ships in port by applying light cleaning pressure or grooming results in a cost effective solution to the underwater fouling problem. The frequency of grooming is selected based on the hull coating and the local fouling pressure on the docked ships or ships at anchor. Frequent grooming prohibits the development of mature fouling colonies and limits fouling to a manageable bio-film layer.

As part of overall HullBUG development the Grooming Tool requires particular attention. This tool and variations of it have been used by FIT during several years of testing activities. FIT was assigned the task to come up with a set of parameters that FIT would want in the next generation tool. SeaRobotics was assigned the task of developing a grooming tool that would address those parameters. After review by Navy and FIT personnel the agreed to design was built and will now be tested.

B. *Technical Approach*

Upon receipt of FIT provided parameters SRC would take these parameters and propose a mechanical configuration that met them along with the electrical requirements to power the new Grooming Tool. A conceptually designed SolidWorks model would be generated to better understand the packaging and mounting of the tool on the FIT vehicle. Motors and controllers would be sized for the expected loads and incorporated into the solid model. After review by Navy and FIT personnel the model would be refined and updated. Once approved, detailed drawings of the Grooming Tool would be generated. These drawings would be vended out to approved vendors for quoting. Quotes would be obtained for different levels of production in order to better understand the savings associated with buying more. Once a good pricing model was developed and quantity purchased determined, parts would be vended out and manufactured. These parts would then be assembled at SRC. A test program would then follow to fully qualify the design.

C. *Progress Summary*

Development efforts to date have emphasized the need to provide a stronger acting and more compliant Grooming Tool. To that end it was determined that a new Grooming Tool would be designed, technically reviewed, constructed and tested.

The following sections summarize the project's current status:

1. *FIT Supplied Parameters*

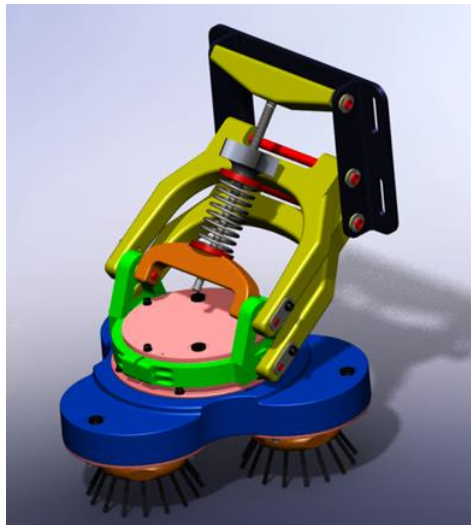
Based on grooming tool studies, FIT has developed a set of specifications that will be the basis of future grooming tool research. More power, more speed and optimal brush to brush center locations were the dominant themes. The following specs were provided by FIT as guidance for future Grooming Tool design.

- 1000 RPM
- 240 mNm per brush
- 12 cm center to center distance

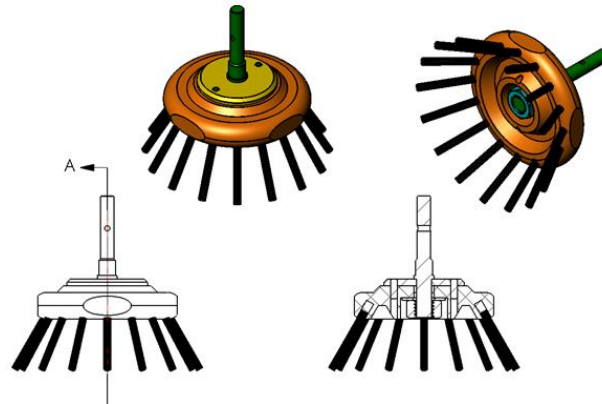
2. *Current Design*

After discussion and design review the current version of the 3 headed Grooming Tool design consists of a 90 watt motor-flat brushless DC “outrunner” style motor coupled to 3 sets of gears, each providing a 1.75 to 1 gear reduction to the brush head. The motor has been repackaged with a more robust bearing set. Each grooming tool shaft is provided with its own set of bearings and seals. The brushes are mounted to the shaft with a commercially accepted bolting arrangement that allows quick change out of the brushes.

A compliant mount was devised that provides near constant vertical force across the full range of travel.



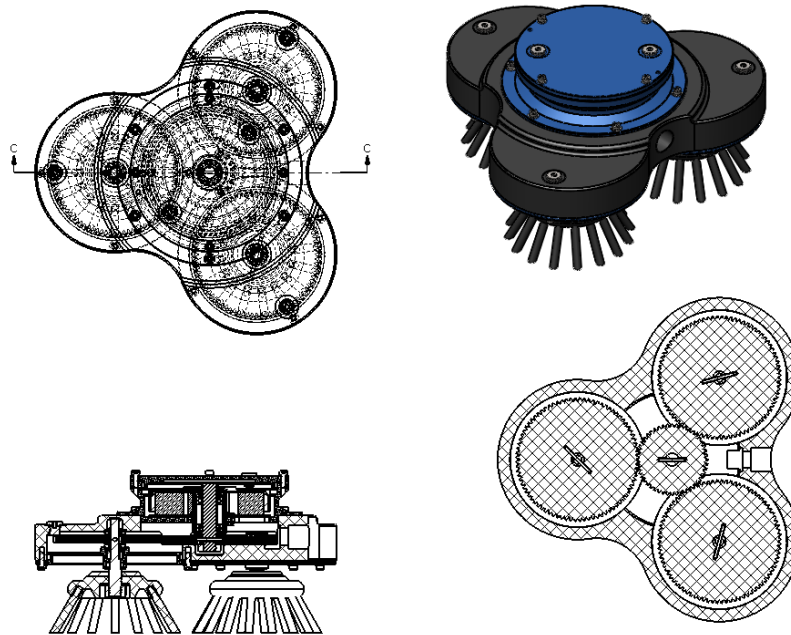
Updated 3 Head Grooming Tool Concept and Compliant Mount



Brush Holder Mount

3. SRC Detailed Design

All of the parts for the 3 headed tool were detailed, dimensioned and tolerances added . A top assembly drawing was created that identified all machined parts as well as all purchased hardware



Top Assembly

4. Grooming Tool Production

Based on total cost, a decision was made to make 1 grooming tool and 1 compliant mechanism. These parts are to be assembled and tested before building more units. Several pictures taken during the assembly process along with the fully assemble items are shown below.



Inner Gear Case with Sun Gear



Planet Gear



Stationary Stator



Rotor with Permanent Magnets



Bottom View of Grooming Tool
with Brushes



Top View of Grooming Tool
and Compliance Mechanism

5. *Testing Strategy*

After general review of several different production and testing strategies it was determined that a single 3 headed Grooming Tool and Compliance Mechanism be constructed for extended testing at SRC. A dedicated rotating disk type testing mechanism would be designed and constructed. Functionally, the disk rotating underwater would allow the Grooming Tool to run continuously over a constantly moving surface. The rotating disk could be painted with more than one different coating allowing the grooming tool to run over different coatings in one revolution of the disk. In this way the grooming tool and compliance mechanism would be endurance tested. The wear resistance of the paint would be tested at the same time. Making the testing even more realistic, bumps and divots could be added simulating the varying surfaces found on a ship hull. This constantly rotating device could run virtually unattended for long periods and work to qualify the Grooming Tool, compliance mechanism, the brushes as well as the paint they are designed to groom.

6. *Test Fixture Design and Fabrication*

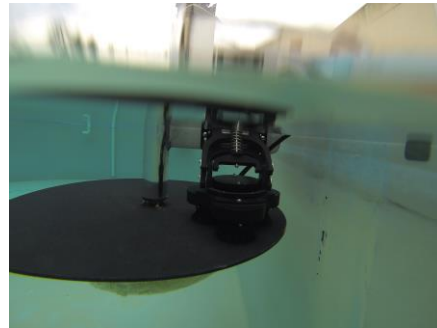
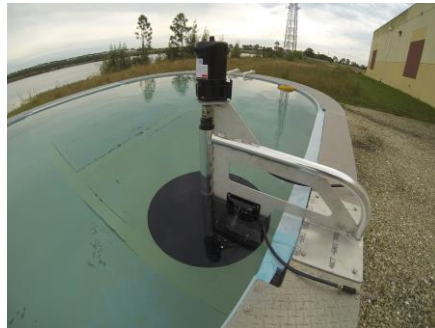
Based on conceptual design parameters a test fixture was designed and fabricated to replicate the movement of the HullBug vehicle at various speeds. A variable frequency drive was chosen to control a 3 phase electric motor to provide variability between minimum and maximum speeds. The following speed limits were determined to be the outer bounds of any reasonable HullBug operating speed.

Minimum Disk 3.6 RPM

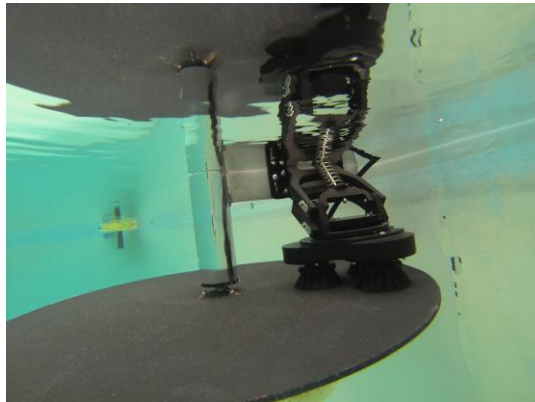
Equivalent HullBug transit velocity 10 cm/s

Maximum Disk 18 RPM

Equivalent HullBug transit velocity 50 cm/s



Underwater Test GT Test Fixture



Test Fixture and Grooming Tool
on Rotating Disk



Test Fixture Motor Drive
under Construction

III. **Near Term Priorities**

A. *Begin Testing*

Develop a test plan and start testing of the grooming tool under simulated conditions utilizing the Rotating Disk Test fixture. Start with the simplest configuration and add variations as nominal operation is proven acceptable.

B. *Develop Surface Variations to Test*

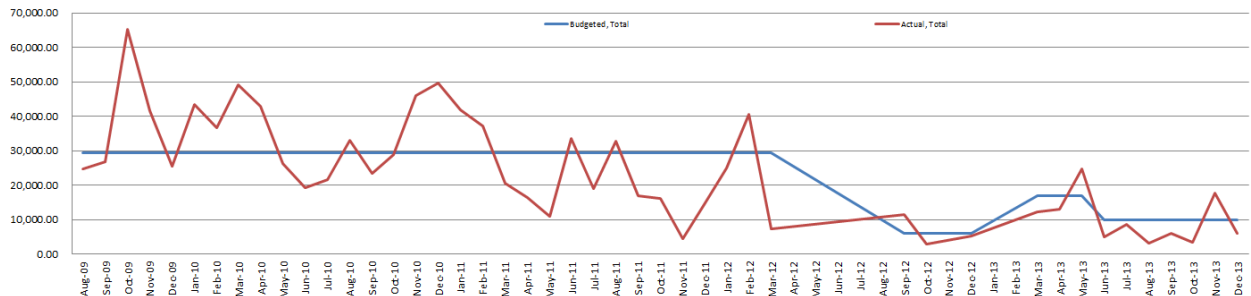
A ship's hull is not flat and contains many humps, bumps, divots and bows in otherwise flat steel that the HullBug must transit over. The simple flat disk simulates movement of the

grooming tool in the simplistic test case. After the simplistic test is proven acceptable the surface of the flat disk should be modified to more closely approximate the uneven surface of a real ship.

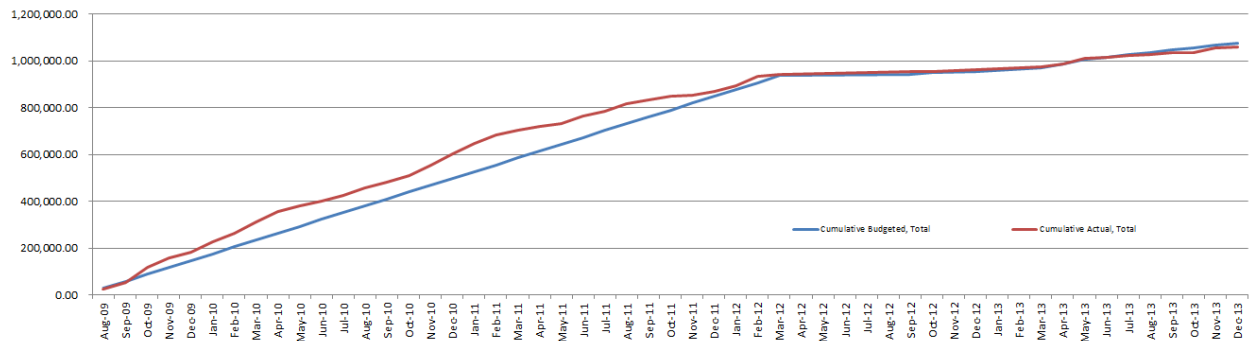
IV. Financial

The following charts and graphs detail the expenditures to date.

Major Cost Elements		Amount for Current Period Billed	Prior Billings	Cumulative Amount From Inception to Date of This Billing
Direct Labor		1,935.61	459,899.42	461,835.03
Onsite Overhead Rate	57.11% of Direct Labor	\$ 1,105.43		
Direct Material		\$ 1,277.33	89,440.27	90,717.60
Travel		\$ 14.43	4,536.50	4,550.93
Subcontracts		\$ -	-	0.00
Total Direct Costs		\$ 4,332.80	791,166.03	795,498.83
General and Administrative	28.71% of Direct Costs	\$ 1,243.95	209,054.92	210,298.87
Total Costs		\$ 5,576.74	1,000,220.96	1,005,797.70
Fix Fee Earned	6.00% of Total Costs	\$ 334.60	60,012.59	60,347.19
Contract Reserves and Adjustments				
Contract Costs Withheld		\$ -	-	-
Fixed Fee Withheld (10% of fee)	0.60% of Costs Withheld	\$ 33.46	5,967.36	6,000.82
Adjusted Amounts Claimed				
Current and Cumulative Costs		\$ 5,576.74	1,000,220.96	1,005,797.70
Fixed Fee Billed		\$ 301.14	54,045.23	54,346.37
Total BVN-0057		\$ 5,877.89	1,054,266.20	1,060,144.08



Monthly Spend Rate



Accumulated Spending