Liquid Robotics® Field Operations

Wave Glider® SV3 Maintenance, Inspection, and Cleaning Standard Operating Procedure (SOP)

Doc #06032 Rev A

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Revision History

REV NUM	DATE	CHANGE DESCRIPTION	AUTHOR	CHECK
A	06/17/14	Initial Release (ECO-00383)	DAB	

Approvals

Department	Date	Approver
Mechanical Engineering		
Legal		
Wave Glider Operations		

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1. OVERVIEW

1.1.Scope

This document outlines the proper cleaning and inspection of a Liquid Robotics SV3 Wave Glider. These procedures should be used in conjunction with the SV3 Maintenance Chart and SV3 Maintenance Log, which specify the frequency and type of procedure to be performed. For additional product support please contact Liquid Robotics, Inc. (LRI) Customer Support. Users of this procedure shall possess training for safely hoisting heavy objects, and need to have a basic understanding of the Wave Glider Management System™ (WGMS).

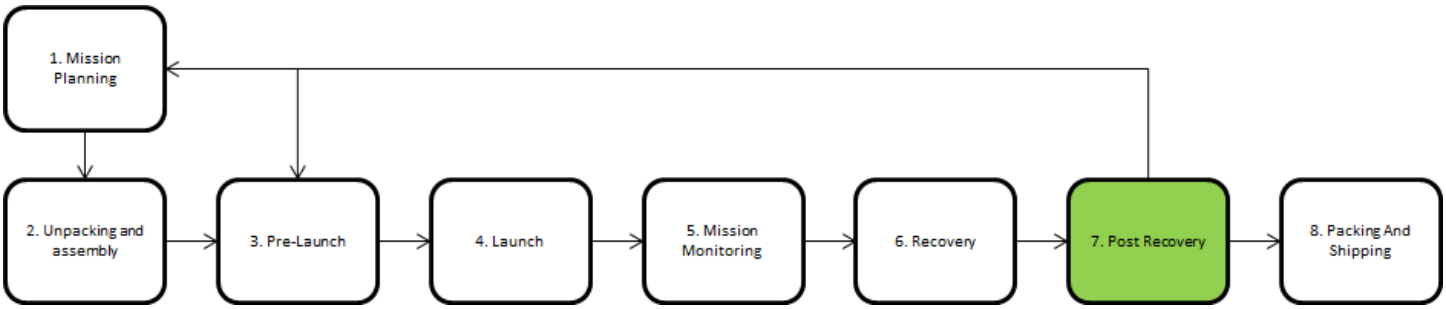

Figure 1: Wave Glider Operations workflow

These inspection and cleaning procedures are part of the Wave Glider Post Recovery & Make Ready operational workflow. The Wave Glider must first be successfully recovered before cleaning and inspection work begins.

1.2.Purpose

This document outlines the procedure for inspecting and cleaning a Wave Glider after a mission on the water. Used in conjunction with the SV3 Maintenance Chart (Appendix-A) and SV3 Maintenance Log (Appendix-B), this document enables Wave Glider operators to properly maintain their vehicle and meet Liquid Robotics warranty requirements. If an operator does not follow these procedures, Liquid Robotics' warranty may not apply.

2. SAFETY

2.1.Health, Safety, Security, & Environment (HSSE) Standards

All personnel are responsible for adherence to their corporate HSSE policy and standards. Personnel performing Wave Glider service must use Personal Protective Equipment (PPE), including safety-toed shoes, long pants and sleeves, safety eyewear and barrier gloves, to minimize risk of injuries or contact with chemicals, if applicable.

Table 1: Safety Concerns and Mitigation

Risk	Description	Mitigation
Contact with biological organisms	Fire worms, sharp barnacles, etc. Note: jellyfish tentacles can stay live for extended periods of time	Proper cleaning prior to servicing. Use PPE (safety eyewear, apron, gloves)
Contact with anti-fouling paint, if present	Anti-fouling paints can contain harmful chemicals	Use of PPE (safety eyewear, apron, gloves). Refer to Material Safety Data Sheet (MSDS) information. Thorough cleansing of tools and equipment after servicing.
Lifting or Hoisting	Components of a Wave Glider are best handled by more than one person and/or mechanical devices. (See Section 2.2 for more detail)	Components of a Wave Glider should be moved and positioned utilizing team lifting and/or mechanical devices according to local safety procedures. (See Section 2.2 for more detail)
Lithium Ion batteries	Transport and use of Lithium Ion batteries	See Section 2.3-2.5 for more detail

2.2.Lifting/Hoisting

Team lifting is required while lifting a Wave Glider or portions of a Wave Glider (float or sub). Basic crane safety guidelines shall be followed at all times when mechanical hoisting is required.

- Ensure proper PPE is worn, e.g. hard hat and safety-toed shoes
- All running rigging and hoisting gear shall be inspected for wear
- Ensure all hoisting gear is properly rated for the load of the Wave Glider
- Only one person shall provide hand signals to the crane or hoist operator
- At no time shall personnel work under a suspended load
- Suspended loads shall not be left unattended
- Refer to the Wave Glider Safe Launch and Recovery Procedures (SOP001) for detailed information regarding the safe and efficient Launch and Recovery (L&R) of the Wave Glider.

2.3.Safety Precautions for Lithium Ion Batteries

The Wave Glider Command and Control Unit (CCU) is fitted with a lithium battery pack.

Lithium based batteries become hazardous (fire and corrosion) if damaged and exposed to air and water. If damaged they may also emit thionyl chloride. Consult the battery manufacturer's MSDS prior to handling or operating lithium based battery products.

Special precautions and regulations apply to transport, handling and disposal of lithium based products. Refer to the manufacture's MSDS for more information.

Lithium batteries are powerful sources of electrical energy and should be handled with care to avoid short-circuiting.

If a battery powered underwater instrument is suspected of flooding, extreme caution must be exercised in opening the instrument in case an internal pressure has developed.

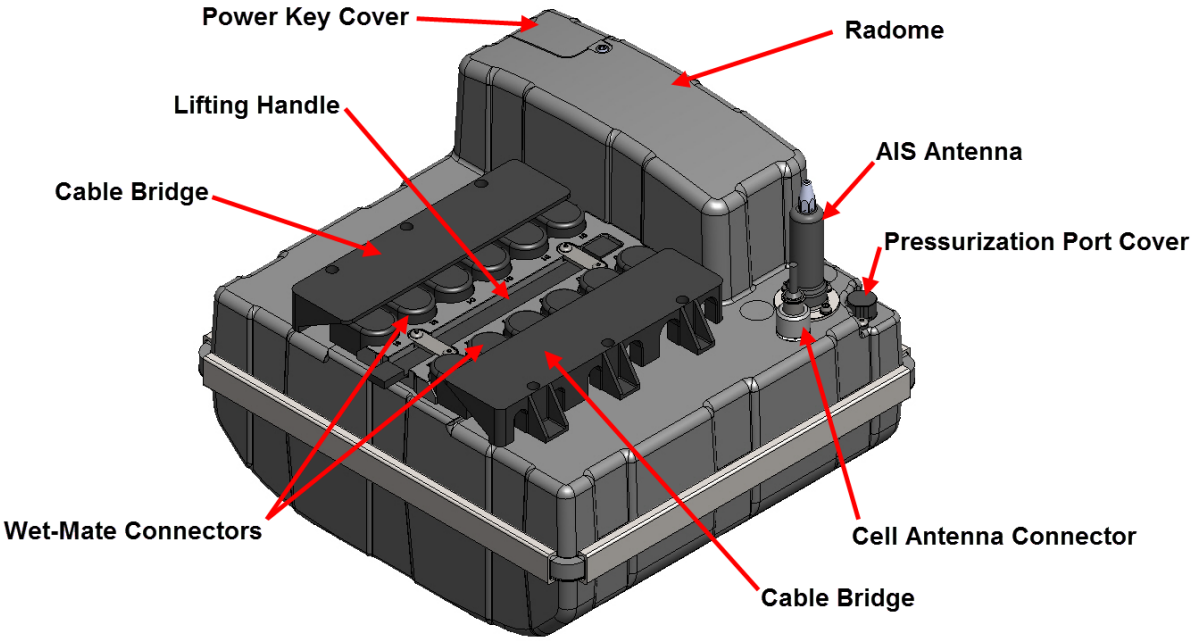

Figure 2: CCU, SV3

2.4.Transporting

When transporting lithium based products it is the operators' responsibility to comply with local, national and international regulations in force at the time of transport. Note that data sheets concerning quantities of lithium per cell are available from cell manufactures and these may change without prior notice, therefore the quantities of lithium per battery pack cannot be verified by Liquid Robotics Inc.

2.5.Disposal

Regulations and laws pertaining to the recycling and disposal of lithium ion batteries vary from country to country as well as by state and local governments. Refer to your local laws and regulations for safe disposal procedures.

3. DISSASEMBLY/INSPECTION, CLEANING & FURTHER INSPECTION

3.1.Overview

After each on-the-water mission (defined as more than three days) the Wave Glider must be cleaned, inspected, and subsequently made ready for redeployment. This document does not cover the scope of third party equipment capable of being installed on a Wave Glider. For sensor inspection, cleaning, and servicing, refer to the sensor manufacturers' documentation. Once cleaning and inspection is completed, LRI trained personnel should replace needed components, reassemble and perform pre-launch procedures for the next deployment.

Before disassembly, the vehicle first must be powered off (Figure 3)

Figure 3: SV3 Power Key (Turn retaining ring counter clockwise)

3.1.1. Required Resources

Table 2: Required Resources

Tools

- Pressure washer - 2500 PSI (17MPa) or less recommended
- Plastic paint scraper
- Protective Eyewear
- Flashlight
- Digital Camera
- Recording Media (notebook)
- 4mm T-handle hex key
- #2phillips screwdriver
- Flat head screwdriver
- 2x10mm wrench
- 8mm wrench
- Calipers
- 0.025" Pick / 0.06mm
- Connector Dummy Plugs (Table 3)

Consumables

- Non-scratch scour pad
- 3M Silicone Lubricant (3M Part #: 62467849303)
- 3M Novec Contact Cleaner or similar product (3M Part# 98021232933)
- Compressed dry air

Safety Equipment

- Latex/Nitrile gloves
- Safety glasses or face shield
- Apron or raingear

Table 3: Dummy Plug Part Numbers

Description	LRI Part Number
2-Pin Female	02693-2
5-Pin Female	02693-5
6-Pin Female	02693-6
8-Pin Female	02693-8
2-Pin Male	02694-2
5-Pin Male	02694-5
6-Pin Male	02694-6
8-Pin Male	02694-8
12-Pin Male	04846

3.1.2. Estimated Duration

- 6-8 hours per Wave Glider

3.1.3. General Handling of Equipment

Do not allow equipment or instruments to be dropped or exposed to shock damage that can cause sensitive internal components to fail.

Minor damage to metal finishes can create burrs that present a hazard to unprotected hands or skin. Solar Panels should never be used as a surface on which to rest equipment.

Water resistance integrity of instruments depends on fine surface finishes, accurate dimensional tolerances and cleanliness of components. The disassembly process should be carried out in a well-lit, well-ventilated, and low traffic area. Servicing must always be carried out by competent personnel with appropriate training.

3.1.4. Handling of Electrical Components

As with most circuit boards, Wave Glider electronics can be easily damaged by static discharge or excessive supply voltage. The best handling for electronics is NO HANDLING. Field service cannot compare to the efficiency and accuracy of the original factory calibration. Field service should be limited to checking for correct calibration and operation (within the limits of the test equipment available). Printed circuit boards or modules should be submitted via LRI's Customer Support with a Return Material Authorization (RMA) for exchange, rather than attempting repairs in the field.

3.1.5. Photo Documentations

Post recovery images and post maintenance images are required to complete the SV3 Maintenance Log and to comply with the terms and conditions of the LRI warranty. Refer to Table 4 for required images. The images must be clear and capture enough detail to assess the Wave Glider condition remotely; macro shots are best.

3.1.6. Post Recovery Document

Photo document the Wave Glider as soon as possible after recovery. Refer to Table 4 for a list of required images. This inspection is intended to record any biofouling, noticeable damage to the system, or other areas of concern. Section 1 of the SV3 Maintenance Log (Appendix B) shall be filled out during this inspection. Keep the photos (preferably digital for ease of transmission) and SV3 Maintenance Log with the rest of the Wave Glider documentation.

Table 4: Required Images

- Solar Panels from fore and aft
- Masts/and instruments attached to masts
- All sides of Float Hull
- Any sensors attached to the Float
- All sides of sub. Capture photos of all connectors, any areas of seams or crevices between materials, and moving hardware
- Any exposed electrical cabling
- Entire Umbilical including macros of termination and U-joint areas
- Wings
- Thrudder
- Sensors attached to the sub

3.1.7. Pressure Washer

Pressure washing is an acceptable method of cleaning a Wave Glider. Below are general guidelines to help prevent damage to paint, conductor cables, and mechanical systems.

- Do not use pressure washer greater than 2500 PSI / 17MPa
- Use a nozzle with a 45° spray pattern.
- Keep nozzle at least 12 inches / 30cm away and at a 45° angle to the part being washed.
- Avoid using the pressure washer on areas where paint has chipped.
- **The pressure washer should not be used on Wave Gliders that are painted with antifouling paint.**
- **Do not power wash any conductor cables, umbilical, solar panels without a glass covering, or any bearings. Doing so could result in damage and may require replacement of parts.**

3.1.8. Cleaning Hard Paint

Use a high volume high pressure washer (2500 PSI / 17MPa max with a 45° spray pattern) to clean the Wave Glider system as described in the overview. When using a pressure washer, make sure to use the 45° nozzle at a distance of 12 inches / 30cm away from the system. If barnacles are present, use a plastic scraper. Be careful not to damage the paint while scraping. The use of a non-scratch scour pad can be used to help clean the system further. See Figure 4 for examples of standard hard paint.

Figure 4: Standard Hard Paint, Yellow & Blue (SV2 shown for reference only)

3.1.9. Cleaning Antifouling Paint

A high volume **low** pressure (50 PSI / 350kPa or less at a distance of 6 inches / 15cm) wash should be used to clean any part of the system covered in antifouling paint. If barnacles are present, use a plastic scraper. Be careful not to damage the paint while scraping by only gently scraping the surface and not digging into the paint. If needed, a soft brush or sponge can be used to clean to further clean the system. See Figure 5 for an example of antifouling paint.

Figure 5: Standard Ant-Foul Black (SV2 shown for reference only)

3.2.Disassembly/Inspection

The electrical connector sockets/pins that are exposed damage easily and should be covered whenever possible. A dummy plug should be used to cover the female connection and a dummy plug or cap should be used to cover the male connection.

As the system is being disassembled, inspect each component looking for corrosion, cracks or signs of fatigue, bushing wear, physical damage, and umbilical and knuckle joint wear (Figure 7-Figure 23). Pay particular attention to all electrical connections to make sure there is no water incursion or patina on copper parts. List your observations and findings in the SV3 Maintenance Log (Appendix B). Take pictures of anything damaged/worn.

3.2.1. Disassembly/Inspection of the Float

Figure 6: Water Speed Sensor

Main system components should be removed and labeled (i.e. solar panels 1, 2, & 3, CCU, and any payloads), Figure 6. Closely inspect each component after removal. **Do not remove the water speed sensor, if present (located in the forward payload bay, Figure 6)**

1. Perform a visual/photo inspection. Make note of any areas of concern and document.
2. Disconnect the electrical leads for the umbilical from the float by removing the 12-pin connector and inspect both the male and female power leads.
3. Remove the umbilical from the Motion Isolator (for instructions, refer to the Wave Glider Unpacking and Assembly Guide).
4. Remove the solar panels and inspect the cable between the solar panel and connecters. Look for nicks or damage and report observations.
5. Remove the CCU.
6. Closely inspect all connectors. Look for water incursion/patina on copper. (Figure 8 & Figure 9)
   a. Check the pressure of the CCU either by using a pressure gauge or in WGMS. Pressure should be 115-120 kpa @ 21°C
   b. If a leak is present, pressurize to 120 kpa and look for leaks. Check after 24 hrs to make sure the CCU held pressure. If it did not hold pressure, pressurize to 135 kpa and submerge under water to look for bubbles. Once leak is found, replace leaking component.
   c. Once component has been replaced, pressurize to 120 kpa and check for leaks again.
7. Remove and inspect any payloads installed – look for nicks or damage on the cables and connectors.
   a. Check the pressures of all pressurized payloads. Pressure should be 115-120 kpa @ 21°C.
   b. If a leak is present, pressurize to 120 kpa and look for leaks. Check after 24 hrs to make sure the payload held pressure. If it did not hold pressure, pressurize to 135 kpa and submerge under water to look for bubbles. Once leak is found, replace leaking component.
   c. Once component has been replaced, pressurize to 120 kpa and check for leaks again.
8. Remove and closely inspect the skeg for damage; look for cracking near the base
9. Release the recovery Buoy and inspect attachment points, all line, and titanium ring for damage, wear, or fatigue.
10. Remove and closely inspect all masts/antennas. Look for crakes in the mast and any damage to the sensors. Inspect all cables looking for nicks or damage.

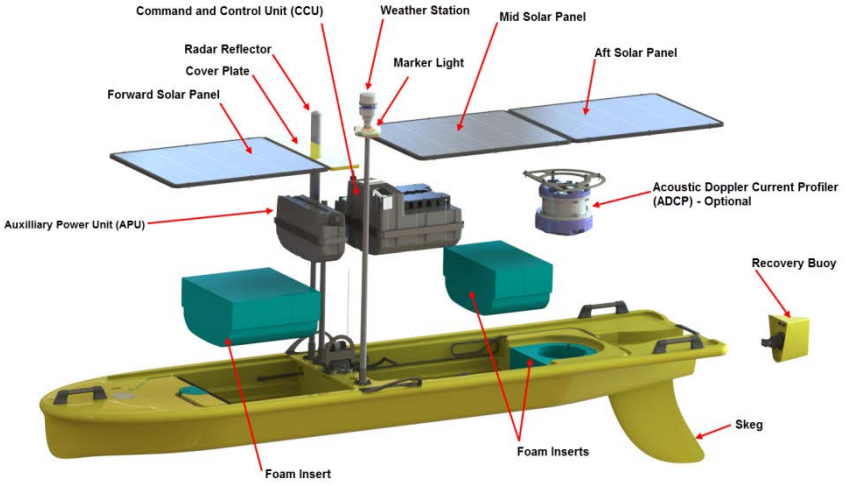

Figure 7: Float, Exploded View, SV3

Figure 8: Non-Corroded Connector

Figure 9: Corroded/Damaged Connector

3.2.2. Disassembly/Inspection of the Sub

1. Visually inspect the Umbilical. Look for nicks or damage.
2. Inspect all umbilical hardware, pins and bushings
3. Closely inspect all 8 bushing. Rotate and move U-Joints/dog ears to feel for excessive wear (Figure 11-Figure 14)
4. Remove the thrudder fairings. Inspect the electrical connections to make sure there is no water incursion, patina on copper parts, or corrosion on the connector
5. Slide wing shafts to one side to allow for pictures and measurements of wear. Note: Do not push sprung shaft (trailing shaft) all the way through sub frame.
6. Using calipers, measure the wear on the sprung shaft.
7. Tolerance: 9.964mm – 10.000mm (0.392” – 0.394”).
8. If the wear on the wing shaft is >0.500mm (>0.020”) (shaft diameter <9.464mm) the shaft should be replaced and the wing stops should be checked (Figure 15 - Figure 17).

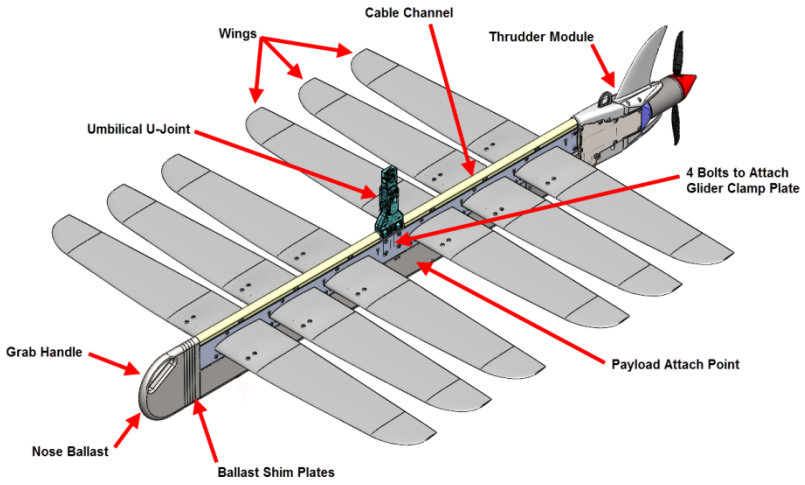

Figure 10: Sub, SV3

Figure 11: Upper U-Joint Bushings

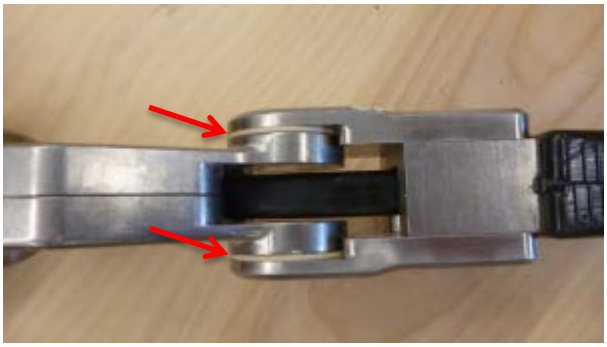

Figure 12: Upper Dog Ear Bushings

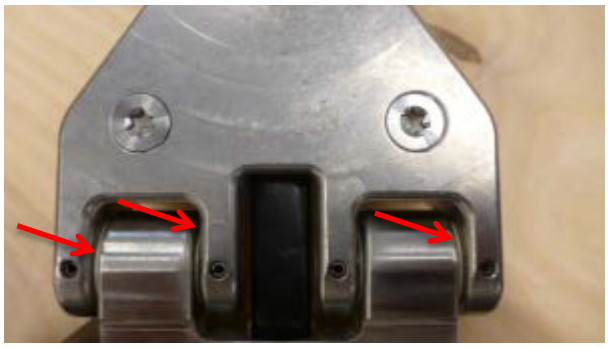

Figure 13: Lower U-Joint Bushings

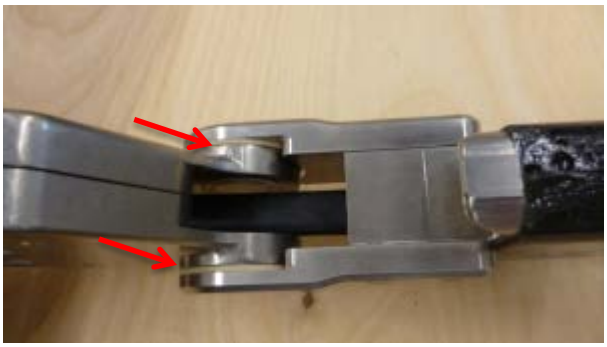

Figure 14: Lower Dog Ear Bushings

Figure 15: Acceptable Wear on Shaft

Figure 16: Damaged/Worn Shaft (Wear >0.5mm)

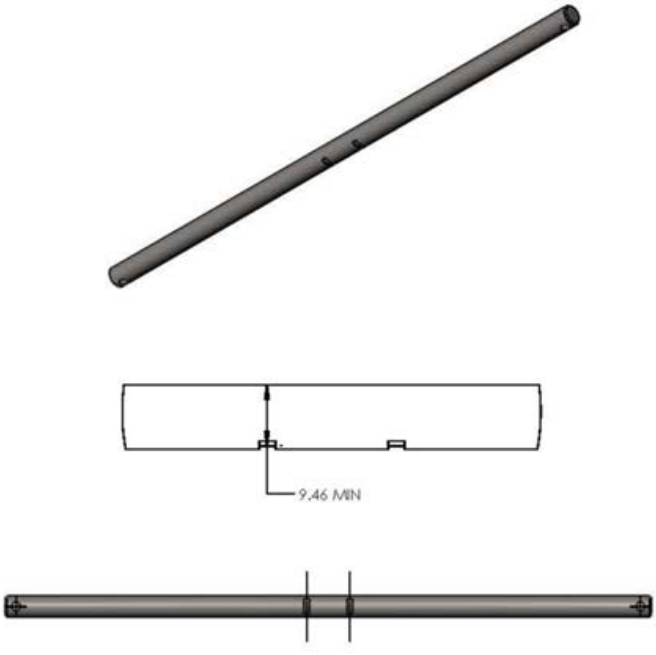

Figure 17: Wing Rod Step Tolerance Detail (dimensions in mm)

3.3. Cleaning the Wave Glider

Cleaning should be performed in an area that is well-ventilated and where debris can be captured and properly disposed. Cleaning of the Wave Glider should be performed after it has been disassembled. Refer to your local laws for disposal of waste water and biological organisms (biofouling).

3.3.1. Float Cleaning Procedure

1. Gently use a plastic scraper to remove any barnacles or solid biofouling.
2. Use a pressure washer to wash the Float (refer to Section 3. 1.7 - 3.1.9). Make sure to clean the payload bays well. Note: spray back will occur when water is sprayed on inside edges.
3. Use a non-scratch scour pad to assist in removing any biofouling that has not been removed on the float and solar panels.

3.3.2. Sub, Wings, Umbilical & Thrudder Cleaning Procedure

1. Use a plastic scraper to remove any barnacles or solid biofouling
2. Pressure wash the top of the Sub (refer to Section 3.1.7 - 3.1.9).
3. Use a non-scratch scour pad to assist in removing any biofouling.
4. Lay wings out and repeat steps 1-3.
5. Lay the umbilical flat, wet with high volume low pressure wash (50 PSI / 350 kPa or less).

6. Use non-scratch scour pad to assist in removing and biofouling from the Umbilical. If needed, a plastic scraper can be used on the U-Joints to remove biofouling.

Be very careful when scrapping around any of the umbilical cables. They can be damaged easily, which may result in replacement of the entire umbilical.

7. Using fresh water (50 PSI / 350 kPa or less), spray water into the cleaning hole of the thrudder. Make sure to thoroughly rinse (Figure 18).

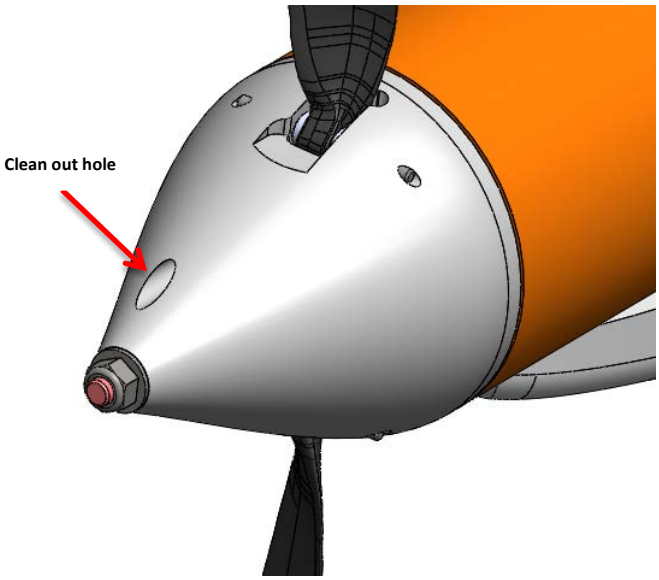

Figure 18: Thrudder Clean Out

3.3.3. Cleaning CCU and Payloads

1. Install a dummy plug or cover over the connectors to protect it from damage
2. Use a plastic scraper to remove any barnacles or solid biofouling.
3. Use a non-scratch scour pad to clean soft biofouling.
4. Use a high volume low pressure (50 PSI / 350 kPa or less) wash to clean dryboxes.
5. Let parts air dry or gently apply compressed air (50 PSI / 350 kPa or less) to remove moisture.

3.3.4. Cleaning the Electrical Connections

Depending on the amount of debris on the connectors, a fresh water rinse may be necessary before proceeding.

1. Using electrical contact cleaner, spray both male and female connectors.

Make sure there is no Acetone in the contact cleaner as this will damage or destroy the connector

2. Dry with compressed dry air (50 PSI /350 kPa or less at a distance of 6 inches / 15cm).
3. If debris is still present, repeat steps 1 & 2.

4. Once completely clean, spray 3M Silicone Lubricant on connectors and plug connector in, or use a dummy plug to keep free of debris.

3.3.5. Cleaning Integrated Sensors

Consult sensor documentation or contact the sensor manufacturer for specific cleaning procedures.

4. FURTHER INSPECTION & RETURN MERCHANDISE AUTHORIZATION (RMA)

Once all components are fully clean, perform a final inspection on all parts and assemblies. Inspect each component looking for corrosion, cracks or fatigue, bushing wear, physical damage, and umbilical and knuckle joint wear. Pay particular attention to all electrical connections to make sure there is no water incursion or patina on copper parts. List your observations and findings in the SV3 Maintenance Report.

If there are any damaged or broken components found during the maintenance of a Wave Glider please contact LRI's Customer Support to receive a RMA (see Section 7). The Customer Service department will give proper labeling and shipping instructions to ensure the parts are properly routed and returned in a timely fashion.

5. MAINTENANCE PROCEDURE

5.1. Repainting

For frequency of painting refer to Appendix A. Painting of the Wave Glider must be done in accordance with all local laws and regulations.

Due to ever increasing health and environmental regulations, LRI recommends having the Wave Glider painted by a professionally licensed paint shop/boat yard.

1. Refer to the paint manufactures' documentation for proper painting instruction
    a. Antifoul Black Paint – Pettit Trinidad Pro Black Antifouling #1088
    b. Hard Yellow Paint – Cardinal Industrial Finishes 6409-YLO1
    c. Hard Blue Paint – Cardinal Industrial Finishes 6402-15050
    d. Hard Black Paint – Cardinal Industrial Finishes 6409-08
2. Note in Maintenance Log that the system was repainted

5.2. Checking Battery Health

1. Plug in CCU charger or set vehicle out in the sun to charge
2. Send a "Retrieve Power Status" command to the vehicle using WGMS
3. Check "Power Control Statuses" in WGMS
4. Repeat steps 2-3 until the power levels are no longer increasing (depending on available sunlight, wall charger, and existing power levels, this may take >8hrs)
5. Check "Battery Power Remaining" for all 10 batteries
6. Send CCU box back to LRI for refurbishment if batteries capacity is ≤ 80%
   Full battery level = 89 Wh
   80% Capacity = 71 Wh
5. Note battery health in Maintenance Log.

6. REASSASEMBLY

Refer to the SV3 Disassemble and Pack Procedure (LRI P/N: 06033)

7. CONTACT

Liquid Robotics, Inc.
1329 Moffett Park Drive
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support@liquidr.com

Appendix-A SV3 Maintenance Schedule

Wave Glider SV3 Preventative Maintenance Schedule									
				Service Interval					
				In Water (Months)					Other
Services	**Short Description**	**FRU #**	**Service #**	**3**	**6**	**9**	**12**	**24**	
Base Vehicle									
Re-apply Top Coat (If AF Black)*	Clean fouling off of float				●				
Repaint*	Repaint						●		
Replace Umbilical & Spring Bar	Replace Umbilical and Spring Bar with FRU				●				
Replace Batteries in CCU	Send the CCU back to have the batteries replaced								**80% Battery Capacity****

*See Section 5.1 for procedure on painting

**See Section 5.2 for procedure on checking battery capacity

Appendix-B SV3 Maintenance Log

1. Post Recovery Inspection	Yes	No	Comments/Observations
Inspection of float			
Look for corrosion, cracks or fatigue, bushing wear, physical damage, and umbilical and knuckle joint wear			
Inspect Hull			
Damage	☐	☐	
Biofouling	☐	☐	
Inspect Solar Panels			
Damage	☐	☐	
Biofouling	☐	☐	
Inspect Masts/Weather station			
Damage	☐	☐	
Inspect Sensors			
Damage	☐	☐	
Biofouling	☐	☐	
Inspection of sub/glider			
Look for corrosion, cracks or fatigue, bushing wear, physical damage, and umbilical and knuckle joint wear			
Inspect Frame			
Damage	☐	☐	
Biofouling	☐	☐	
Inspect Thrudder			
Damage	☐	☐	
Corrosion	☐	☐	
Inspect Umbilical			
Damage	☐	☐	

Post Recovery Inspection (Cont.)	Yes	No	Comments/Observation
Photo Documentation			
Take Photos per Section 3.1.6	☐	☐	

Technician Signature:_____

Date: _____

2. Cleaning & Inspection

	Yes	No	Comments/Observations
Inspection of float			
Look for corrosion, cracks or fatigue, bushing wear, physical damage, and umbilical and knuckle joint wear			
Inspect Hull			
Damage	☐	☐	
Biofouling	☐	☐	
Inspect Solar Panels			
Damage	☐	☐	
Biofouling	☐	☐	
Inspect Masts/Weather station			
Damage	☐	☐	
Inspect Sensors			
Damage	☐	☐	
Biofouling	☐	☐	
Inspection of sub/glider			
Look for corrosion, cracks or fatigue, bushing wear, physical damage, and umbilical and knuckle joint wear			
Inspect Frame			
Damage	☐	☐	
Biofouling	☐	☐	
Inspect Thrudder			
Damage	☐	☐	
Corrosion	☐	☐	
Inspect Umbilical			
Damage	☐	☐	

Post Recovery Inspection (Cont.)	Yes	No	Comments/Observation
Photo Documentation			
Take Photos	☐	☐	

Technician Signature:_____

Date: _____

3. Maintenance	Yes	No	Comments/Observations

Check Battery Health

Batteries are in spec ☐ ☐

Battery Levels at full charge

Battery 1: Battery 2: Battery 3: Battery 4:

Battery 5: Battery 6: Battery 7: Battery 8:

Battery 9: Battery 10:

System Repaint

System repainted due to damage ☐ ☐

System repainted due to anti-foul req. ☐ ☐

System repainted due to payload integration ☐ ☐

Technician Signature:_____

Date: _____