AUTONAUT
WAVE PROPELLED
UNMANNED SURFACE VESSEL (USV)

TECHNICAL MANUAL

Customer: NTNU, Trondheim,

AutoNaut Ltd, Unit A2 The Boatyard, Chichester Marina, Chichester, PO20 7EJ

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1 INTRODUCTION

AutoNaut® is a wave-propelled Unmanned Surface Vessel (USV) manufactured by AutoNaut Ltd. Each AutoNaut is built and configured for its customer. This Technical Manual relates specifically to AutoNaut AN/5.5 supplied to NTNU, Trondheim.

AutoNaut is 5 metres overall length, is propelled predominantly by wave energy and so moves slowly (1-3 knots). It has a steering system that can be integrated into a command and control system. An Auxiliary Thruster is fitted, designed to provide propulsion in calm conditions, to ‘get out of trouble’, and to manoeuvre away from a slipway.

The vessel, when fitted with a suitable command and control system is autonomous (i.e. with no operator on board) there remains an important principle in the operation of an Unmanned Maritime System (UMS) that there is still a person controlling the vessel from the shore. Advice on operating the vessel autonomously is provided in this manual for future reference.

The purpose of this Manual is to provide the user with sufficient detail to build and operate AutoNaut safely. A companion Maintenance Manual is also provided. Being a new technology, AutoNaut Ltd wishes to maintain a close, two-way liaison with NTNU to learn from any experience and issues, and details for feedback are also included.

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1 OVERVIEW

2.1 Summary

AutoNaut® is wave propelled and performs almost equally well on all headings including directly into wind and waves. She has zero emissions, and can roam the oceans for very long periods, transmitting data via satellite to shore when a suitable command and control system has been integrated. This extreme endurance is coupled with a unique and elegant solution to the speed / payload / power balance for unmanned surface vessels (USVs).

Hull motions in waves are converted directly and silently into propulsive thrust. This gives speeds of up to 3 knots for a 5m vessel. AutoNaut patented wave propulsion technology is completely scalable, so larger boats with more capacity and power can be tailored to customer requirements – as can smaller boats.

There are few moving parts and the control and mission systems operate with minimal electrical power. Batteries store electrical energy which is generated from an array of PV solar panels fitted across the deck of the vessel.

AutoNaut can be deployed and recovered either from a support boat or a slipway.

2.2 Hull Platform

The hull is robustly constructed from composites and is intended to withstand operations at sea for many months without any physical human intervention. It incorporates watertight sub-divisions and in-built buoyancy. When designing new AutoNauts the number and use of compartments may be varied to meet customer requirements. Compartments can be independently opened and sealed with a watertight hatch to gain access to the internal equipment and mission system. The hull is fitted with a metal hoop at the bow and at the stern which has undergone functional element analysis and is rated for lifting and towing.

2.3 AutoNaut Wave Foil Propulsion - Motion from the Ocean

The hull is shaped and ballasted to harvest as much energy as possible from the pitching and rolling motion in waves. Two hydrofoils are mounted horizontally below the keel at both ends of the hull. The foils are located on struts bolted to the hull. The foils and struts may be detached from the hull for transport. The foils and their springs are carefully balanced to deliver the propulsion thrust and no adjustments are necessary.

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2.4 Batteries

- Type*:* The 5 m AutoNaut is fitted with four 12 volt 70Ah batteries. She may be fitted with other batteries and converters for payload and steering needs.
- Size: The main batteries are a simple valve-regulated lead-gel model because weight is useful for ballasting the hull. If battery replacement is required for any reason consult AutoNaut Ltd for advice. In normal use, this type of battery can be considered sealed. However, the battery compartment is vented via Gore waterproof vents in the deck which will allow the escape of hydrogen as a product of charging, as well as by the bilge pump which is self-priming and pumps air/gas out of the compartment when run dry. The batteries are fitted near to the centre of the vessel. On completion of a mission, the battery compartment hatch should be removed to allow hydrogen gas to vent before switching any onboard systems.

2.5 Auxiliary Power Pod

This AutoNaut is provided with a small electrically powered propulsion pod for auxiliary propulsion. This will propel the vessel at up to 1 knot.

Operational Control

The AN/5.5 supplied does not have a command and control system, however the intention is that one will be developed by the customer for the vessel to operate autonomously. There remains an important principle that there is still a human controlling and monitoring the vessel from the shore at all times. A complete operational system should be in place for autonomous missions which includes the vessel (platform and mission system) and shore side equipment and personnel.

2.6 Sensors

With AutoNaut's operating potential come new ways to deploy a wide range of sensors. The vessel is equipped with the following customer specified sensors:

2.6.1 *MAST*

- Airmar weather station.
- Cameras - to be ordered

2.6.2 *HULL*

- Seabird EcoTriplet
- Seabird 49 FastCAT CTD
- Aanderaa Oxygen Optode 4835
- Nortek Signature 500 ADCP

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Figure 1 Airmar weather station

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ECO Triplet
Scattering Fluorescence Sensor

The Triplet is a special-order, three optical-sensor instrument available in a user-defined configuration. The Triplet addresses the need for multiple simoultaneous scattering and fluoresence snsors for autonomous and unattended measurement platforms.

Features

- Addresses the need for multiple simultaneous scattering and fluorescence sensors for autonomous and unattended measurement platforms
- Performs a free space measurement and requires no pump. It accommodates a variety of deployment options
- Provides excellent precision, reliability, and overall performance at a fraction of the cost and size of similar instruments
- Ships with WET Labs' ECOView host software for communication and configuration
- Provides multiple measurements in a compact design, making the ECO Triplet unique among *in-situ* fluorometers

Options

Configuration options:

- Three scattering
- Two scattering, one fluorescence
- Three fluorescence
- One scattering, two fluorescence

Measurement options:

- Blue scattering
- Green scattering
- Red scattering
- Chlorophyll fluorescence
- CDOM fluorescence
- Phycocyanin fluorescence
- Phycoerythrin fluorescence
- Rhodamine fluorescence

ECO Triplet

- ECO Triplet—Capable of data logging and periodic sampling.
- ECO Triplet B—Provides the capabilities of the Triplet with internal batteries for autonomous operation.

Optical

Scattering wavelengths Sensitivity, all Range, typical	470, 532, 650, or 700 nm 0.003 m^{-1} 0–5 m^{-1}
Chlorophyll EX/EM Sensitivity Range, typical	470/695 nm 0.025 µg/l 0–50 µg/l
CDOM EX/EM Sensitivity Range, typical	370/460 nm 0.28 ppb 0–375 ppb
Uranine EX/EM Sensitivity Range, typical	470/530 nm 0.15 ppb 0-300 ppb
Rhodamine EX/EM	518/595 nm
Phycocyanin EX/EM	630/680 nm
Phycoerythrin EX/EM Sensitivity Range Linearity (all)	518/595 nm 0.09 ppb 0–175 ppb 99% R2

Electrical

Digital output resolution	12 bit
Internal data logging	Yes
Internal batteries	Optional
Connector	MCBH6M
Input	7–15 VDC
Current, typical	60 mA
Current, sleep	140 µA
Data memory	77,000 samples
Sample rate	User selectable to 4 Hz
RS-232 output	19200 baud

Mechanical

Diameter	6.3 cm
Length	12.7 cm (std)
Weight in air	0.4 kg
Weight in water*	0.02 kg
Materials	Acetal co-polymer

Environmental

Pressure/temperature sensor	Optional
Temperature Range	0 - 30 °C
Depth Rating	600 m

*Backscattering specifications are given in beam c_p (m^{-1}) based on the regression of the response of the instrument relative to the beam c_p measured at the coincident wavelength using an ac-s spectrophotometer. Scale factors for backscattering incorporate the target weighting function and the solid angle subtended.

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Figure 2 Seabird EcoTriplet Datasheet

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SBE 49
FastCAT CTD Sensor

The SBE 49 FastCAT is an integrated CTD sensor intended for use as a modular component in towed vehicles, ROVs, AUVs, or other autonomous platforms that can supply DC power and acquire serial data. It is an easy-to-use, light, and compact instrument, well suited to even the smallest vehicle. FastCAT must be externally powered, and its RS-232C data logged or telemetered by the vehicle to which it is mounted. FastCAT does not support auxiliary sensors; if such sensors are required, the user's vehicle must be equipped to acquire their signals independently.

FastCAT's pump-controlled / TC-ducted flow feature minimizes salinity spiking, and its 16 Hz sampling provides very high spatial resolution of oceanographic structures and gradients. Measured data and derived variables (salinity and sound velocity) are output in real-time in engineering units or raw HEX.

Features

- Conductivity, Temperature, and Pressure at 16 Hz (16 samples/second) or polled sample acquisition.
- Integral pump.
- RS-232 interface, no memory or batteries — intended for use on vehicles that can supply power and acquire data.
- Unique flow path, pumping regimen, and (optional) expendable anti-foulant devices, for maximum bio-fouling protection
- Pump-controlled, T-C ducted flow to minimize salinity spiking.
- Programmable real-time processing (aligning, filtering, and correcting for conductivity cell thermal mass effects) provides high-quality data for applications where post-processing is not feasible.
- Depths to 350, 7000, or 10,500 m.
- Seasoft© V2 Windows software package (setup, real-time data acquisition, and data processing).
- Five-year limited warranty.

Components

- Unique internal-field conductivity cell permits use of T-C Duct, minimizing salinity spiking.
- Aged and pressure-protected thermistor has a long history of exceptional accuracy and stability.
- Pressure sensor with temperature compensation is available in nine strain-gauge ranges (to 10,500 m).
- Pump runs continuously for 16 Hz sampling, providing correlation of CTD measurements.

www.seabird.com sales@seabird.com +1 425-643-9866

SBE Sea-Bird Electronics

SBE 49 FastCAT

Options

- Plastic (350 m) or titanium (7000 or 10,500 m) housing.
- XSG/AG or wet-pluggable MCBH connectors.
- Expendable anti-foulant devices.
- SBE 36 CTD Deck Unit & PDIM or SBE 33 Deck Unit & Sea-Bird water sampler (real-time operation on single-core armored cable to 10,000 m).

Measurement Range

Conductivity	0 to 9 S/m
Temperature	-5 to 35 °C
Pressure	0 to 20 / 100 / 350 / 600 / 1000 / 2000 / 3500 / 7000 / 10,500 m

Initial Accuracy

Conductivity	± 0.0003 S/m
Temperature	± 0.002 °C
Pressure	± 0.1% of full scale range

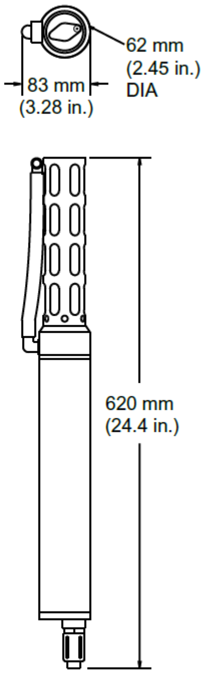
Typical Stability

Conductivity	0.0003 S/m per month
Temperature	0.0002 °C per month
Pressure	± 0.05% of full scale range per year

Resolution

Conductivity	0.00005 S/m (most oceanic waters; 0.4 ppm in salinity)
Temperature	0.0001 °C
Pressure	0.002% of full scale range

Sampling Speed	16 Hz (16 samples/sec)
External Power Requirements	Input power: 0.75 Amps at 9-24 VDC Turn-on transient: 750 mA Sampling and transmitting (includes pump): 350 mA at 9 V; 285 mA at 12 V; 180 mA at 19 V
Housing, Depth Rating, & Weight	Plastic, 350 m, in air 1.8 kg, in water 0.5 kg Titanium, 7000 or 10,500 m, in air 2.7 kg, in water 1.4 kg



FastCAT on Hydroid

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Figure 3 Seabird 49 FastCAT CTD datasheet

AANDERAA
a xylem brand

Oxygen Optode 4835

is a compact fully integrated sensor for measuring the O_2-concentration in shallow water.

Advantages:

- Optical measurement principle
- Lifetime-based luminescence quenching principle
- Long time stability
- More than one year without recalibration
- Low maintenance needs
- User friendly
- Use with Aanderaa SmartGuard/SeaGuard
- Automatically detected and recognized
- Use as stand-alone sensor
- Output format: CANbus AiCaP, RS232
- Operating range: 0-300 meters

Since oxygen is involved in most of the biological and chemical processes in aquatic environments, it is one of the most important parameters needed to be measured. Oxygen can also be used as a tracer in oceanographic studies.

For environmental reasons it is critical to monitor oxygen in areas where the supply of oxygen is limited compared to demand, e.g.

- In shallow coastal areas with significant algae blooms
- In fjords or other areas with limited exchange of water
- Around fish farms
- Areas of interest for dumping of mine or dredging waste

The Aanderaa oxygen optodes are based on the ability of selected substances to act as dynamic fluorescence quenchers. The fluorescent indicator is a special platinum porphyrin complex embedded in a gas permeable foil that is exposed to the surrounding water. A black optical isolation coating protects the complex from sunlight and fluorescent particles in the water. This sensing foil is attached to a sapphire window providing optical access for the measuring system from inside a watertight housing.

The lifetime-based luminescence quenching principle offers the following advantages over electro-chemical sensors:

- Not stirring sensitive (it consumes no oxygen)
- Less affected by fouling
- Measures absolute oxygen concentrations without repeated calibrations
- Better long-term stability
- Less affected by pressure
- Pressure behaviour is predictable
- Faster response time

The oxygen optode outputs data in AiCaP CANbus and RS-232. The sensor can present the O_2 concentration in µM, the Air Saturation in % and the Temperature in °C.

The SmartGuard and SeaGuard data logger and the smart sensor are interfaced by means of a reliable CANbus interface (AiCaP), using XML for plug and play capabilities.

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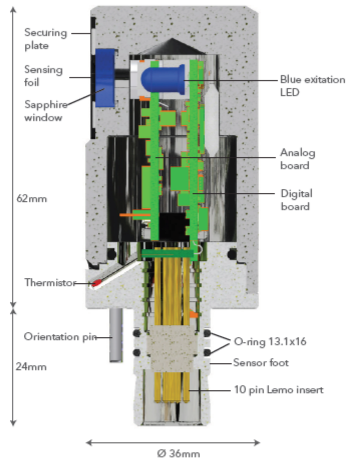
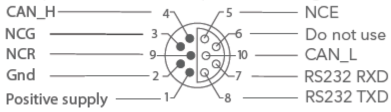


PIN CONFIGURATION

Receptacle, exterior view; pin = • bushing = ∘



Operating Principle

The sensing foil is excited by modulated blue light; the sensor measures the phase of the returned red light. For improved stability the optode also performes a reference phase reading by use of a red LED that do not produce fluorescence in the foil. The sensor has an incorporated temperature thermistor which enables linearization and temperature compensation of the phasemeasurements to provide the absolute O_2-concentration.

Cable from sensor to:	Cable
PC with waterproof SP, RS-232	4865
Seaguard as sixth sensor on top-end plate	4999
Seaguard with waterproof top end plate connection	4793
SmartGuard single sensor with SP	5236
User furnished data logger, CSP to free end	4762

Oxygen:	O_2-Concentration Air Saturation
Measurement Range:	0 - 500 µM[1] 0 - 150%
Resolution:	< 1 µM 0.4 %
Accuracy:	<8 µM or 5%[2] <5 %[3] whichever is greater
Response Time (63%):	<25 sec
Temperature:	
Range:	-5 to +40°C (23 - 104°F)
Resolution:	0.01°C (0.018°F)
Accuracy:	±0.1°C (0.18°F)[4]
Response Time (63%):	<10 sec
Output format:	AiCaP CANbus, RS-232
Output parameters:	O_2-Concentration in µM, Air Saturation in %, Temperature in °C, Oxygen raw data and Temperature raw data
Sampling interval:	2 sec – 255 min
Supply voltage:	5 to 14Vdc
Current drain:	
Average:	0.16 +48mA/S where S is sampling interval in seconds
Maximum:	100mA
Quiescent:	0.16mA
Operating depth:	0 – 300m (0 – 984.3ft)
Elec. connection:	10-pin receptacle mating plug SP
Dimensions (WxDxH):	Ø36 x 86mm (Ø1.4"x 3.4")
Weight:	118g (4.16oz)
Materials:	Titanium, Hostaform (POM)
Accessories:	Foil Service Kit 4733/4794 PSt
(not included):	AiCap extension cable with SP 4793
	SP to free end cable 4762
	SP to PC cable 4865
	Set-up and config Cable 3855[5]/3855A[5]

(1) O_2 concentration in µM = µmol/l. To obtain mg/l, divide by 31.25
(2) requires salinity compensation for salinity variation > 1mS/cm, and pressure compensation for pressure > 100 meter
(3) within calibrated range 0 - 120% / 0 - 30°C
(4) within calibrated range 0 - 36°C
(5) only for laboratory use

Specifications subject to change without prior notice.

SP. Sealing Plug

Foil Service Kit 4733/4794. PSt

xylem
Let's Solve Water

Visit our Web site for the latest version of this document and more information
www.aanderaa.no

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Figure 4 Aanderaa Oxygen Optode 4835 datasheet

Technical Specifications

Water Velocity Measurements		
	Signature1000	**Signature500**
Profiling Range*	30m	70m
Cell Size	0.2 - 2m	0.5 - 4m
Min. Blanking	0.1m	0.5m
Max # cells	128(burst)/200(average)	128(burst)/200(average)
Velocity Range (along beam)	User Selectable 1.0, 1.25, 2.5, 3.75, 5.0, 20 m/s	User Selectable 1.0, 1.25, 2.5, 3.75, 5.0, 20 m/s
Minimum accuracy: (Inquire for more accurate firmware or hardware versions)	0.3% of measured value +- 0.3cm/s	0.3% of measured value +- 0.3cm/s
Velocity Resolution	0.1 cm/s	0.1 cm/s
Max Sampling Rate	16Hz	8Hz
Max Sampling Rate Five beams	8Hz	4Hz

*) maximum range depends on transmit power and acoustic scattering conditions

Echo Intensity	
Sampling:	Same as velocity
Resolution:	0.5dB
Dynamic range:	70dB
No. of beams:	5, 4 slanted at 25°, 1 vertical
Beam width:	2.9°
Sensors	
Temperature:	Thermistor embedded in head
Range:	–4°C to 40°C
Accuracy/Resolution:	0.1°C/0.01°C
Time response:	2 min
Compass:	Solid State Magnetometer
Accuracy/Resolution:	2° for tilt <20°/0.01°
Tilt:	Solid State Accelerometer
Accuracy/Resolution:	0.2° for tilt <30°/0.01°
Maximum tilt:	Full 3D
Up or down:	Automatic detect
Pressure:	Piezoresistive
Standard Range:	0–100m (inquire for options)
Accuracy/Precision:	0.1% FS / Better than 0.002% of full scale
Data Communication	
I/O:	Ethernet or configurable RS-232/RS422
Serial Communication Baud rate:	300–1250000 baud
Recorder download baud rate:	20 Mbit/s (Ethernet only) - 1 GByte in 6 minutes
Controller Interface:	ASCII command interface with telemetry options over Telnet and serial interface. Complete data download over standard Ethernet FTP. Telemetry file downloadable over serial interface. See interface manual for more information.
Data Recording	
Capacity (standard):	16 GB / Optional 64 GB
Data record:	86 bytes + 4 x Nbeams x Ncells
Mode:	Stop when full
Real Time Clock	
Accuracy:	±1 min/year
Clock retention in absence of external power:	1 year

Backup battery recharges automatically when the instrument is powered

Software	
Operating system:	Windows® 7 or later
Functions:	Deployment planning, start with alarm, data retrieval, conversion to ASCII and Matlab format.
Online data:	Collection and graphical display.
Power	
DC input:	12–48VDC
Max. average consumption at 1Hz:	8 Watts. Peak currents 1.5A at 12V, 1A at 24V. Ethernet adds 0.75 W
Typical average consumption:	See deployment software

Sleep Consumption:	100uA, power depends on supply voltage
Transmit power:	0.3–30W per beam, adjustable levels
Ping sequence:	Parallel
Materials	
Connectors:	MCBH6F-G2-WB with water block MCBH2F-G2-WB with water block
Standard model:	Delrin® with titanium bolts.
Environmental	
Operating temperature:	–4°C to 40°C
Storage temperature:	–20°C to 60°C
Shock and vibration:	IEC 60068-1/IEC60068-2-64
Depth rating:	300 m
Batteries	
Internal:	1MHz:100Wh, 500kHz:180Wh
External:	Single or double alkaline 540Wh or lithium 1800 Wh
Duration	See deployment software

The battery consumption is a complex function of the instrument configuration. Please consult the Signature deployment software for more information

Dimensions		
	See drawings	
	Signature1000	**Signature500**
Weight in air:	2.92Kg	8.20Kg
Weight in water:	0.62Kg	1.45Kg

Wave Measurement option	
Maximum Depth:	30 /70m
Height Range:	-15 to +15m
Accuracy/Resolution (Hs):	<1% of measured value / 2cm
Accuracy/Resolution (Dir):	2° / 0.1°
Period Range:	2-50s
Cut-Off Period(Hs):	25m depth; 1 sec 50m depth; 2 sec
Cut-off Period (dir):	Please inquire
Sampling Rate (Velocity and AST):	4Hz
Max altitude	1MHz: 30m, 500kHz: 100m
Min Altitude	1MHz: 1m, 500kHz: 2m
Precision	2 cm

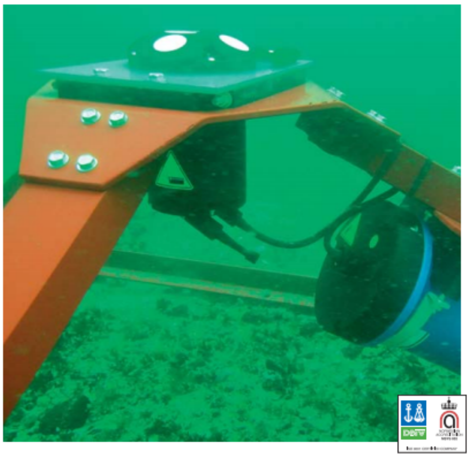

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Figure 5 Nortek Signature 500 ADCP datasheet

2.7 Design Specification - 5m AutoNaut

Vessel Specification	
Hull Type	Monohull
Length	5 m
Beam	0.8 m
Draft	0.7 m
Displacement	230 kg
Average Speed	Up to 2 knots
Endurance	3+ Months; dependent on hull fouling.
Observability	Silent, Active Radar transponder, overt colour.
Transportation	Two-person portable, air freight compatible. Maximum freight length <2.5m
Materials	
Hull Material	Fibre Glass Monolithic Laminate.
Internal Structure	Structural PVC Foam / Fibre Glass Sandwich.
Mast	Woven Carbon Fibre. 1.5 m above DWL.
Operations	
Launch / Recovery	Slipway Launch. Boat crane / davit launch and recovery.
Navigation	
GPS	Marine GPS.
Powering	
Primary Propulsion	Wave Foil Technology. Direct wave propulsion (Pitch and Roll). Zero emission, zero noise.
Auxiliary Propulsion	Electric Propulsion Pod for calm sea states. (Up to 1 knot).
Battery	4 x 70Ah 12V Lead Gel Batteries.
Solar Charging	300 Watt peak Photovoltaic Solar Panels.
Payloads	
Volume	500 Litres.
Max Payload Weight	130 kg
Base Sensor Fit	Airmar Weather Station
Safety	
Emergency Location	2nm all-round white LED navigational Light. Active Radar transponder.
Marine	No danger to marine life or environment. Silent. Zero emissions. Macglide silicon based non-

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Environment	toxic antifoul on hull. Coppercoat antifoul on struts and foils.

2.8 Internal Layout

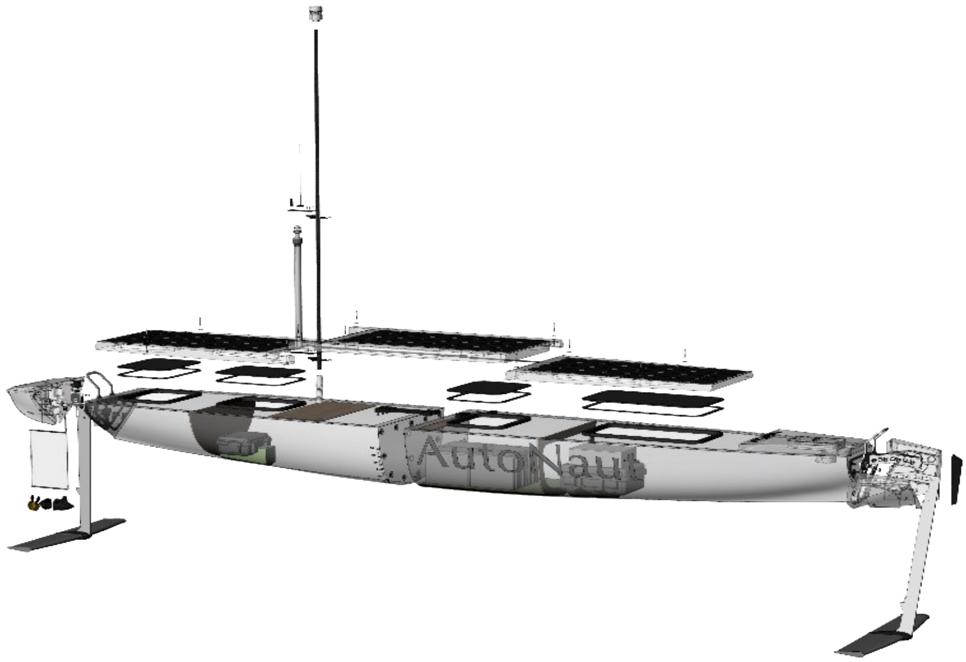
Figure 6 Exploded Hull

The Bareboat version of the AutoNaut has the following components within the forward hull

- Batteries x 4
- Bilge pump
- Floor mounting plates
- GPS mounting plate

The Bareboat version of the AutoNaut has the following components within the Aft hull, (main section)

- Bilge pump
- Sensor Mounts
- Floor mounting plates

The Bareboat version of the AutoNaut has the following components within the Aft hull, (Stern section)

- Bilge pump

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- Floor mounting plates
- POD Enclosure, PDE

3 Operation

3.1 Care Instructions

3.1.1 Tools Supplied

A toolkit will be provided for preparing AutoNaut for launch containing:

- Allen Key Set
- Extended 3mm Allen key
- Socket Set
- Adjustable spanner medium
- Molykote 44
- Torque wrench
- Build Up Box
- Boat trollies

3.1.2 *Handling with Care*

The robust **hull** is made of resin infused GRP inside and out. Internal watertight bulkheads add to the strength. However, point loading the hull when it is fully ballasted needs to be avoided to prevent potential structural damage. Examples might be resting the hull on a sharp object, or impact through dropping the vessel. Use the trolleys provided for building and moving the AutoNaut on dry land.
The hull has *Macglide* applied, a silicon based anti-foul coating that has been applied as a black vinyl wrap up to the water line. This anti-foul is nontoxic and does not leach any chemicals into the water but requires care when handling to protect the surface from physical damage.

The **foils** and their systems are vulnerable to knocking and kicking while launching and recovering the vessel. When the boat is being prepared for launch, or after recovery, while the foils are still attached to the struts, they should be either covered with high visibility material to prevent being trodden on, or a portable barrier (e.g. a cone) should be placed adjacent to the foils to prevent people tripping over or standing on them. Care needs to be taken throughout all phases of launch and recovery to prevent the foils being loaded in an inappropriate way. This includes going astern violently in a support vessel when AutoNaut is secured alongside which could over-stress the foil spring return mechanisms.
The foils and struts are coated with *Coppercoat* antifoul, a non-leaching antifoul agent which fully complies with current (2001) International Maritime Organisation (IMO) Resolution MEPC.102(48).

The **mast** and aerials are vulnerable while launching and recovering from a support vessel either while using a boat hook or due to the swinging of a davit/crane hook. Great care should be taken to prevent the AutoNaut from coming into heavy contact with hooks, shackles or any hoisting apparatus.

Two lifting hoops are fitted to allow the boat to be lifted by hooks while onshore. The lifting hoops on the AutoNaut are robust enough for use by a static crane or hoist onshore and for dynamic loading from a vessel mounted crane offshore. Care needs to be taken to avoid contact between the mast and any lifting tackle. The hull can also be lifted by under-hull strops >50mm wide but care needs to be taken to avoid damaging the anti-fouling coating, the foils or any through hull sensors during such an evolution. Strops must be secured fore and aft on deck to prevent them slipping along the hull.

Any drop of the vessel onto land or a hard surface (e.g. a deck or dockside) will probably damage the propulsion system and may damage the hull. If this occurs the vessel should not be put into operation and must be immediately recovered. It is then necessary to fully survey the vessel before further operational use. AutoNaut Ltd will be happy to advise on damage, local repairs, or returning the vehicle to the AutoNaut Ltd factory.
All drop incidents should be entered into the AutoNaut's log book and AutoNaut Ltd contacted if repairs are required. Any areas of damage should be recorded, ideally with photographs sent back to AutoNaut Ltd for inspection and to contribute to the advice given on the most appropriate action.

3.2 Preparing for sea

3.2.1 Joining the hull sections

AutoNaut is delivered in 2 hull sections (Figure 7) which must be securely joined before installing the system electronics. Fixing studs to join the hulls are mounted on the stern hull section, matching holes are in the bow section as shown in Figure 8. There is a through hull gland for cabling. Use the trolleys provided but beware of single halves being unstable when on an individual trolley (e.g. strap them to the trolley), also make sure the under-hull penetrations for the sensors are not obstructed by the trolleys.

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Figure 7 Stern (left) and Bow (Right) hull sections

Figure 8 Stern (left) and Bow (Right) hull sections

The cables should be passed through the gland in the other half of the hull, and rubber washers placed over each of the studs before joining the hulls.

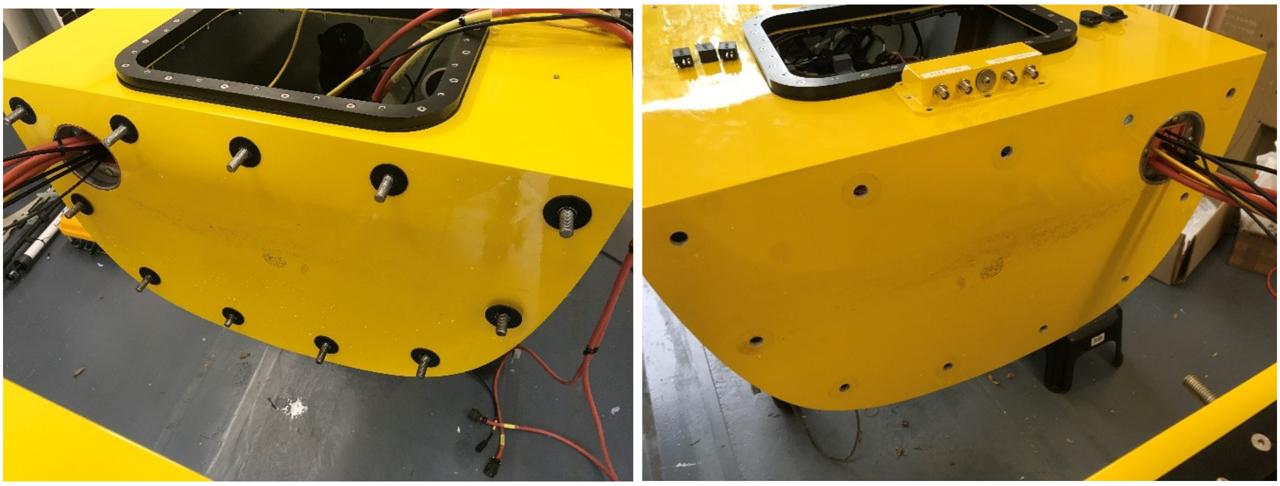

Figure 9 Stern (left) and Bow (Right) hull sections

The hull sections can then be carefully brought together, taking care to keep the two halves at approximately the same height and angle as each other.

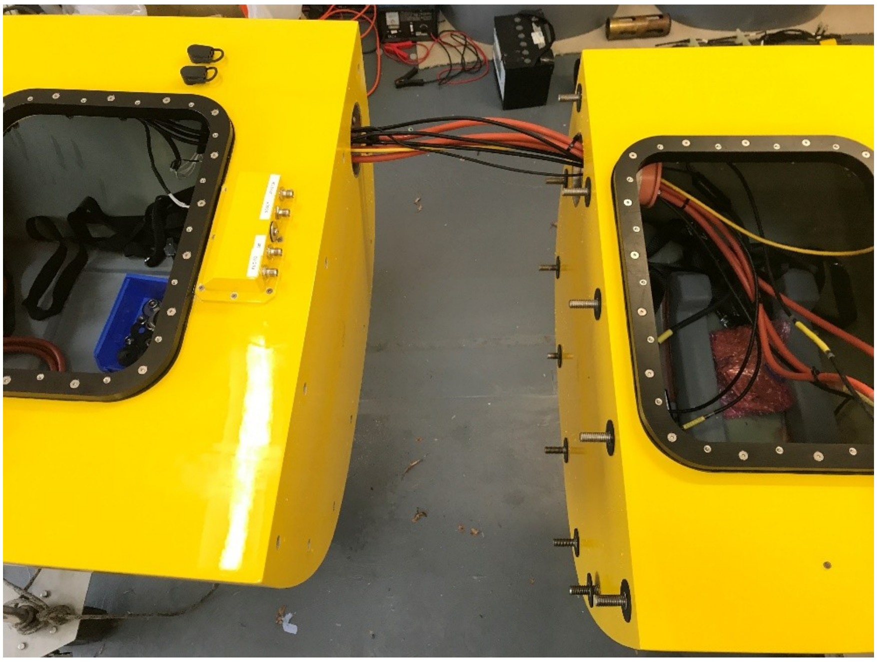

Figure 10 Rubber washers on bolts, cables passed through gland, ready to join hulls

Once together, place metal washers and nyloc nuts on the studs now protruding inside the hull and tighten to a torque of 28 N m using the19mm socket or ring spanner and Torque

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wrench supplied. A socket extender will be required for the nut adjacent to the hull gland. Rubber washers on the studs inside the hull are not required.

Figure 11 Note metal washers in place before tightening nyloc nuts

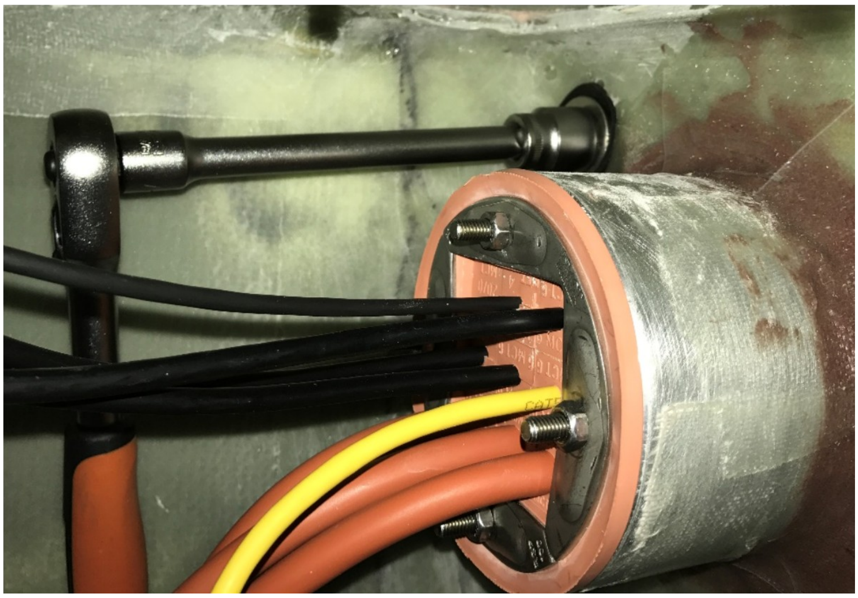

Figure 12 Socket extender required for nut adjacent to hull gland

After securing the hulls together, the through hull gland must be assembled. The blocks should be correctly sized according to the cable diameters and are shown in the table below:

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Figure 13 Stern through Gland Cable Layout

Table 1 Stern through hull gland cable layout

Temporary RC Receiver Power (20/07)	Blank (20/20)	Blank (20/20)
Blank (20/20)	Thruster Power (20/09)	Blank (20/20)
Blank (20/20)	Blank (20/20)	Rudder Power (20/09)

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Once the cables and gland blocks are in place the 4 nuts can be tightened using a 10mm spanner, as shown in Figure 14 below tighten the nuts until 12 – 15 mm of threaded bar is visible after the nut.


Figure 14 Guide showing gland nuts when tightened

It is vital that the hull joins and through hull gland are correctly assembled and checked – significant water ingress is possible if not completed correctly.

Replacement or additional Gland blocks for other cable diameters can be sourced from AutoNaut Ltd or from MCT Brattberg.

The Block is size 20.

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3.2.2 *Stern Section Glands*

2 sets of 2 cables pass through internal glands to the aft compartment for connection to the POD enclosure. These glands are loosened and tightened using a crosshead screwdriver: remove the screws, put the cables through the gland cover and into the rubber seal holes (through the slots) and tighten the screws holding the gland cover with the rubber gland material in place around the cables.

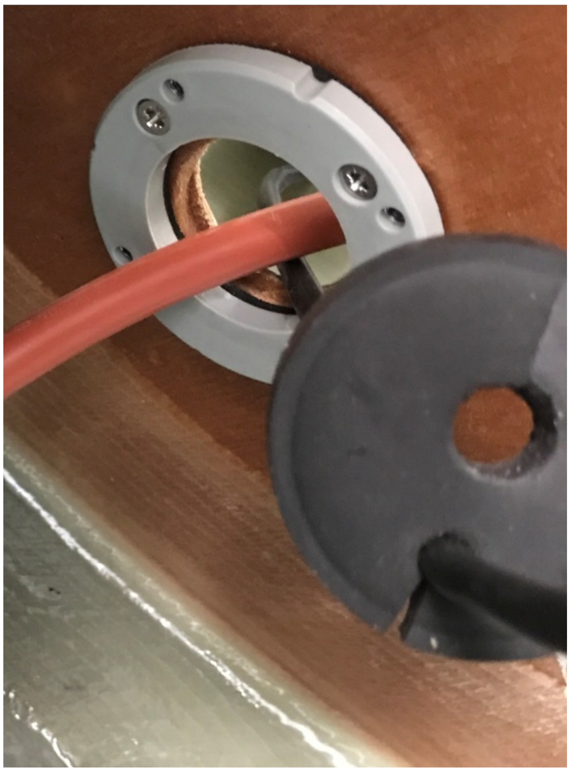

Figure 15 Aft internal gland with cables passed through, ready to fit rubber and tighten fixings

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3.2.3 Fitting sensors

Each Sensor needs to be carefully fitted to ensure it is correctly sealed to the boat in order to prevent leaks.
This should be carried out in a clean dry space.

3.2.3.1 Nortek ADCP

The ADCP is mounted through the hull from the underside.
There are 2 watertight barriers, an O-ring mounted un the under side of the hull and a rubber boot that seals to the hull and the ADCP once installed. Both should be checked for damage and cleaned prior to installation.

Figure 16 Internal and External images of ADCP mount.

Locate the ADCP in the hole from the underside of the AutoNaut and push into place.
Locate the 4 bolts in the holes and fasten using a 5mm Allen Key.

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Figure 17 ADCP Mounted in place

Next, tighten the jubilee clips around the rubber boot at the base of the Hull collar and then around the ADCP. Ensure the Jubilee clip is below the raised lip on the hull fitting and then the clips should be tightened with an 8mm socket to a torque of between 9 and 10 Nm

Figure 18 ADCP in position and fitted by tightening jubilee clip on rubber boot around white mount

The ADCP cables can now be fitted inside the boat and connected as required.

3.2.3.2 Seabird CTD

The CTD can only be fitted once the two halves of the hull are mated together.
Ensure the cable is pre-fitted through the hull gland and the gland is loose allowing the cable to be slid through it.

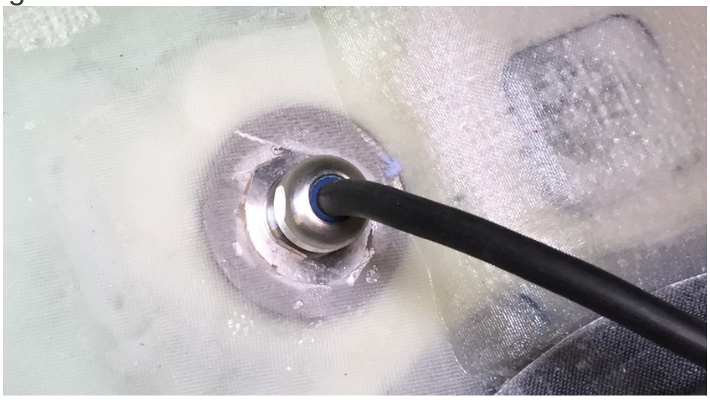

Figure 19 Through Hull Gland

Offer the CTD up to the hull and mate the connector using Molykote 44 grease on the connector pins.

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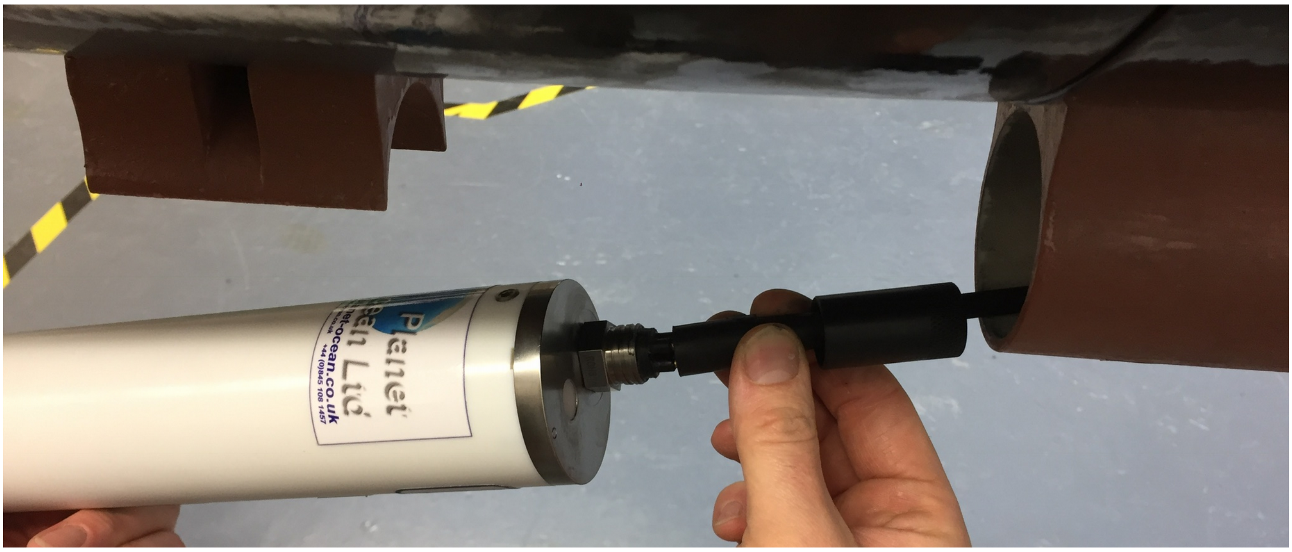

Figure 20 CTD Connection

Insert the CTD into its back bracket whilst carefully pulling the connector cable through the gland.

Figure 21 Slide CTD into back bracket

Slide the CTD in until it is fully home as shown below and then cable tie in place on the forward mount.

Figure 22 Final CTD Position

Finally, Tighten the internal gland to seal the cable entry.

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3.2.3.3 Fin Sensors – Optode & Eco Triplet

Both the Optode and Eco Triplet are mounted on the fin. In order to fit these sensors the Fin needs to be fitted to the hull.
First, run any cables through the glands so that the connectors are on the outside of the hull with approximately 50cm of cable available. This will ensure it is easy to attach the sensors once the fin is in place.

Next, mount the fin using the 6 machine screws provided. Note it is best to start all six screws in their threads before tightening them up.
Once all six are started, tighten the screws until the fin is tightly against the hull. It is a good idea to use a thread lock on these fixings.

Figure 23 Mounting the Fin

Once the Fin is secured fit the Optode and Eco triplet to the fin base plate as shown below.

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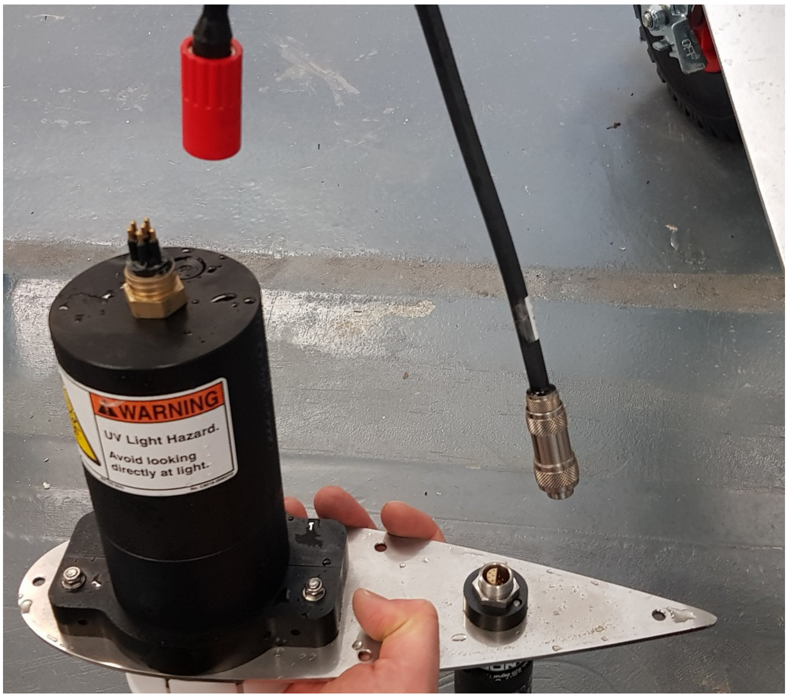

Figure 24 Fin Base Plate Assembly

Connect sensor cables and ensure sensors are secures to plate.

Figure 25 Connect Sensors

Offer the base plate up to the fin pulling the slack cable through the hull glands as it is positioned. Then bolt the base plate in place using the fixings provided.
Once the fin is fully secured tighten the cable glands to seal the penetrations.

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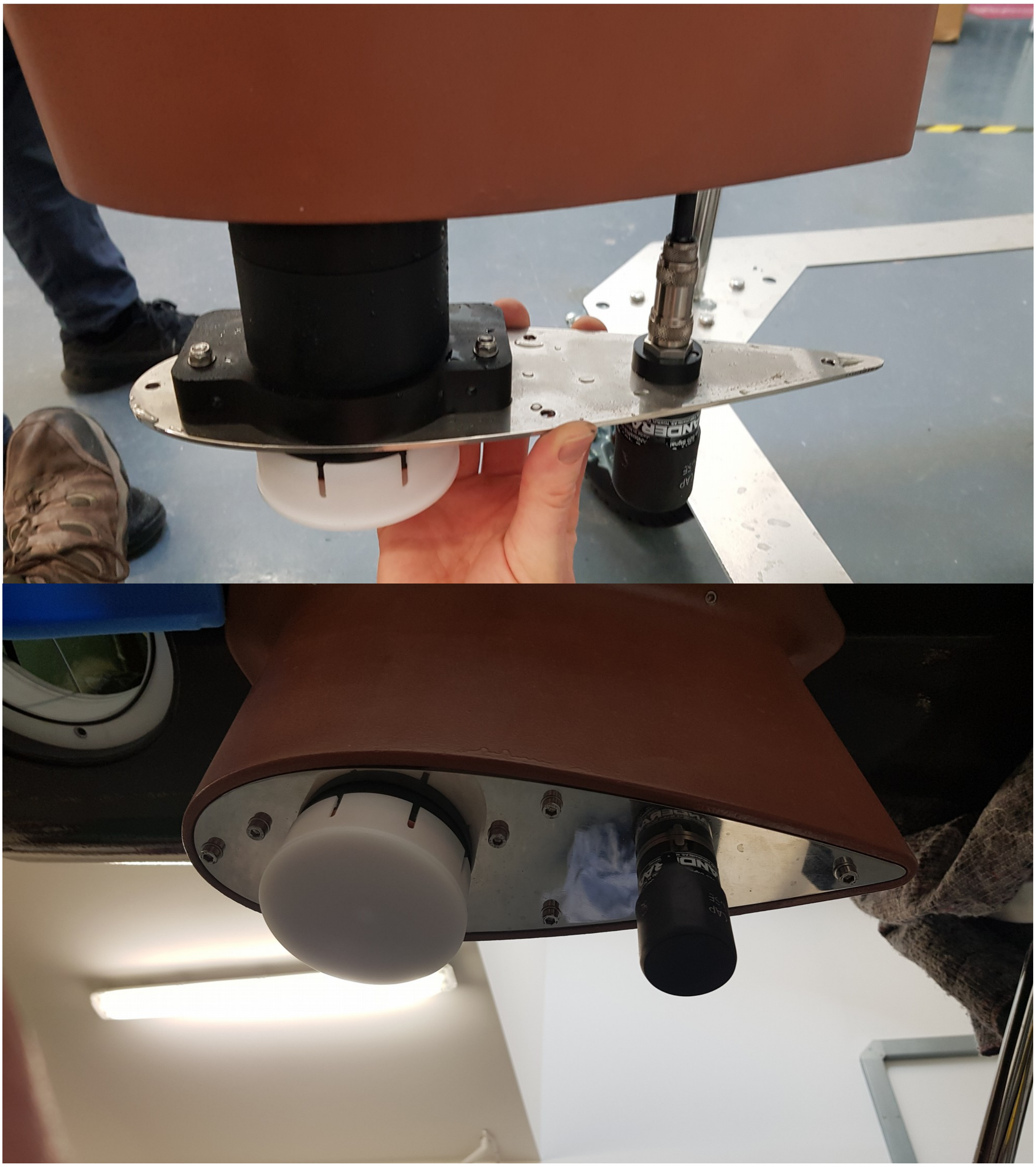

Figure 26 Fin Sensors in position

It is vital that the sensors and seals are correctly assembled and checked – significant water ingress is possible if not completed correctly.

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3.2.4

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With all sensors in place the boat should look as follows:

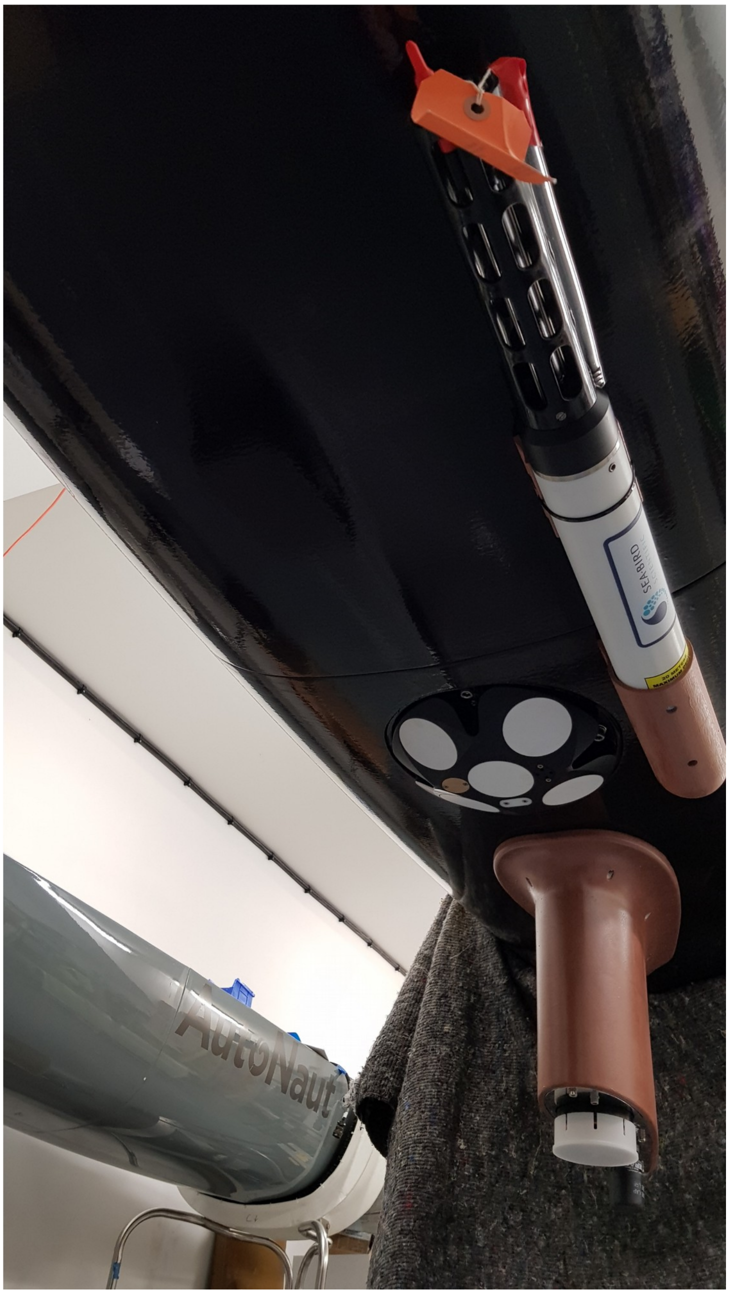

Figure 27 Sensors Fitted

3.2.5 Foil Struts

The struts for the foils can now be fitted to the bow and stern metalwork respectively. The stern strut is easy to identify as it has the Rudder fitted, the bow strut has a fixed plate as shown below.

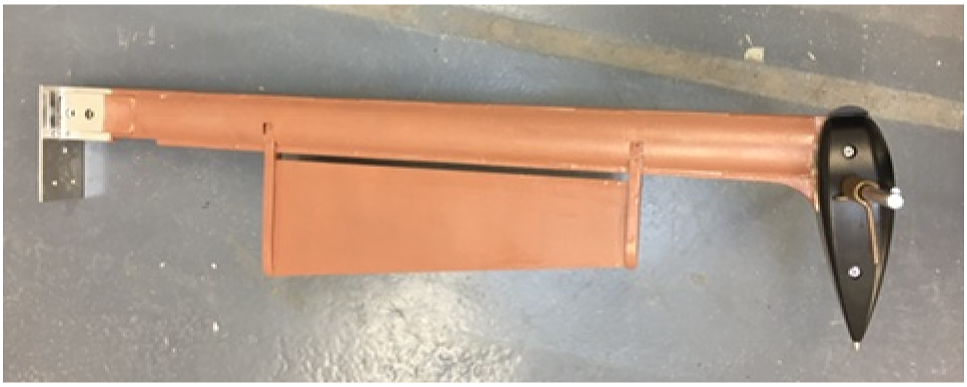

Figure 28 Bow strut.

With the vessel on its trollies the struts are attached by sliding onto the bulkhead metalwork with the ballast blocks hanging below the vessel.

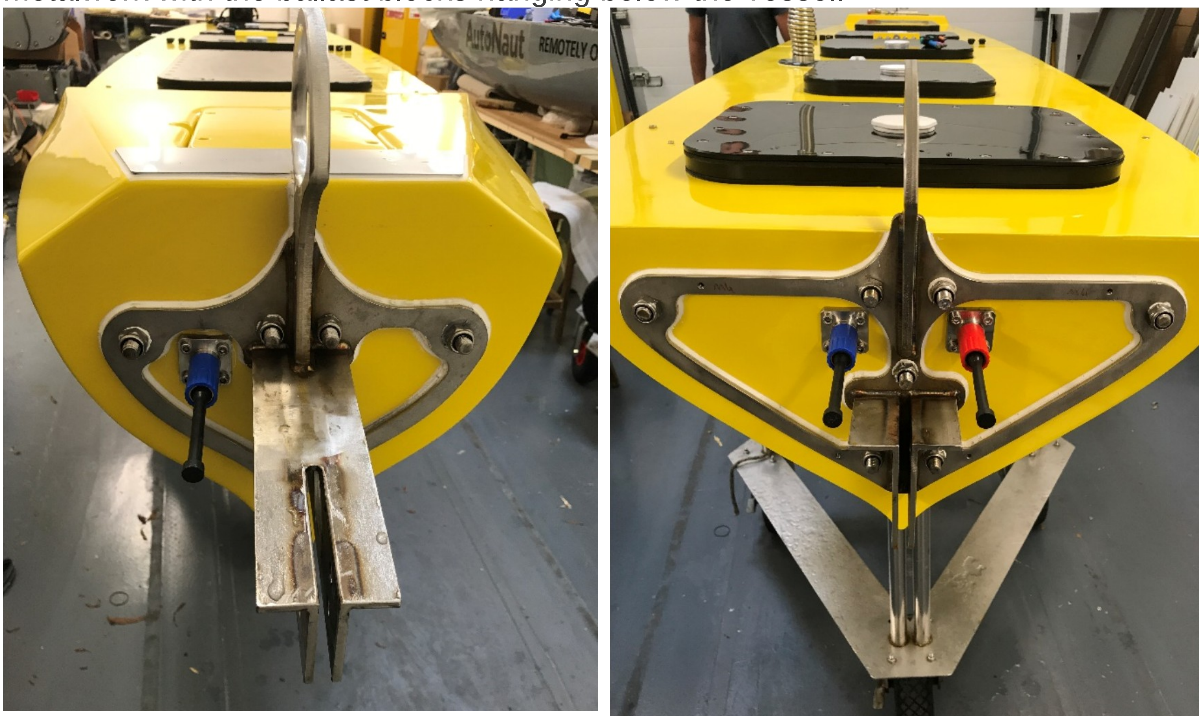

Figure 29 Bow assembly (left) Stern assembly (right) before strut is fitted

Push the struts into place until the fixing holes align, then fit the 2 off M12 bolts and tighten with the nuts supplied, see Figure 30

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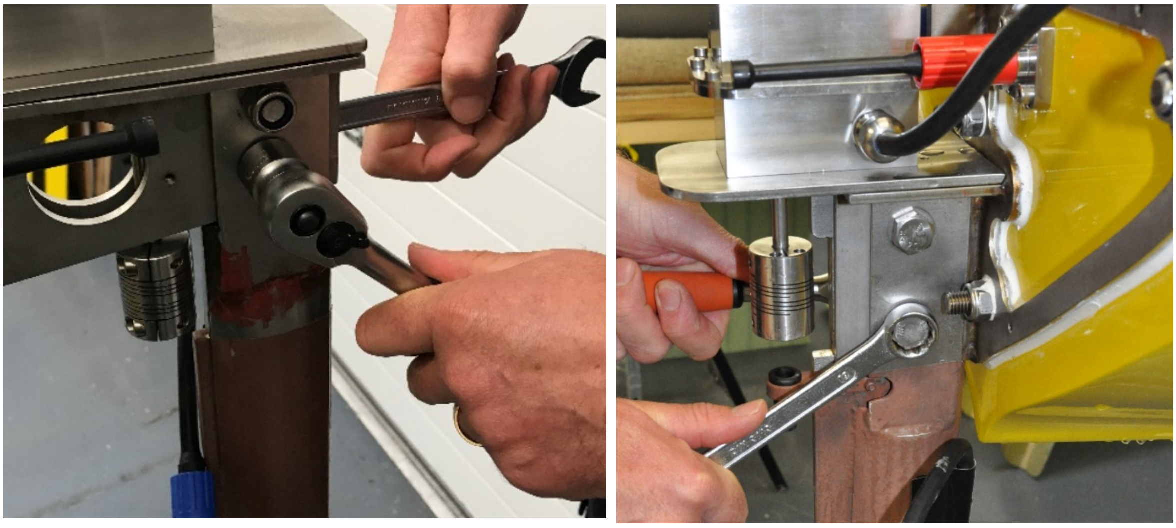

Figure 30 Slide strut into position, place fixing bolts through holes and secure in place using nyloc nut, 19mm socket and 19mm spanner. Bow (left) Stern (right)

When the struts are in position it is time to fit the rudder shown in Figure 31 (if not already fitted). This is completed by first placing the axle through the grommet ensuring the plastic insert is in place and locating into the rudder coupling. Then seat the base of rudder in the pintle before adding thread lock to the fixing threads and tightening the fixings of the rudder coupling shown in Figure 32 using M5 and M3 allen keys.

The M3 shear pins should be made hand tight using a 2.5mm Allen head driver. The M5 clamp screws should be tightened to a torque of greater than 12Nm using a 4mm Allen head driver.

Figure 31 Stern rudder

MISSION CRITICAL: Check the rudder shaft is secured properly to the rudder coupling.

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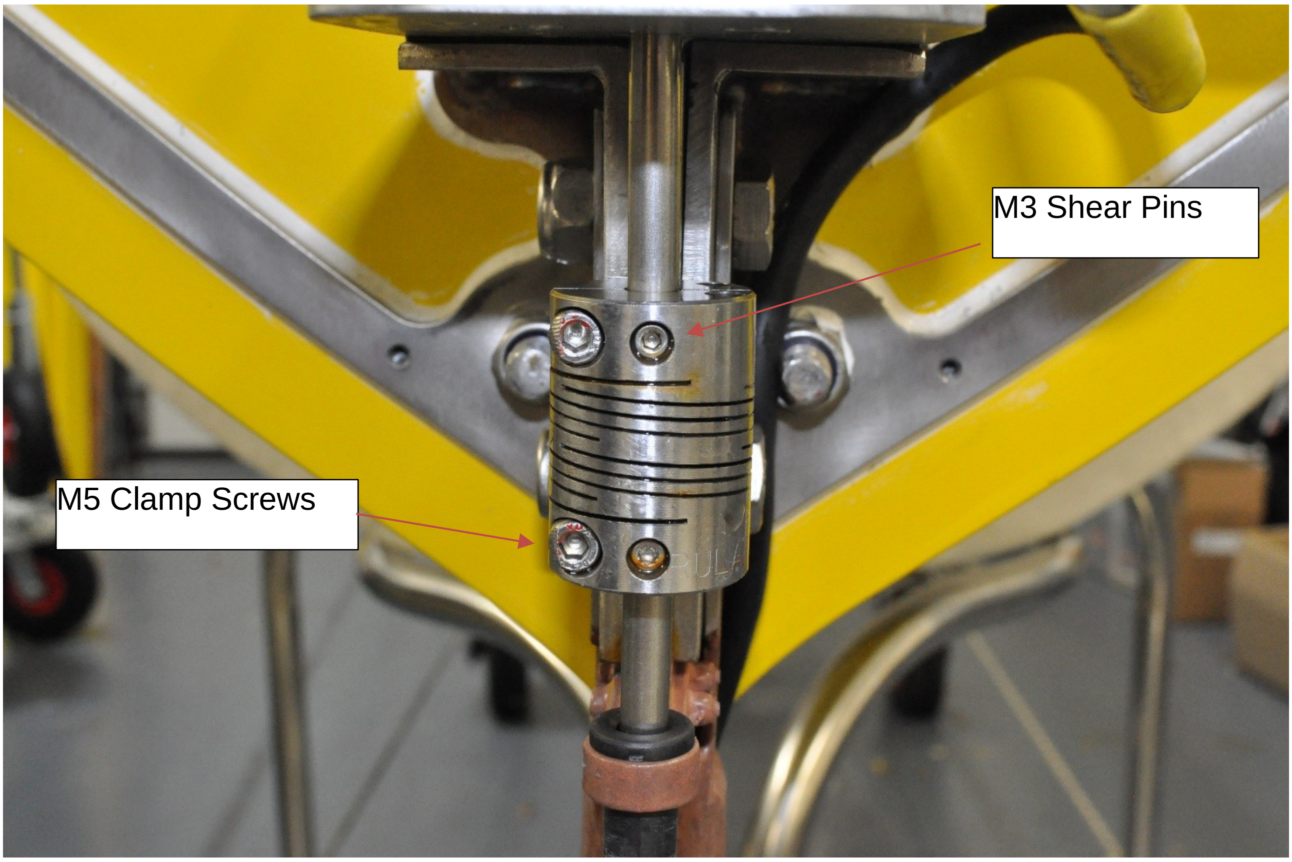

Figure 32 Rudder shaft in place and fixings tightened.

To complete the strut installation, remove the blanking plugs from the hull and connect the rudder and Thruster cables on the stern strut by pushing in and turning the red & blue plastic connectors finger tight.

The connectors are designed with different pin configurations so that it should not be possible to fit them the wrong way around.

The connectors should be fitted as follows: -

Red – Thruster – 3 Pin
Blue – Rudder – 5 Pin

3.2.6 Foils

The foils can now be fitted, though it is recommended to take a sensible decision on when to complete this stage as they protrude out to the side of the USV and present a trip hazard. **Care must be taken not to damage the foils or fixings.** If fitting the foils and leaving the vessel in storage, it is recommended to place high visibility material over the foils or a physical barrier like cones to prevent people from unwittingly walking into them.

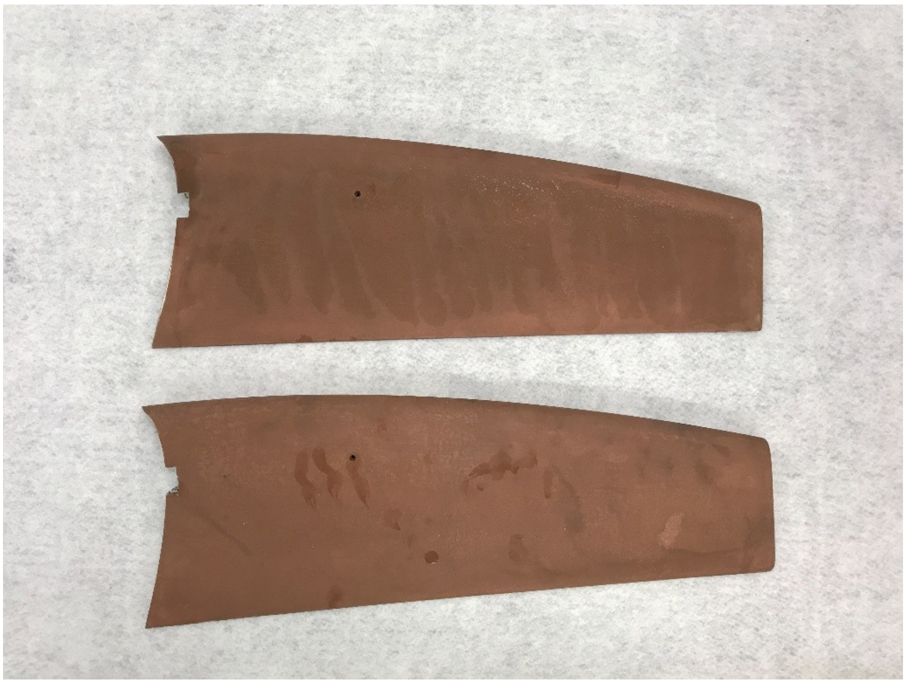

Figure 33 Foils which are identical for bow and stern

Before fitting the foils the springs must be fitted to the strut axles. These are put over the axles and seat into position as in the picture below;

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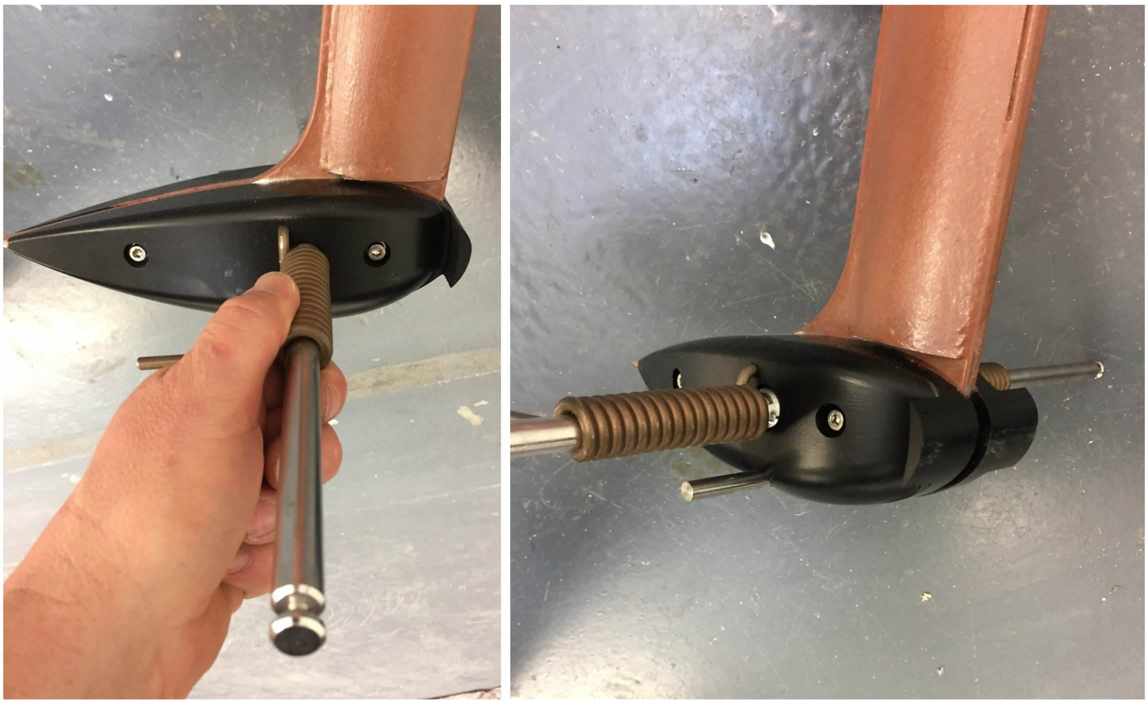

Figure 34 Fitting springs to strut axles

The springs are all identical, note that the seating point is on top of the axle on the starboard side and underneath the axle on the port side. It is best to fit the springs with the fixings for the black ballast blocks slightly loose in order to take account of minor manufacturing differences. Once the spring is fitted to the block, the fixings can be tightened.

When the springs are located, the foils slide on over the axle and are secured in position using a M3 x 30mm socket head fixing, the nut is held in position by the foil for tightening.

As with the springs, the fixings are identical and the socket head bolt will be on top on one side and underneath on the opposing side. A 2.5mm Allen key is required for this operation

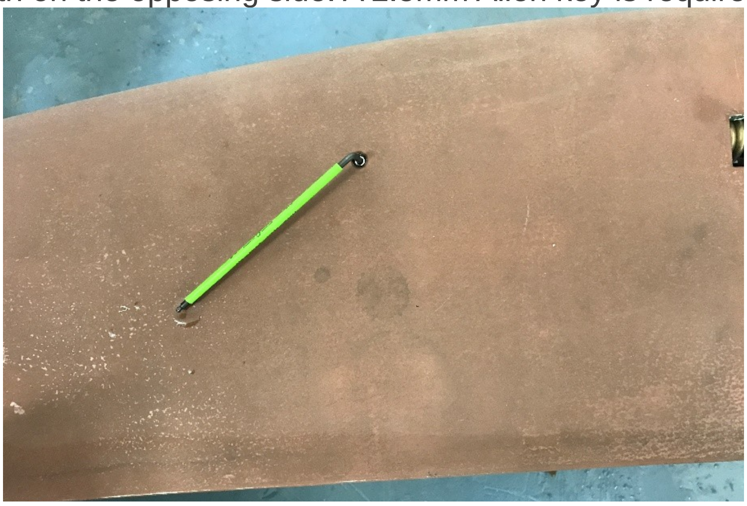

Figure 35 Foil in position and fixing secured with Allen key

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MISSION CRITICAL: Check the foil springs and foil fixings are in place and secure.

3.2.7 Bow and Stern Cones

With the struts and rudders in position it is now time to fit the bow and stern cones.
The bow cone is in 2 halves, the port side can be secured in position first before securing the starboard half in position and then completing with the through cone fixings.

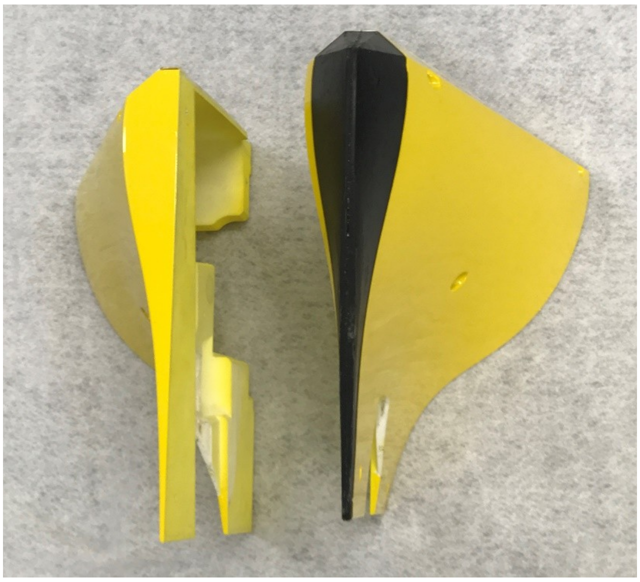

Figure 36 Bow cone starboard side (left) port side (right)

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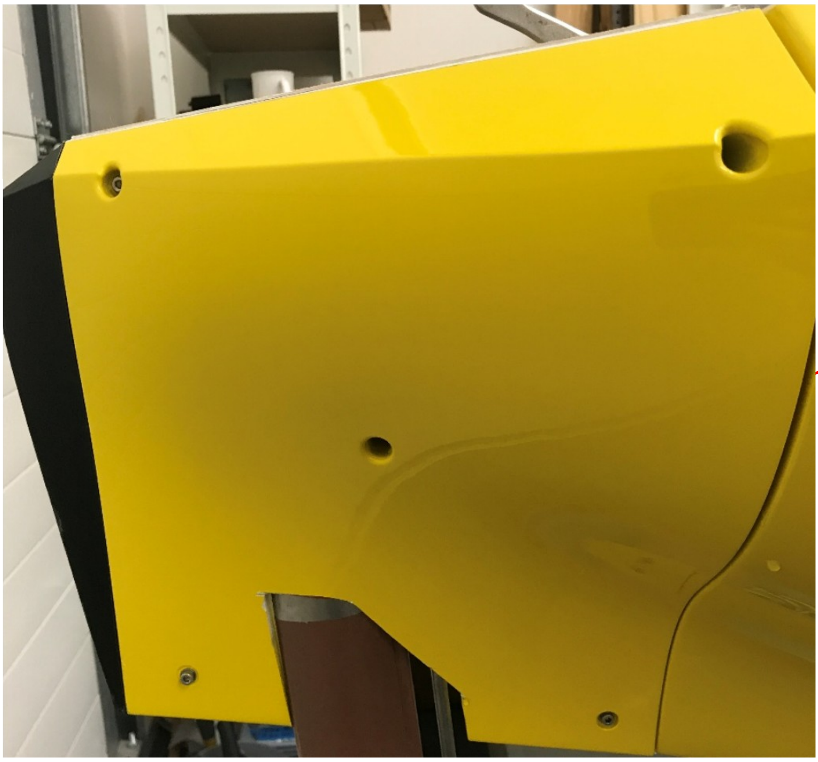
These fixings go through both halves of the cone and require an Allen key and socket to tighten.



There are 4 fixings points on each side of the bow cone.

These fix into the vessel metal work and require a long 3mm Allen key

Figure 37 Bow cone port side in position

Fit the Port side bow cone first as shown in Figures below:

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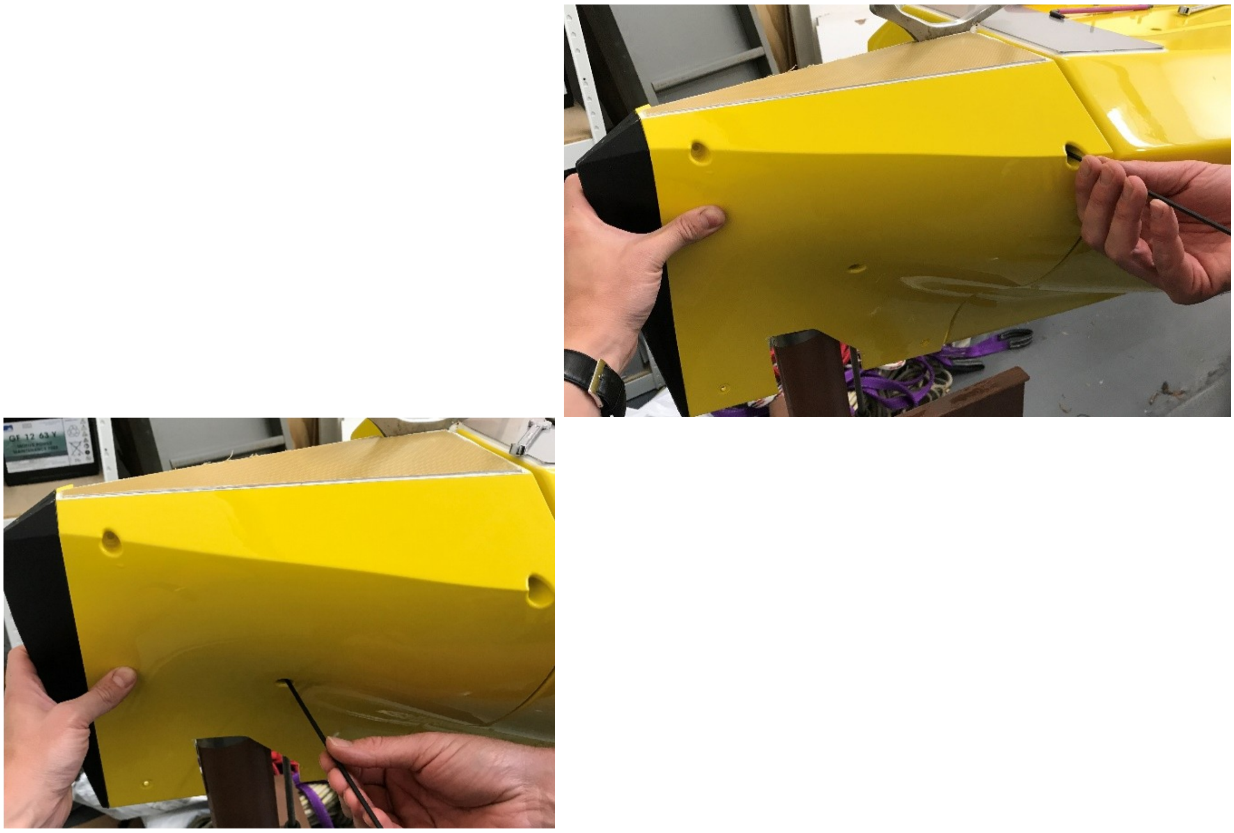

Figure 38 Have one person hold the cone half and one person secure fixings

Then fit the Stb side cone as shown below:

Figure 39 Starboard side bow cone placed into position

Figure 40 Starboard side bow cone securing in position with Allen key

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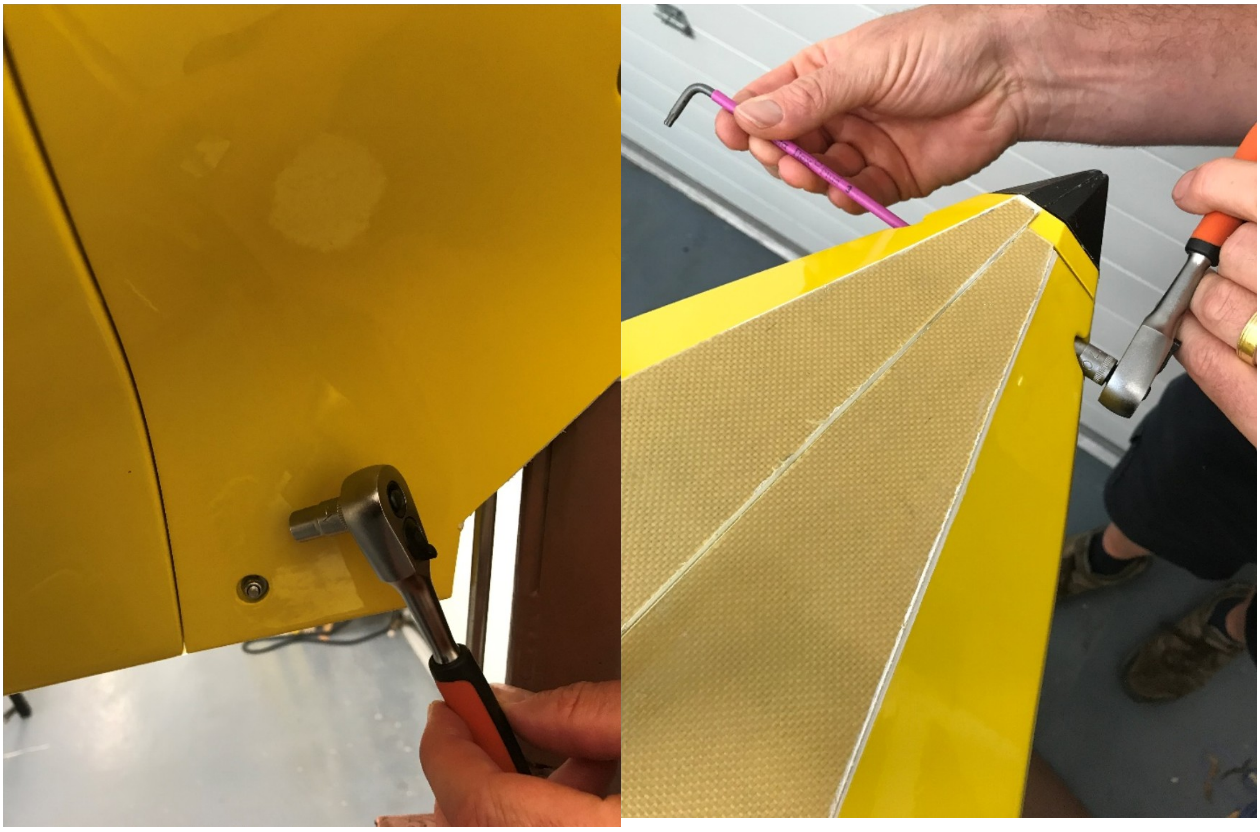

Figure 41 Securing through cone fixings. Ensure washers are in place and tighten with Allen key and socket

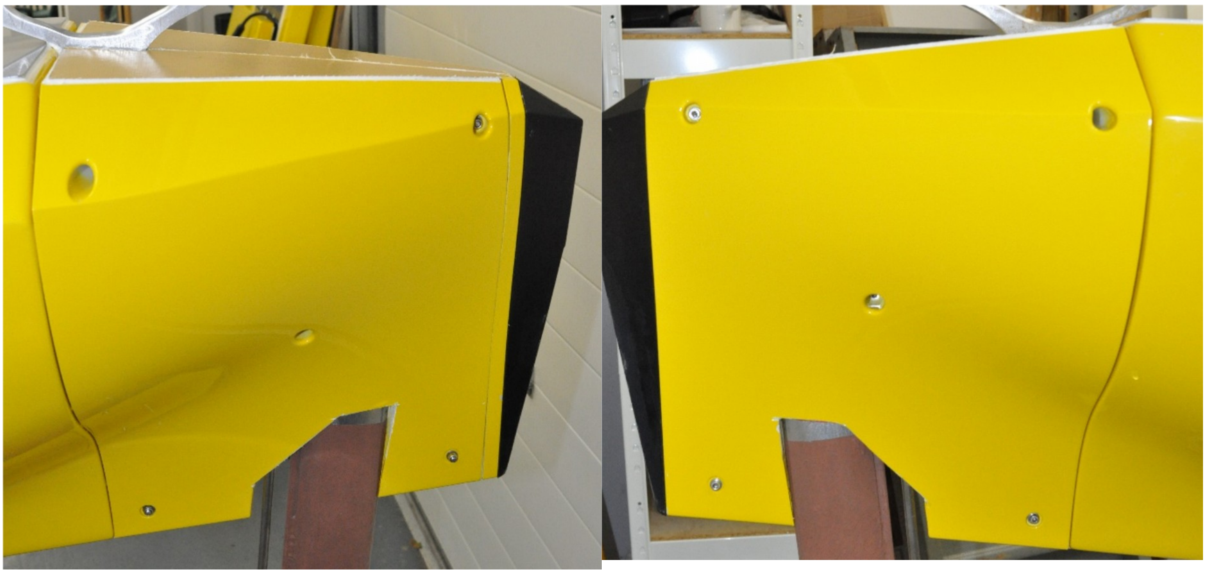

Figure 42 Bow cone secured for deployment

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The Stern cone is attached with the 4 off M3 socket head screws supplied as shown below:

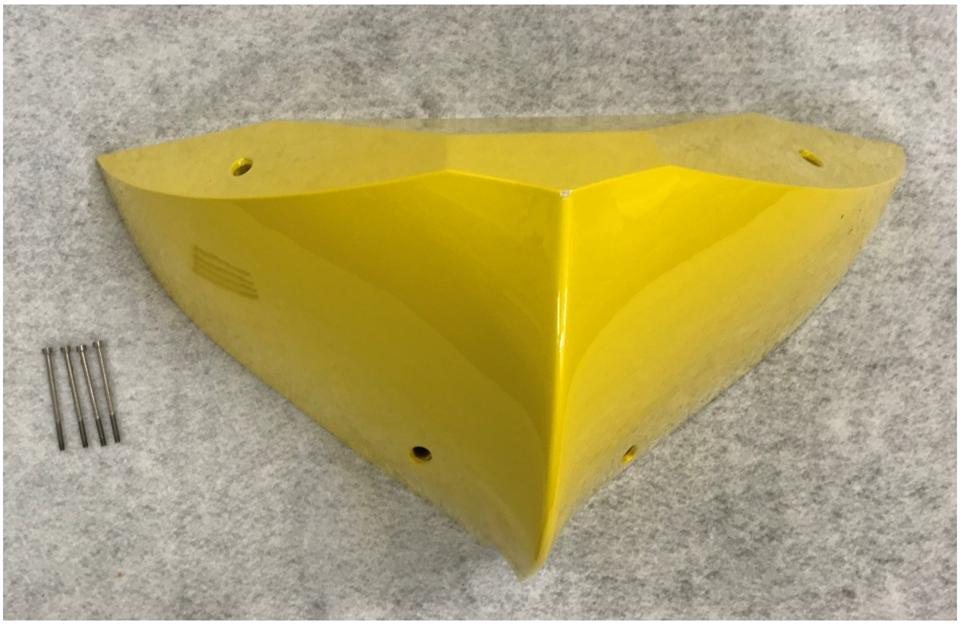

Figure 43 Stern cone and fixings

Before securing the stern cone, it is important to locate the rudder and POD cables as shown in the picture below, this will allow the stern cone to sit properly and be secured for deployment.

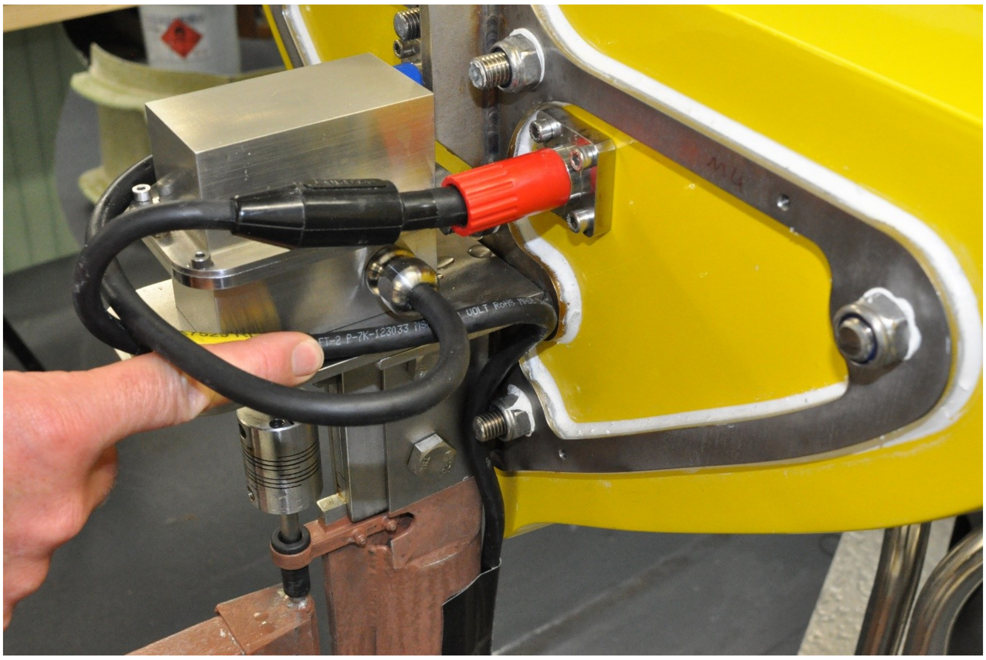

Figure 44 Stern rudder and POD cables in correct position before fitting stern cone

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Tighten the fixings using a long 3mm Alen key.

Figure 45 Fixing stern cone into position using long Allen key

3.2.8 Mast

The mast is shipped with navigation light and wind sensor pre-installed. The mast base and spring is installed on the hull ready for the mast to be secured. Place the mast into the mast base and secure with Allen bolts.

Figure 46 Mast complete with, light and wind sensor

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Figure 47 Secure mast into mast base with allen bolts

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3.2.8.1 *Mast Antennas*

A deck connector box has been provided for the mounting of antenna connectors, the Airmar connector is already fitted and the 5 other positions have blanks.

Figure 48 Mast antenna connector box

The Nav light / Echomax connector is mounted on the side deck as shown below and should be lightly greased with the Molykote 44 before being mated. Note there is a space for a second connector to be added if required.

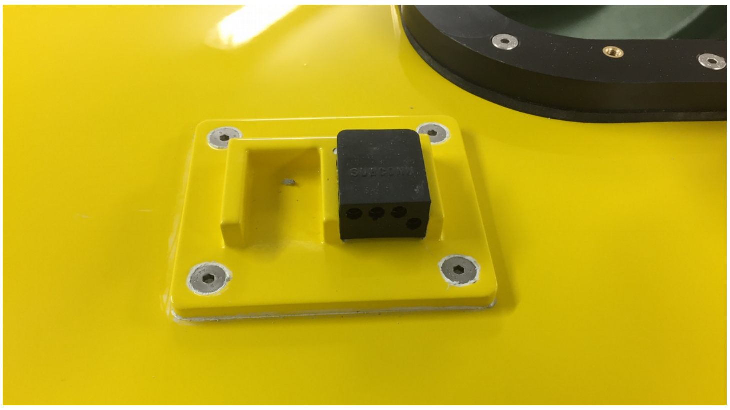

Figure 49 Echomax mast connector

The orientation of the antenna platforms may need adjusting, use an Allen key to loosen the bolts, rotate the antenna mount and tighten when in position.

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Figure 50 Antenna mounting

A camera connector box has been provided with a black gland. Behind the gland are 4 off USB3 connectors that lead through the deck. These can be used for cameras or other deck sensors.
The gland should be punched to the correct cable diameter prior to using.


Figure 51 Camera Connector Box

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Note, the USB3 connectors behind the gland are not water resistant and will corrode if they get wet so ensure the front gland is properly sealed.

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3.2.9 *Internal electronics*

The internal electronics consists of a single enclosure for the thruster and rudder motor controllers.

The enclosure is labelled PDE and locates in the Stern compartment.

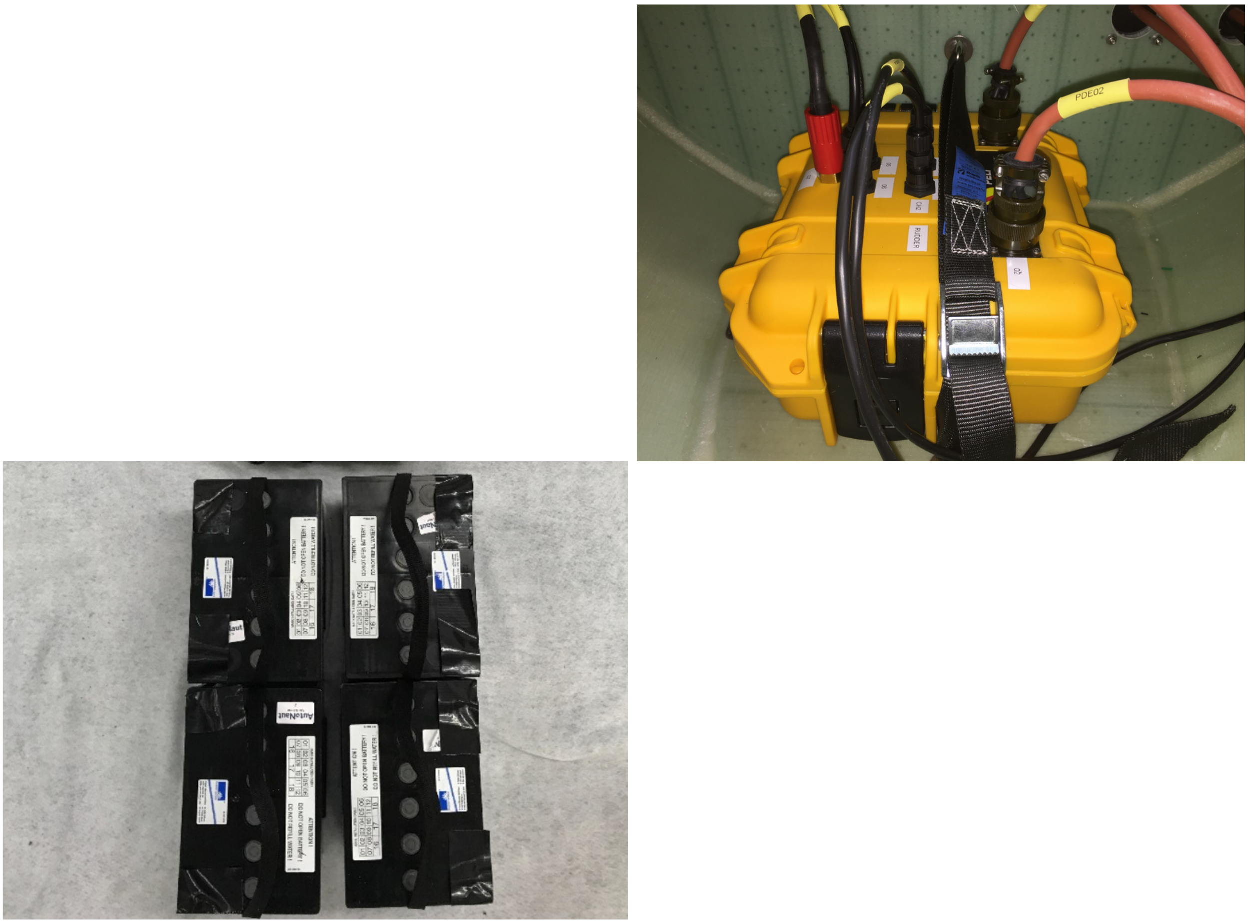

Figure 52 Bow batteries (left) Stern electronics (right)

The internal structure of the AutoNaut has been designed for the batteries to sit securely with tie town points and straps to secure the internals prior to deployment.
There are base sections fitted throughout the hulls that can be used to mount other enclosures or floors as required.

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3.2.9.1 Batteries

Four off 70 Amp hour Lead Acid Gel batteries are supplied with the AutoNaut to provide the electrical power storage.

Place the four batteries in the bow section adjacent to the hull join. Connect the cables to the terminals using a 10mm spanner and taking extra care to ensure they are connected correctly: red cables to the +ve terminals; black cables to the -ve terminals. Use tape to cover the terminals not being worked on as a safety precaution to prevent shorting across the terminals with metal tools. On completion a second person is to check the battery terminals are connected correctly. Secure with straps when in position and tighten as firmly as possible.

Caution, the batteries are heavy and care should be taken when lifting into and out of the hull.

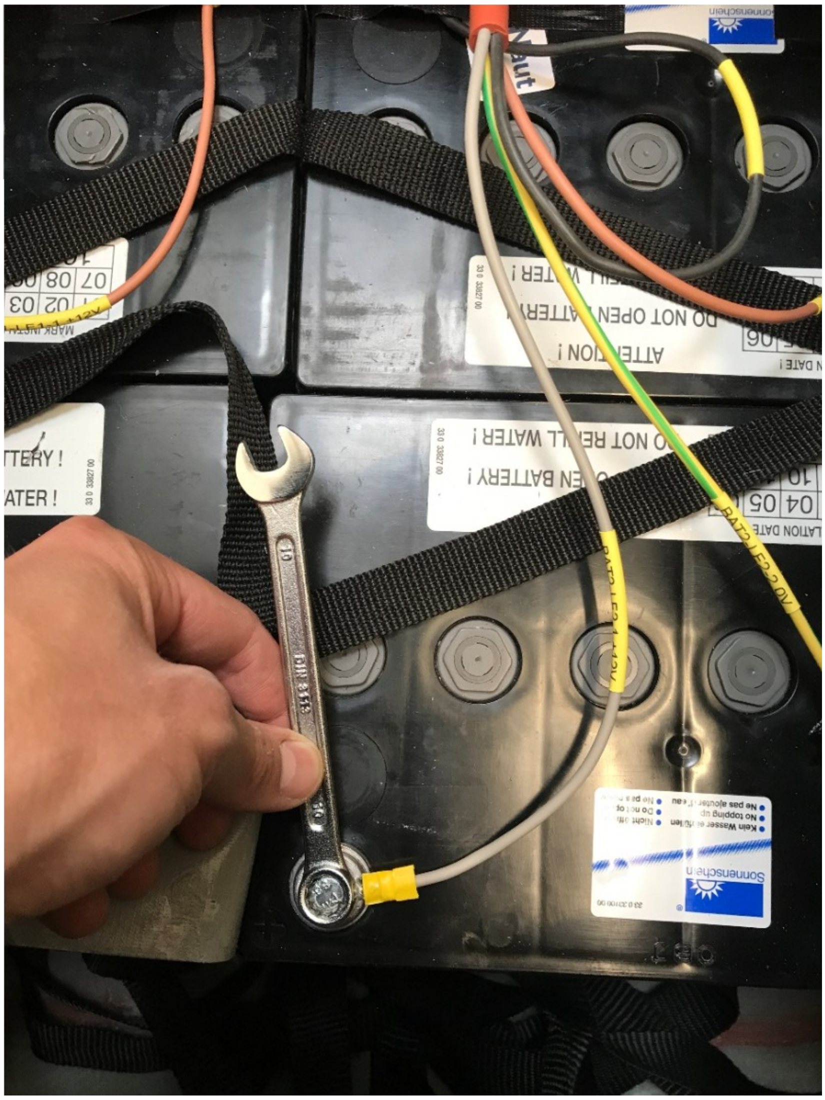

Figure 53 Connect cables to battery terminals

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3.2.9.2 Thruster Enclosure (PDE)

In the furthest aft hull section, connect the cables to the PDE and place in position. All connections should be checked by a second person on completion. Secure the PDE with the strap and tighten as firmly as possible.

Figure 54 PDE in position and secured

3.2.10 Full Systems Test

Once system checks are successfully completed the vessel can be closed up ready for launch.

Be aware that the system as provided does not have an external on/off switch and that all systems are live as soon as the batteries are connected.
It is anticipated that the owner shall introduce a suitable power management system before using the AutoNaut, the supplied cable systems are purely for demonstration purposes. A bow connector / key switch box has been provided with a blank plate in order to allow the end user to fit their own preferred system.

Figure 55 Blank bow connector / key switch plate

The plate has a cover which is secured with the six fixings provided.

3.2.11 Closing down and Sealing Hatches

Figure 56 Hatches (left) and seals (right)

Visually inspect and clean all hatch joining faces (i.e. black plastic) with rubbing alcohol, Isopropyl Alcohol (IPA) is recommended. Care must be taken to ensure the sealing surfaces are fully cleaned with non-abrasive materials and that they are not severely scratched.

Inspect and clean rubber seals if required. It is recommended to use warm, lightly soapy water for cleaning the rubber. **Do not us the IPA on the rubber seals**.

Ensure all surfaces have fully dried before placing the seals around the hatch openings, accurately lining up the fixing holes.

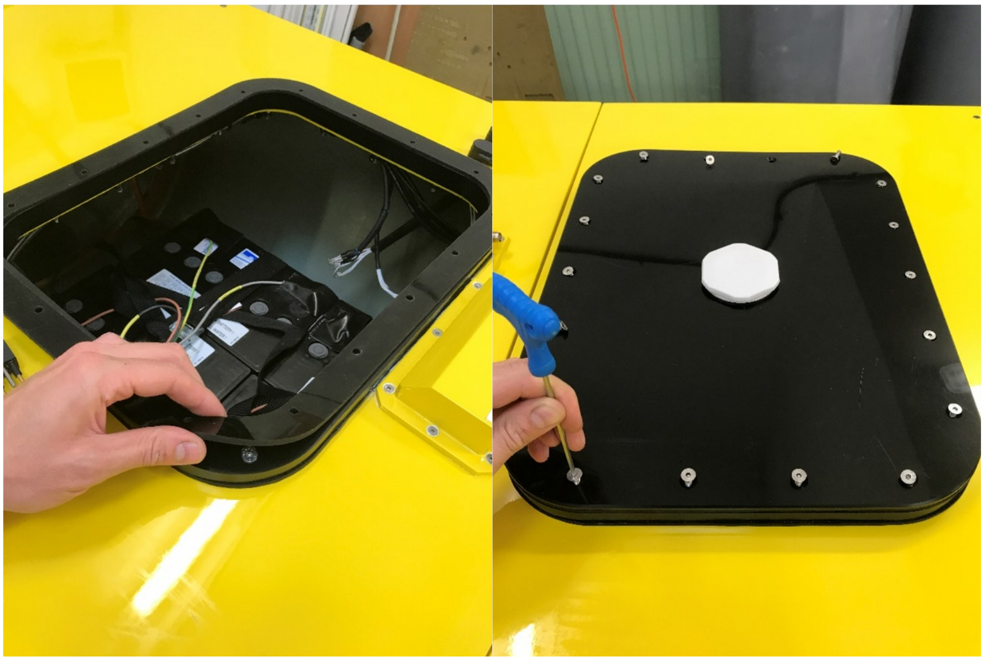

Figure 57 Hatch seal in position (left) and securing hatch in position (right)

Carefully place the hatches into position on top of the gaskets, lining up the fixing holes and secure using the M4 countersunk fixings supplied with a 3mm Allen key. Do not over tighten, use enough torque to see the rubber deform slightly around the outside of the gasket i.e. a slight 'bulge'.

Visually double check all hatches to ensure correct seating.

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3.2.12 Photovoltaic Panels

The Photovoltaic (PV) panels are the last components to go on the vessel once the hatches have been closed. Place each PV panel on the boat. The deck connectors should then be lightly lubricated with the Molykote44 silicone grease and connected to the plugs beneath the middle PV panel port side.

Once securely connected, seat the panel on the securing studs. Place the securing machine screws (with thread lock), rubber washers and penny washers and the fixings near the mast base. When satisfied the panels are correctly aligned and have the correct screws they may be tightened down. Do not over tighten as the PV panels are mounted on foam encased in epoxy & glass fibre and may be crushed.

Test that PV panels are functioning prior to launch (ensure nothing is covering any of the PV panels).

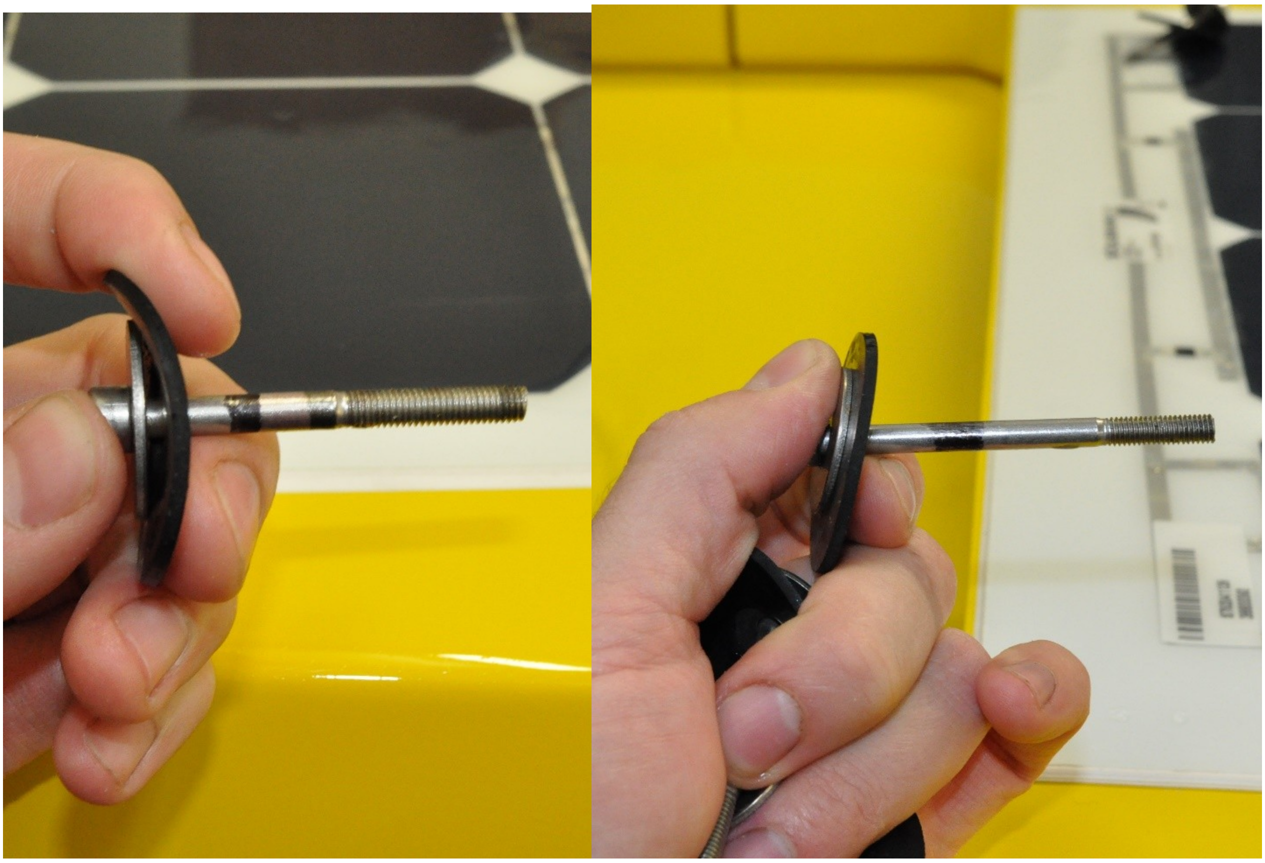

Figure 58 PV panel fixings

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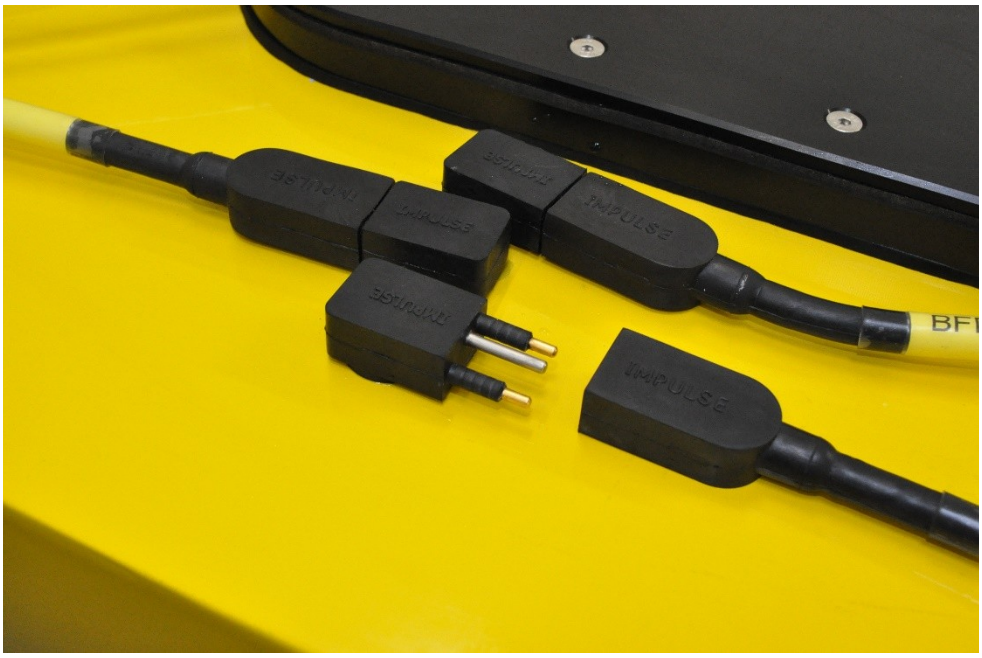

Figure 59 PV panel connectors, 2 are connected, 1 is ready to connect

Figure 60 PV panels secured in position. The vessel is ready for launch

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3.3 Launching Operations

Handling and Lifting

The AutoNaut is **too heavy for single person lifting**. The safe limit of 25kg per person is considered reasonable for bending and lifting a load manually. Carrying between two people is only acceptable for a dismantled AutoNaut without any systems or ballast on board.
As a consequence lifting points are built into the AutoNaut hull and should be used ashore. These require a crane or hoist of sufficient load capacity (>500kg) and lifting strops that should be suitably certified for the lifting load. The lifting points are tested during manufacture and do not require re-testing as they are embedded into the primary structure of the hull. Visual inspection for damage of the lifting points themselves and the surrounding structure is sufficient during life. Any cracking or discolouration of the area around the lifting points must be recorded and the AutoNaut not lifted until further inspection has taken place.

It is possible to Launch an AutoNaut either from a slipway using the trollies or by craning the vessel into the water from the shore or from a larger vessel. This section will cover the launching operations relevant to getting the 5m AutoNaut from a quayside to operating at sea. A safe lifting plan is provided with the AutoNaut documents to give a flowchart and checklist for performing lifting operations

3.3.1 Launch from a Slipway

A trolley system has been designed to move the AutoNaut on land. The trolley can also support the weight of the vessel during a crane transfer to a support vessel by acting as a cradle.
The trolleys are primarily used to launch and recover the vessel from a slipway.

Lifting by crane
It is also possible to lift the AutoNaut with a two-point lift using strops attached to the bow/stern lifting hoops, from a central lifting hook or a spreader bar with separate strops to each end from the bow/stern hoops. Take care not to damage the mast sensors with the lifting strops. If deploying by crane offshore it is possible to use suitably rated quick release shackles or underslung strops and a RHIB/support vessel for removal of the strops.

3.3.1.1 Pre-Launch Checks:

A checklist is recommended to ensure all pre launch checks have been carried out and the AutoNaut is ready for at sea operations. Pre launch checks for the vessel as supplied includes the following steps:

- The boat is fully prepared and switched on.
- The hatches are sealed down and effectively watertight.

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- The PV panels are fitted and connected.
- Test operation of the rudder and propulsion pod.
- Ensure all antenna, mast and deck connectors are secured.

3.3.1.2 Equipment Checklist

Checklist of equipment required for slipway launch using the trolleys:

- Towing rope (e.g. 8 - 10mm braided nylon or polyester) 30m (Note: we **strongly** recommend using a floating line for towing, this is because when towing in heavy seas the AutoNaut and the support boat will surge, causing loops of slack in the line which if it gets caught around a foil can damaged the foil/spring and strut).
- Stern line for control on slipway, and mooring, e.g. up to 15m long
- Boat hook (preferably a traditional blunt point and hook. Modern plastic double hooked ends have been found to jam in the lifting hoops and not release)
- Waders (if necessary)
- Wetsuit or drysuit for staff to enter water
- Trolley link line (as shown in Figure 60)

Preparations for slipway launch:

- Secure bow/tow line to fwd hoop; coil and stow on deck.
- Secure stern line to aft hoop; coil and stow on deck.
- Prepare 2 staff to enter water with the boat: one wearing dry suit (or similar), one wearing waders (if required).
- Position support vessel (if required) off the end of slipway with communications to launch personnel.
- Tie a recovery line onto the aft trolley.
- Check operation of rudder and propulsion pod.
- Check slipway above and below waterline for trip hazards and slipperiness.
- Brief launch team on procedure and hazards.
- Prepare boat and trollies to move down slipway, bow first.
- Position staff member wearing dry suit at bow trolley; staff member wearing waders at stern trolley; position third staff member astern of boat with stern and recovery lines in hand.

3.3.1.3 Launch Procedure

1) Move boat and trollies onto slipway; third staff member to control speed of descent down slipway, bow and stern staff members to steer straight down slipway.
2) Carefully roll the trolleys into the water until vessel is floating: bow staff member enters water with boat; stern staff member waits at water's edge in case of need; third staff member controls position of boat with stern and recovery lines.

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3) Staff member in the water can remove the trolleys from one side of the vessel by angling them and pulling them clear; align the trollies so that they can be pulled clear of the water. Second staff member can pull the trolleys ashore using the recovery rope; third staff member helps the staff member in the water to control the boat's position using the stern line.
4) From this point forward the AutoNaut is free to move and any waves or pitching motion will cause the vessel to start propelling. Therefore, the staff must maintain control of the AutoNaut using bow and stern lines as necessary.
5) AutoNaut can then be attached to a support vessel by the bow line and towed away from the slipway after the stern line has been coiled down on deck or disconnected from the AutoNaut if no longer required.
6) AutoNaut can also be driven away from the slipway under joystick control, using the propulsion pod either out to a support boat, or away from the slipway and into waves. AutoNaut must be supervised at all times when being operated in a port or harbour or in close proximity to other vessels.

3.3.2 Towing

For towing AutoNaut attach the tow-line by passing one end through the bow hoop and keeping both ends on the tow vessel. Then paying out the lines to achieve the desired tow length and so that the tow line forms a loop through the bow hoop: this will make releasing the tow a simple act of untying one end of the line on the tow vessel and pulling the line through the bow hoop and back onto the tow vessel – without getting the loose end around the tow vessel's propeller.
AutoNaut may be towed at up to 5 knots water speed, but the speed will depend on the length of tow-line, the wake of the towing vessel, and the sea state prevailing. In order to maintain control of the AutoNaut under tow it is advisable to steer her so that she follows the tow vessel without moving out to either side during turns or when moving through waves.

Do not tow in excess of 5 knots to avoid potential damage to the propulsion system.

Never drive/pull the AutoNaut astern as it can damage the propulsion and steering systems.

Sharing some experiences of towing:

- In heavy following seas AutoNaut will surge forward and then slow. Depending on the characteristics of the towing vessel, which will also surge and slow, some experiment may be required to achieve a satisfactory balance between speed and length of tow line depending on size and period of the waves and to avoid excessive snatching/loading of the tow.

- The two events to avoid are firstly a collision between the two vessels, and secondly a loop of tow rope getting around a bow foil and then being pulled hard as the boats surge at different times.
- Use of floating line will help to prevent this. However, until a stable tow is established it may also be prudent to manually pay the tow line in and out to maintain a taut tow line and to prevent a loop of slack forming.
- Generally speaking a long tow line will prove satisfactory. In channels, harbour mouths and other restricted places AutoNaut can be kept on a short tow (e.g. 10m – 20m long).

3.3.3 Release from a Towing Vessel

1) Check that the AutoNaut is under operator control prior to release from the tow.

2) When releasing AutoNaut the towing vessel operator should:
   - keep the towing vessel speed between 1-2 knots
   - Judge what heading is appropriate in the prevailing conditions to allow the AutoNaut to safely be steered away from the support boat when released. Support boat characteristics and conditions will vary. Generally it is best to head parallel to the waves with the wind abeam, and to prepare to release the AutoNaut from the leeward side of the stern. This is because in larger head and stern seas AutoNaut may surge ahead more quickly than the support boat can respond to. Releasing the tow when running across the waves gives better control of the evolution. However if the support boat rolls heavily another heading may be preferred.

3) Releasing from the tow should be done smartly. Take care to:
   - Have a boathook to hand to fend off the AutoNaut if needed
   - have the tow line ready to slip without tangling
   - avoid the rope twisting around itself as it is pulled through
   - avoid loops of slack getting around the bow foils
   - keep rope tails clear of the support boat propulsion system
   - keep the support boat moving forward

4) The load on release will be small but in the process **care should be taken not to turn AutoNaut towards the towing vessel.** AutoNaut will be moving slowly at this point and therefore may be unable to manoeuvre to avoid a close quarter's situation with the support vessel. The helmsman of the support vessel may need to manoeuvre to avoid the AutoNaut as necessary.
   - AutoNaut's operator should help by steering her away from the support vessel, and the propulsion thruster may also be used if necessary.

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- On release of the tow it is advisable to alter the course of the towing vessel into wind and waves just before release. This will give distance between the towing vessel and AutoNaut which is always in wave-propelled mode.
- Once AutoNaut is released the towing vessel should move smartly ahead, away from the AutoNaut and the operator should handover control to remote pilots on a previously agreed bearing away from the support boat.

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3.4 Recovering the AutoNaut

3.4.1 Recovery to a Towing Vessel

A recovery procedure has been developed for attachment of a tow line to the bow hoop in order to take the AutoNaut under tow in a low risk operation. This procedure reduces potential hazards for personnel operating over the side of small vessels.

The most common hazard in the recovery phase is that the AutoNaut cannot stop if there is any significant wave action. It will always continue to move forwards, therefore recovery needs to be carried out by the support vessel operating at the same speed that AutoNaut is making – typically about two knots. However the fact that both vessels have steerage way gives better control for the procedure and avoids potential hazards both to personnel and the AutoNaut. The recovery plan must be fully briefed between the skipper of the support boat and the crew members who are securing the tow line and steering AutoNaut with the joystick.

Various pickup devices can be used depending on the freeboard of the towing vessel. From a RIB or similar low freeboard vessel it is simplest to manually feed the tow line through the bow hoop. From a vessel with higher freeboard it may not be possible to reach down far enough to do this. In which case a pickup device (e.g. boathook or similar) may be essential to pass the tow line through the hoop and recover it onboard. A large snap hook on a pole, which is designed to disengage when the pole is pulled, with the tow line attached to the snap hook also works well.

Checklist of equipment to prepare for recovery:

- Boathooks to hand to fend off the AutoNaut if necessary
- Tow line flaked on deck and free to run
- Pickup device, with end of tow line attached correctly
- Deck crew in lifejackets
- One crew with harness on in case there is a need to work outside the rail/gunwale of the support boat.
- Pilot with Joystick controller with good visibility of evolution

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3.4.2 Pickup procedure

This procedure is a tried and tested method but may not be appropriate for all circumstances and is therefore included for completeness. A thorough, independent Risk Assessment MUST be carried out prior to undertaking this manoeuvre and the procedure agreed with the master of the support vessel before undertaking it.

- Bring AutoNaut under Joystick control alongside support boat with the wind and waves on the beam. (Again it is for the operator and skipper to decide if this is the best heading in the prevailing conditions)
- The operator maintains AutoNauts heading throughout
- Place the pickup crew in the best position on the leeward side (e.g. near the stern on displacement support boat, amidships for a RIB).
- Bring the support boat alongside to windward with the vessels about 2 metres apart.
- Match the speed of the AutoNaut and then bring the support boat slowly ahead so that the recovery takes place in the correct position. The support boat must keep moving ahead.
- Crew stand by with boathook(s).
- Using a pickup device feed the tow rope through the bow hoop and back to the support boat. (Or use snap hooks, or manually feed tow rope through bow hoop).
- As soon as the tow line is through the bow hoop move the support boat ahead of AutoNaut to avoid collision or damage to foils and keep going slow ahead while paying out the tow line before securing at the selected tow length.

Note:

- To avoid damage to mast and foils do not let AutoNaut get too close to the support boat, use boathooks to fend off at a safe distance which still allows the tow to be rigged through the bow hoop.
- Never drive/pull the AutoNaut astern as it can damage the propulsion and steering systems

3.4.3 Recovery Lift Ashore

The AutoNaut may be lifted directly with a two-point lift at the bow and stern which requires rated strops to be attached to the fwd and aft hoops and a shoreside crane. Alternatively, the AutoNaut can be recovered on a slipway using the trolley in a reverse procedure to the launch.

3.4.4 Recovery to Slipway

The AutoNaut can be recovered to shore using a slipway by reversing the operation as detailed in 4.3.1.

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4 At Sea Operations

4.1 Operation of the Power and Propulsion Systems

4.1.1 Main Propulsion – Wave Power

The main propulsion foils are entirely passive in their operation and, once fitted and tested, should be left free to oscillate against their springs. Prior to launch, the foil retaining mechanism must be checked for security, and the spring system checked for freedom of movement.

4.1.2 Auxiliary Propulsion – Pod

The auxiliary propulsion system can be used when required. The system is not designed to be used continuously, only as a “get out of trouble” method. It can be used when conditions are flat calm or to aid steerage in difficult conditions.

4.1.3 Risk Management

Whilst AutoNaut Ltd provides the AutoNaut as a system for the study of the oceanographic environment for various scientific, commercial and governmental purposes the objectives of these operations are not covered within this manual and no representation is provided for the safety of any decisions based upon the data gathered by AutoNaut operations.
The customer organisation will need to provide appropriate support and facilities for the operators of the AutoNaut system, particularly in terms of health and safety arrangements, appropriate facilities and computer systems and communications systems to enable control of the AutoNaut whilst the vehicle is at sea.
Each operation should be covered by an appropriate mission Risk Assessment.

5 Safety

Chapters 1 and 2 provide the technical details required by an operator of AutoNaut centered on the vessel itself. However, there are broader considerations to operating an Unmanned Surface Vessel, concerning Safety, Regulations and Training, where guidance can be offered to the immediate operator and their management. The emergence of highly capable USVs has greatly outpaced agreement on national and international regulatory regimes. While this remains the case, it is incumbent on USV suppliers to take a proactive role in promoting best practice in Safety, Regulation and Training. The UK Marine Industries Alliance formed a working group to identify issues related to the operation of Marine Autonomous Systems and has produced a code of practice which AutoNaut complies with (http://www.ukmarinealliance.co.uk/content/masrwg-code-practice). This Chapter is included for completeness and as a reference: however **operators of the AutoNaut system are to formulate their own Safety and Operating systems which are based on their own territorial regulatory requirements. This Chapter is NOT prescriptive, but it does reflect one proven approach to safe operations.**

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5.1.1 Introduction to Unmanned Maritime Systems (UMS) safety

Principle: There are no people in the unmanned vehicle itself, however there are people in a system that operates unmanned vehicles. Therefore:

- The operator must maintain a suitable watch over the AutoNaut. This depends upon the mission and the hazard that may be presented to other shipping by the presence of the AutoNaut.
- A set of Manuals, Checklists and logbooks is provided covering systems and equipment operating techniques and requirements, planned maintenance, Health and Safety issues etc.
- Clear responsibility for Command and Control of the AutoNaut should be identified and formally allocated for each mission (the person undertaking this ultimate responsibility should be familiar with the seamanship requirements of small boats, where for example strong currents, high winds, or a lee shore can cause high risks).
- Responsible mission planning is considered to be the most effective risk mitigation measure and should be undertaken thoroughly by suitably qualified and experienced personnel (SQEP).
- A balance for "water space segregation" needs to be achieved for each mission, e.g. in areas where there is fixed infrastructure such as oil and gas platforms, and the correct deployment of "Sense and Avoid" procedures, e.g. when in the vicinity of shipping lanes.

5.1.2 Systems Concept

The concept of the AutoNaut includes all systems, associated components and subsystems needed to operate the vessel e.g. control system, vehicle, logistics and interacting personnel as outlined in the following table:

Table 1: UMS system components.

UMS systems	Description
Platform	Seagoing part (or parts) typically consisting of Vehicle and Mission equipment, including sensors and instruments.
Base station	Equipment needed for remote control and monitoring of one or more Platforms.
Support system	Maintenance equipment, spare parts, documentation and other logistics.
Personnel	SQEP as needed, typically interacting with Vessel, Base Station and Support system.

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5.1.3 Categorisation of UMS

When compiling a Risk Assessment for the use of an USV there is broad agreement for the use of four key factors to assess the risks: size, speed, endurance, and kinetic energy when underway[1].

Using this methodology the AutoNaut can be categorised as follows:

- Size Small
- Speed Low end
- Endurance High end
- Kinetic Energy 337 J (max 300kg at 3kts) hence Category II

This inherently makes the AutoNaut 'safe' and its small size and slow speed means that it is highly unlikely to cause damage through collision with another vessel. AutoNaut represents a very small target for collision and most ships would push it away with the bow wave.

Although the AutoNaut poses a minimal threat to fishing gear, appropriate planning action should be taken if possible to avoid risk to fishing nets. Similarly, for mission planning purposes, operators and management should recognize that while AutoNaut may use AIS signals broadcast by other vessels in order to avoid collision, small craft are not obliged to carry AIS. This may be of minimal concern in mid-ocean, but of considerable concern in coastal waters where a boat operating at night will rely on sight and hence the all-round white navigation light is important.

5.1.4 Mission Planning

Each mission should be planned between management commissioning the mission and the platform operator. This mission planning must take into account the risks of collision within the mission area. Therefore the operator must be trained and competent in mission planning and consideration of risk avoidance.

5.1.5 Mission Risk Assessment

A Mission Risk Assessment (MRA) is an essential component of the safety management system. This is carried out during the planning of each mission. This requires consideration of the hazards in the area of operation and decisions to be taken regarding the frequency of communications and reporting by the AutoNaut. The area of operations must be identified and shipping lanes, navigational and meteorological hazards recorded within the mission risk assessment. A Risk Assessment form has been developed to assist in this process and prompt the operator for likely risks. This form has been designed to be consistent with the onboard control and communications systems settings in order to assist the operator in programming the mission scenarios and search patterns.

It is recommended that the Risk Assessment is signed off by the operator's manager (e.g. line manager or Duty Holder) and retained by the operator. It is also recommended all such Risk Assessments are filed together.

1 Safety and Regulations for European Unmanned Maritime Systems (SARUMS)

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5.1.6 Risk List

AutoNaut has been designed to mitigate or reduce risks to a level which is as low as reasonably practicable (ALARP). Possible mission risks include:

- Collision
- Third party tampering or theft
- Unexpected change in weather conditions
- Maritime wildlife disturbance
- Third party maritime/environmental pollution
- Damage at sea
- Reliability of systems/equipment
- Operator workload
- Personnel injury whilst launching/recovering the AutoNaut
- Mission equipment hazards
- Out of control operation
- Communication loss between platform and base station

The AutoNaut is marked with serial number and contact details of the operator in case of accident or loss.

5.1.7 Safety Reviews

Safety reviews should be carried out for the whole cycle of an AutoNaut mission. It is best practice for operators to hold a safety review as part of planning each mission and to include all persons involved. The customer for the mission data should also participate to ensure that they have an appreciation of the hazards and risks involved.
A safety review of AutoNaut operations is recommended every six months to consider the whole safe system of operation. AutoNaut Ltd would appreciate being advised of any suggestions for improvements to the craft, documentation or safety management systems which are resolved at such reviews. New hazards identified should also be notified to AutoNaut Ltd to assist with designing in mitigations to future AutoNauts.

Event driven safety reviews should be conducted at any time that an incident occurs which results in injury to personnel or loss of or serious damage to an AutoNaut. AutoNaut Ltd would like to be informed of these and would wish to be invited to participate (by phone or video conference if the travel distances are long) in such reviews. Participation is a part of the standard support package for each customer.

Updates - AutoNaut Ltd run regular safety reviews to oversee the development and lifecycle of the AutoNaut family of systems. This may result in adjustments to the AutoNaut platform, equipment, software, documentation, training, safety management system and guidance provided to customers. Notices may be issued to customers and operators in the event of a new or particular hazard being identified.

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Regulation - AutoNaut Ltd will also monitor the development of regulations that may be applicable to unmanned surface vessels. This may influence future development or retrofit of equipment or safety management arrangements to existing AutoNauts.

Environmental Impacts and Risks

Criteria for both environmental impacts and environmental risks are defined using an approved process applying the following definitions:

- Environmental Impacts:
  - All actions will have some impact on the environment. Thus, there will be a spectrum of direct consequences for the environment that are planned or inevitable. These consequences are termed environmental impacts.
- Environmental Risks:
  - Environmental harm can arise from unplanned events or equipment failure. Thus, environmental risks represent the combination of the likelihood of the unplanned occurrence (frequency) together with the probable consequence(s) on the environment.

Loss of Platform

There is the possibility of the loss of an AutoNaut during operations. Risk of loss of position information is substantially reduced by AutoNaut carrying a completely independent GPS Iridium tracker which provides position, course and speed via Iridium satellite anywhere in the world. There are also two forms of communication connection (UHF and Iridium satellite). A radar transponder is fitted to further increase the probability of relocation should other forms of communication be reduced, e.g. if lost and undamaged, a ping from a vessel's navigation radar would trigger a response from the AutoNaut, making it visible on the radar. If the power generation system remains operational the AutoNaut will continue with the mission plan until recovered or commanded to change.

The risk of loss through sinking has been reduced by watertight sub-division of the hull and the use of structural foam buoyancy. In the event of a collision at least some of the AutoNaut is likely to remain afloat and the GPS Iridium tracker would continue to operate and give accurate positions. To increase the chance of recovery and reporting AutoNauts are all fitted with an identification plate. This provides a serial number and contact details for AutoNaut Ltd and/or the owner. If a salvage claim is raised this will be passed on to the legal owner.

Total loss by sinking is possible if the craft is destroyed by natural action of waves against a solid object (e.g. rocks) or by collision and break up. The mission and GPS Tracker systems would report the last known position of the AutoNaut but there is no separate mechanism for recovering the hull or the datalogger beyond standard salvage routines. There is no underwater locator beacon fitted as standard to an AutoNaut.

In the event of salvage being required a complete pack of information should be immediately available for handover to the local/relevant authorities when it is known that a craft has been lost.

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Loss of Communication

Loss of communication is a higher probability event than complete loss of the craft. For this reason the AutoNauts mission system will report its location in every communications message. The Iridium GPS Tracker will continue to provide position, course and speed (PCS) data.

The AutoNaut is designed and programmed to restore the mission control system with its pre-programmed mission and communications when it recovers power. In the absence of a mission control and communications system the AutoNaut will continue to sail on its last selected mission plan/track until command and control is re-established. Throughout this period the tracker will continue to send Position Course and Speed data and the pilot will be able to take decisions about mission abort and recovery, if necessary, based on full knowledge of the AutoNauts overall situation.

Loss of control

In the event that the AutoNaut has lost control, e.g. due to the rudder being damaged or lost, or the steering mechanism failing, the pilot will see that it is not following the set track or heading. There is a series of steps the pilot may take to try to recover control described in the piloting manual. If none of these are effective it must be assumed that control is lost. The situation must then be assessed, taking into account the position, conditions, any surrounding vessels, land or dangers. Without rudder control AutoNaut will take up a heading according to the balance of forces acting upon her and any fixed position the rudder may be stuck in. Typically this may be a heading close to or directly into the wind or it may be the last course set. Once settled on a heading AutoNaut generally has good directional stability. This means that as the wind changes direction her course may change to follow it. The pilot will be able to observe this either via the pilot displays or tracker data. Therefore attention to forecast winds, currents and tides will enable a view to be taken on where she is likely to go, and the next steps that are required for recovery.

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6 Training

6.1.1 Introduction

Operating the AutoNaut requires knowledge of the sea and its users, and what other vessels can be expected to do. However, there are additional challenges that are generic to unmanned surface vessels, such as relying on a synthetic presentation to develop situational awareness, the inability to make warning signals, and also the operator is not on-board experiencing the conditions and motions AutoNaut is experiencing. Other challenges are unique to AutoNaut, such as the fact that it cannot stop or go astern.
At a minimum AutoNaut operators must:

- be capable of safely conducting missions including precise and efficient response to emergency situations. These unique skills are especially critical when operating in conjunction with other manned and unmanned maritime systems.
- have the ability to use and understand standard procedures and checklists throughout the mission and how their system operates within a defined task.
- understand how to coordinate with Sea Traffic Services as required. This needs understanding of relevant maritime regulations of national and international controlling authorities, as well as to achieve integration with other maritime activities.

With the AutoNaut operating at long range there is no possibility of intervening manually. The pilot has to interpret the situation in the location of the vessel from the information that is presented on the Base Station. This requires the pilot to be familiar with collision avoidance methods, rules of the road and the likely behavior of other vessels detected via AutoNauts collision avoidance system. All pilots must therefore be trained in the use of and interpretation of the pilot software and must be able to predict what is likely to happen. Seagoing experience is clearly very helpful.

6.1.2 General qualification precepts

AutoNaut Ltd will continue to improve training scenarios that show the potential hazards and appropriate actions to take, and those to avoid when operating AutoNaut. The company will provide training to customers' staff. The content of this training will depend on the needs and prior experience of the customer's staff involved.
At present no specific qualification is required of an USV operator. However, as has been made clear, owners, management and operators are legally responsible for safe navigation.
It is therefore prudent, if not mandatory, for owners and management responsible for AutoNaut to ensure that as part of safe navigation their AutoNaut pilots have adequate background experience and knowledge of the sea, and training in the new vehicle.

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6.1.3 Strategy

Of key importance is to understand the AutoNaut safe navigation strategy. AIS-Class B which also transmits AutoNauts position, course and speed as well as making other shipping aware of it being a USV is utilized in this AutoNaut. It is important that the Remote Pilots understand The International Regulations for Preventing Collisions at Sea (COLREGS).

For smaller vessels not transmitting AIS, and therefore not detectable, the AutoNaut strategy is to maintain a 'slow, small and light-weight' profile extremely unlikely to damage anything it contacts. In addition high visibility paint and a bright all-round light will enable small craft to see and avoid it.

Pilot training

Training of the pilot controlling the Base Station is essential in order to appreciate the hazards associated with autonomous operation. The pilot must be familiar with the operational environment and they need to appreciate and understand the likely course of action that other shipping would take in different circumstances if they were to become aware of the presence of the AutoNaut.

Similarly they must be familiar with the location of shipping lanes, busy channels, fishing 'hot-spots' and practices, and other navigational hazards that limit the manoeuvrability of other vessels and therefore reduce their ability to change course (or where they will most probably change course, e.g. at a navigation mark). The rules of the road and collision avoidance regulations must also be clearly understood by the pilot.

Operation of the AutoNaut is intended to be by people who have experience of the marine environment and can therefore develop good situational understanding from the user interface presented by the pilot software. It is not simply a matter of learning how to use the pilot software: as a wave powered vessel AutoNaut is different and the pilot cannot intervene to drive rapidly ahead or astern, stop, or make warning signals.

The depth of knowledge required of pilots will depend on the intended pattern of operation of the AutoNaut, individual missions, and the operating environment.

The following list, which is not exhaustive, reflects general knowledge requirements:

- Operating area structure and operating requirements
- Maritime rules and regulations
- AutoNaut hydrodynamics, including effects of controls
- AutoNaut system knowhow
- AutoNaut performance
- Navigation
- Meteorology, tides and currents
- Communications procedures
- Mission preparation

In addition to base qualification and prior experience, pilots should undertake training. Training shall be tailored to the needs of different AutoNaut personnel (e.g. Pilot, maintenance crew, etc.)

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Pilot(s) are understood to be one (or more) person(s) working through the pilot software to monitor and control one (or more) AutoNaut. Other AutoNaut personnel, such as engineers, maintenance crew etc. will also need suitable training.

New customers should carry out a safety review prior to commencement of operations. This is to ensure familiarity with the potential hazards and the mitigations described within this manual. It should establish that the operator understands the mission hazards. The person with overall responsibility for the safe operation of the AutoNaut(s) should be identified and they must be clear about their duties and responsibilities for safety.

Continuous Improvement

Minimum standards of competence for operators in charge of the AutoNaut should cover proficiency to an achieved level, and currency maintained though study and practice.
AutoNaut Ltd has a policy of continuous improvement for AutoNaut and all its systems and will be happy to share and disseminate learning to its users.

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7 User Feedback to AutoNaut Ltd

AutoNaut Ltd wishes to maintain a proactive communication with all its customers, and will establish an agreed routine for regular exchange of user experience and product development.
At the end of each mission, the user is requested to send a Feedback Report to AutoNaut Ltd, containing the following information:

1. From:
2. Reference:
3. AutoNaut Serial Number:
4. Owner:
5. Date of deployment
6. Period of deployment (Days and Hours)
7. Task type
8. Max Sea State
9. Min Sea State
10. Distance covered
11. Overall performance rating (Very Good, Good, Satisfactory, Minor Concerns, Unsatisfactory)
12. Supporting evidence:
    a. Hull
        i. Struts
        ii. Stress cracks
        iii. Internal moisture level
        iv. External Fouling
    b. Power system (Battery, Fuel Cell)
    c. Sensor effectiveness
    d. Communications quality
    e. Navigation accuracy
13. Recommendations for improvement
14. Comments

AutoNaut Ltd may be contacted as follows:

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