SOI ROV Progress Update

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Director of Research

Robotic vehicle development as part of the Schmidt Ocean Institute research program

Schmidt Ocean Institute was founded to advance the frontiers of ocean research and exploration through innovative technologies, intelligent observation and analysis, and open sharing of information.

Schmidt Ocean Institute core focus areas:

- Commitment to Excellence in Oceanographic Research Operations
- **Infrastructure, Platform, and Technology Development for Marine Sciences**
- Collaborative Scientific Research aboard Falkor
- Communications, Education, and Outreach Program
- Open Sharing of Information, Data, and Research Outcomes

Infrastructure, Platform, and Technology Development for Marine Sciences

- **Robotic research vehicles (HROV, ROV, AUV, ASV, UAV, gliders, etc.)**
- **Deployable scientific platforms and analytical instruments**
- **At-sea R&D in technologies and computational algorithms on R/V Falkor and vehicles**
- **Technology focused R&D projects as part of Falkor cruise program**

Long term goal is to develop a robotic system to support regular full ocean depth scientific operations from R/V Falkor

SOI vehicle program goals

In coordination with the Board of Directors, Schmidt Ocean Institute is planning to develop a series of three remotely controlled and one autonomous robotic vehicles for use on research vessel Falkor.

The remotely controlled vehicles will be developed sequentially, with gradually advancing depth and operational capabilities, with the goal to support scientific research throughout wide range of ocean depths, including scientific operations at full ocean depth.

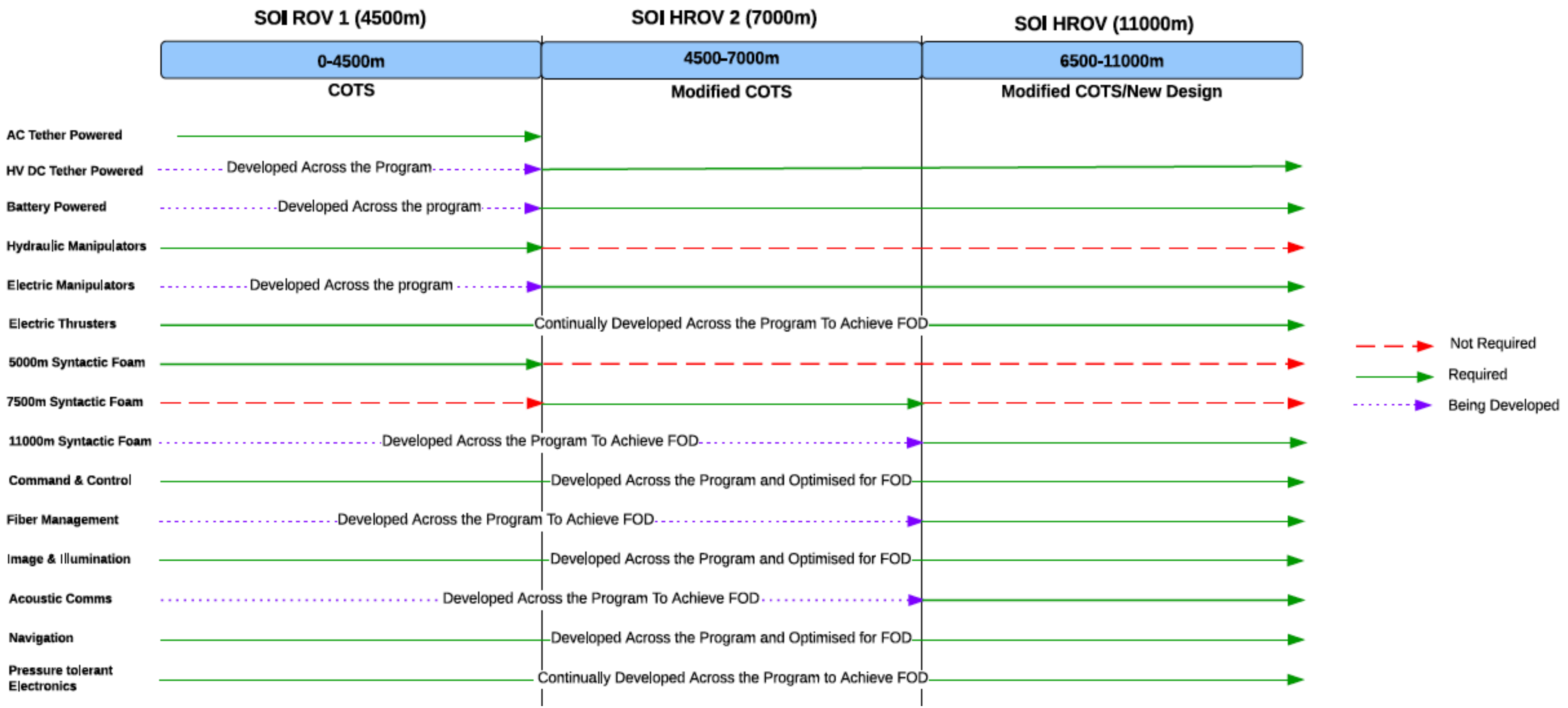
The goal for the first 4500m vehicle development is not to push the boundaries of high risk technology R&D, as will be the case for the subsequent vehicles, but to demonstrate the ability of the SOI engineering team to manage the vehicle development and on-time delivery before initiating the development of higher risk vehicles and technologies.

Vehicles under development and consideration

SOI anticipates to develop robotic vehicles with annual iterations:

- 4500m remotely operated hydraulic vehicle based on COTS technologies
  - Develop the engineering team, culture and prove SOI can deliver its own vehicle
  - Provides SOI with a robotic platform to R/V Falkor to develop operational experience
- 6000m maneuverable autonomous underwater vehicle
  - "Companion" vehicle to support surveys ahead of the 4500m ROV operations
  - Development of scientific mission requirements commencing in 2015
- 7500m battery powered hybrid remotely operated vehicle
  - Develops the knowledge & technologies for FOD
- 11000m battery powered hybrid remotely operated vehicle
  - Capability to support regular scientific operations at full ocean depth

Continuity of vehicle subsystem development



ROV Program Schedule

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4500m ROV development: key project dates

Preliminary Design Review (PDR)	Wed 9/2/15	Fri 9/4/15
Detailed Design Review (DDR)	Thu 12/17/15	Fri 12/18/15
Conduct Factory Acceptance Test (FAT)	Mon 4/11/16	Wed 4/20/16
MBARI tank testing	Thu 4/21/16	Sun 5/1/16
System mobilization on R/V Falkor (Guam)	Mon 5/30/16	Fri 6/3/16
Deadhead transit preparations (Vietnam - Guam)	Thu 6/23/16	Fri 7/1/16
Falkor integration	Fri 7/1/16	Sun 8/14/16
- Winch System	Fri 7/1/16	Sun 7/3/16
- Docking Head	Fri 7/1/16	Sun 7/3/16
Sea Acceptance Trial (winch & docking head)	Mon 7/4/16	Thu 7/7/16
Sea Trial 1 (Engineering)	Tue 7/12/16	Sat 7/30/16
Sea Trial 2 (Confirmation)	Sun 7/31/16	Sun 8/14/16
Science Verification Cruise (SVC)	Fri 11/18/16	Tue 11/29/16

Scientific Advisory Group: Structure and Tasks

- Scientific mission requirements for the SOI 4500m ROV are developed in coordination with an international group of 44 deep sea researchers and technology developers
- Research fields represented in the SAG:
  - Geosciences – 8 experts
  - Marine Biology – 9 experts
  - Microbiology – 8 experts
  - Geochemistry – 7 experts
  - Ocean Technology – 13 experts
- Countries:
  - Australia, Canada, Germany, Japan, Singapore, UK, USA
- Participation:
  - Survey 1 (Science Mission Requirements): 28 experts responded
  - Survey 2 (Instrument Selection): 30 experts responded

Scientific Advisory Group: Composition

SAG representatives who participated in both surveys and agreed to be identified in both cases:

- Marine Biology:
  - Chris Kelley, U. Hawaii, USA
  - Erik Cordes, Temple U., USA
  - Cindy Van Dover, Duke U., USA
  - Charles Fisher, PennState, USA
- Microbiology:
  - Kim Juniper, U. Victoria, Canada
  - Gregory Dick, U. Michigan, USA
  - Doug Bartlett, SIO, USA
  - Jon Kaye, GBMF, USA
  - Peter Girguis, Harvard, USA
- Geosciences:
  - Bill Chadwick, PMEL / OSU, USA
  - Colin Devey, GEOMAR, Germany
  - Neil Mitchell, U. Manchester, UK
- Geochemistry:
  - Tom Kwasnitchka, GEOMAR, Germany
  - Tina Treude, UCLA, USA
- Ocean Technology:
  - Vicki Ferrini, LDEO, USA
  - Mandar Chitre, Natl. U. of Singapore
  - Brian Midson, NSF, USA

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4500m ROV Instrument Selection:

Core and Add-On Instruments

System/Sensor Specified	Agree	Neutral	Disagree	SMR Priority
	(# responses)	(# responses)	(# responses)	(5 is highest)
Core System Sensors				
CTD Sensor - Seabird FastCAT CTD Sensor (SBE49)	**22**	**3**	**1**	**4.68** ± 0.78
Pressure Depth Sensor - Paroscientific 8000 Series Submersible Depth Sensor	**20**	**6**	**0**	**N/A**
Oxygen Sensor - Contros Hydroflash O2 Sensor	**13**	**11**	**0**	**4.36** ± 0.83
Add-On System Sensors				
Turbidity Sensor - Sea-Point Turbidity Meter (STM/MCBH6M)	**16**	**9**	**1**	**3.67** ± 1.4
Carbon Dioxide Sensor - Contros HydroC CO2	**14**	**11**	**0**	**3.8** ± 0.73
Nitrate Sensor - Seabird DeepSUNA	**12**	**11**	**2**	**2.2** ± 1.0
In-situ Mass Spectrometer - Sea Monitor	**13**	**11**	**1**	**3.5** ± 0.78
High Temperature Water Sensor - TBD	**14**	**8**	**2**	**4.15** ± 1.2
Biomolecular Analyzer - TBD	**11**	**12**	**1**	**2.84** ± 1.4
Redox Potential Sensor - TBD	**10**	**10**	**3**	**3.83** ± 1.4
Fluorometer - TBD	**8**	**9**	**6**	**3.2** ± 1.3

System/Sensor Specified	Agree (# responses)	Neutral (# responses)	Disagree (# responses)		SMR Priority (5 is highest)
Core Imaging Suite					
Situational Video - Sulis-1 4K video camera	**17**	**8**	**0**		**4.59** ± 0.73
HD Science Zoom - Insite Zeus Plus	**22**	**2**	**0**		**N/A**
HD Camera - HD Multi SeaCam 6150	**18**	**6**	**0**		**N/A**
Pan / Tilt / Zoom - Schilling	**16**	**6**	**0**		**4.75** ± 0.84
High Resolution Still Image Capture - Sulis	**16**	**5**	**1**		**4.82** ± 0.48
Full Spectrum LED Lighting - DeepSea Power & Light, Inc. SLS-6150	**21**	**2**	**0**		**4.79** ± 0.42
Video recording system - Triton Technical	**18**	**5**	**0**		**3.83** ± 1.2
Frame Grabber - Greensea Systems	**18**	**4**	**1**		**4.64** ± 0.91
Add-On Imaging Suite					
3DHD - TBD	**14**	**8**	**2**		**3.28** ± 1.4
Audio Recording Capability - TBD	**7**	**10**	**7**		**3.19** ± 1.5

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4500m ROV Instrument Selection:

Core and Add-On Imaging Systems

4500m ROV Instrument Selection:

Core and Add-On Sampling Systems

System/Sensor Specified	Agree	Neutral	Disagree		SMR Priority
	(# responses)	(# responses)	(# responses)		(5 is highest)
Core Sampling System					
Water Sampler - Optimized Niskin Design	**16**	**9**	**0**		**4.11** ± 1.2
Add-On Sampling Systems					
Multi-Chamber Suction Sampler - Custom Build	**17**	**5**	**2**		**4.69** ± 0.62
Push Core - Custom Build	**18**	**4**	**1**		**4.32** ± 0.86
Rock Saw / Cutter / Splitter / Core - TBD	**11**	**11**	**1**		**3.4** ± 0.99
Multichamber Insulated Bioboxes (for fragile animals) - TBD	**16**	**5**	**2**		**4.75** ± 0.44

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4500m ROV Instrument Selection:

Core and Add-On Survey Systems

System/Sensor Specified	Agree (# responses)	Neutral (# responses)	Disagree (# responses)		SMR Priority (5 is highest)
Core Sonar Systems					
Forward Looking Imaging and Multibeam Mapping Sonar - M3 Multibeam Echosounder	**16**	**7**	**0**		**4.67** ± 0.67
Singlebeam 360° scanning sonar - Mesotech 1071 Series Sonar Head	**17**	**5**	**0**		**2.87** ± 1.6
Add-On Sonar Systems					
Sidescan Sonar - TBD	**11**	**7**	**5**		**3.05** ± 1.5
Magnetometer - TBD	**12**	**9**	**2**		**2.7** ± 1.3
Sub-Bottom Profiler - TBD	**11**	**10**	**2**		**2.95** ± 1.3
Photographic Seafloor 3d/2d Mosaicing - TBD	**13**	**9**	**1**		**4.63** ± 0.65

4500m ROV Instrument Selection:

Payload Interfaces

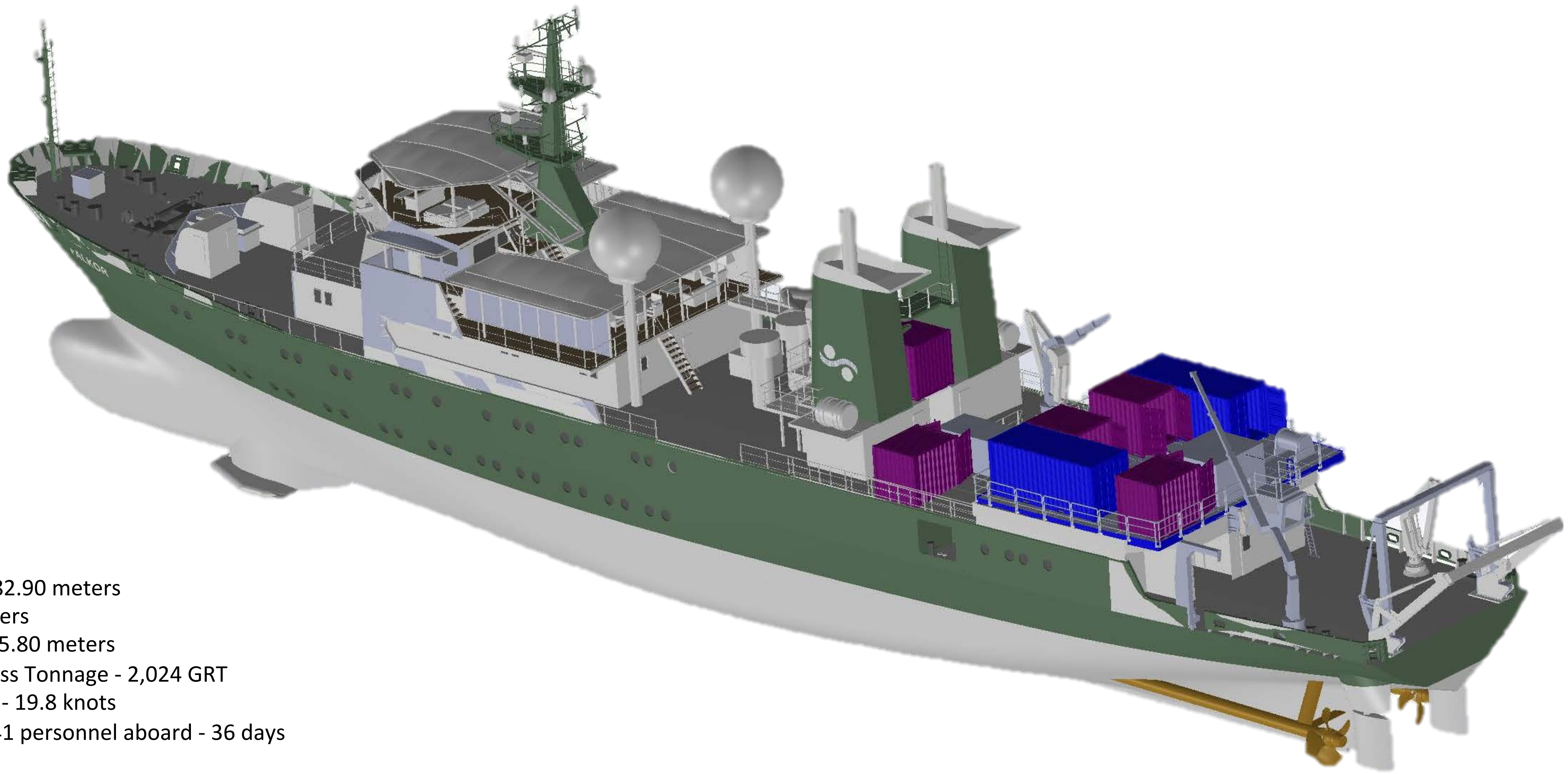
System/Sensor Specified	Agree (# responses)	Neutral (# responses)	Disagree (# responses)		SMR Priority (5 is highest)
Vehicle Interfaces					
RS-232 ports up to 115 Kbps - Core Interface	**17**	**7**	**0**		**4.5** ± 0.94
RS-485/RS-422 ports up to 2.5 Mbps	**16**	**7**	**0**		**4** ± 1.2
Ethernet 10/100 Mbps	**18**	**5**	**0**		**4.86** ± 0.36
Time-to-live (TTL) link	**9**	**14**	**0**		**3.2** ± 0.84
3 optical fibers for high speed data transfer	**18**	**5**	**0**		**3.93** ± 1.3
Power 5 VDC, 12 VDC, 24 VDC, and 230 VAC	**19**	**4**	**0**		**5** ± 0
At least four (4) hydraulic rate valve pack channels	**14**	**9**	**0**		**4.11** ± 0.78
At least two (2) hydraulic servo valve pack channels	**14**	**9**	**0**		**4.4** ± 0.84

4500m ROV Instrument Selection:

Core and Add-On Navigation Systems

System/Sensor Specified	Agree (# responses)	Neutral (# responses)	Disagree (# responses)		SMR Priority (5 is highest)
Core Naviagation Systems					
Ring Laser Gyro - Sonardyne Lodestar	**16**	**8**	**0**		**4.78** ± 0.44
Inertial Measurement Unit / Inertial Navigation System (IMU/INS) - Sonardyne Sprint	**14**	**9**	**0**		**4.5** ± 0.73
Ultra-Short Baseline (USBL) Transponder - Sonardyne WMT	**19**	**4**	**0**		**4.85** ± 0.67
Doppler Velocity Log (DVL) - Sonardyne Syrinx	**20**	**3**	**0**		**4.84** ± 0.37
Global Positioning System (GPS) antenna - Iridium XEOS	**18**	**3**	**0**		**3.39** ± 1.9
Add-On Naviagation Systems					
Acoustic Doppler Current Profiler (ADCP) - TBD	**12**	**10**	**2**		**3.67** ± 1.1

R/V Falkor drives 4500m ROV design



Length Overall - 82.90 meters
Beam -13.00 meters
Draft (gondola) - 5.80 meters
International Gross Tonnage - 2,024 GRT
Maximum Speed - 19.8 knots
Endurance with 41 personnel aboard - 36 days

4500m ROV Design Constraints Snapshot

R/V Falkor

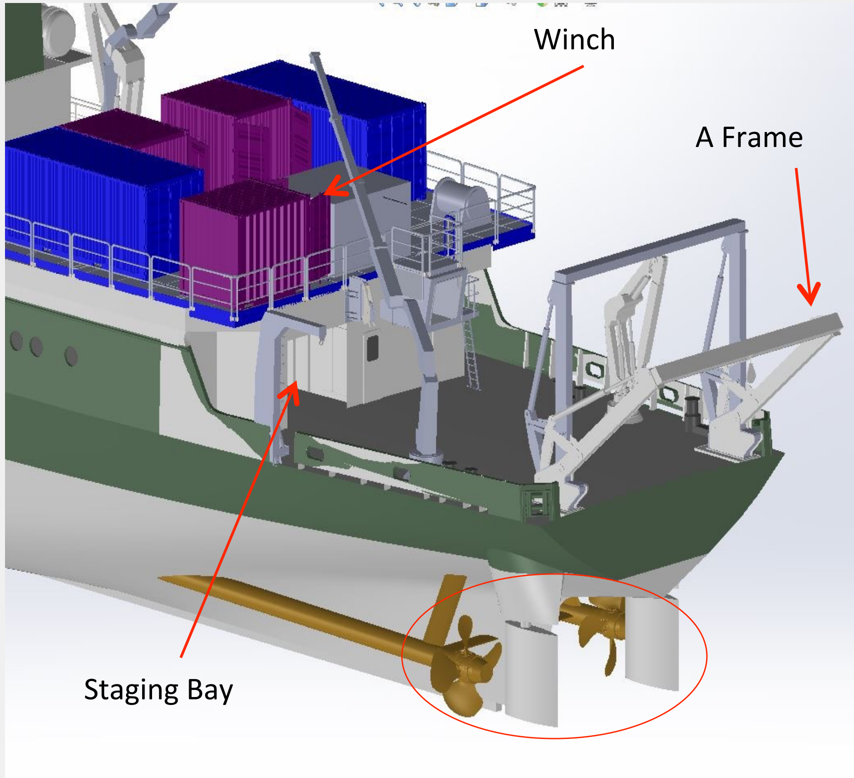
- A Frame (4500kg (veh 3200kg & docking head 1300kg))
- HIAB 301 rating – Emergency Recovery
- Storage Deck Loading (42ton (Winch & Container Weight))
- Staging Bay (hangar 2030mm x 2290mm)
- Dynamic Positioning limited capability (approx 50m watch circle)
- Propulsion and Fan Tail Layout
- Native Power (50Hz 380V)
- Science Control Room

Schedule

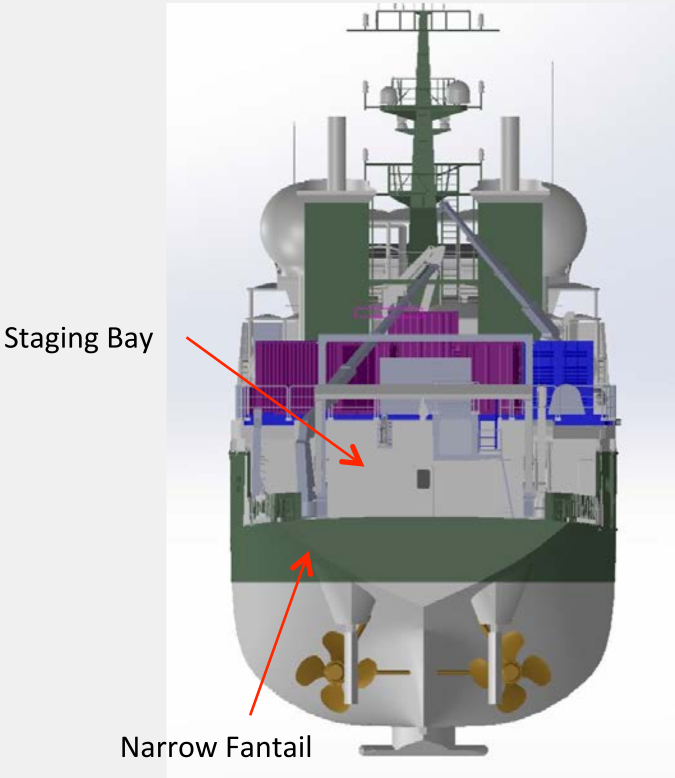
- FAT by End April 2016

R/V Falkor aft working deck

Falkor Danger Zone

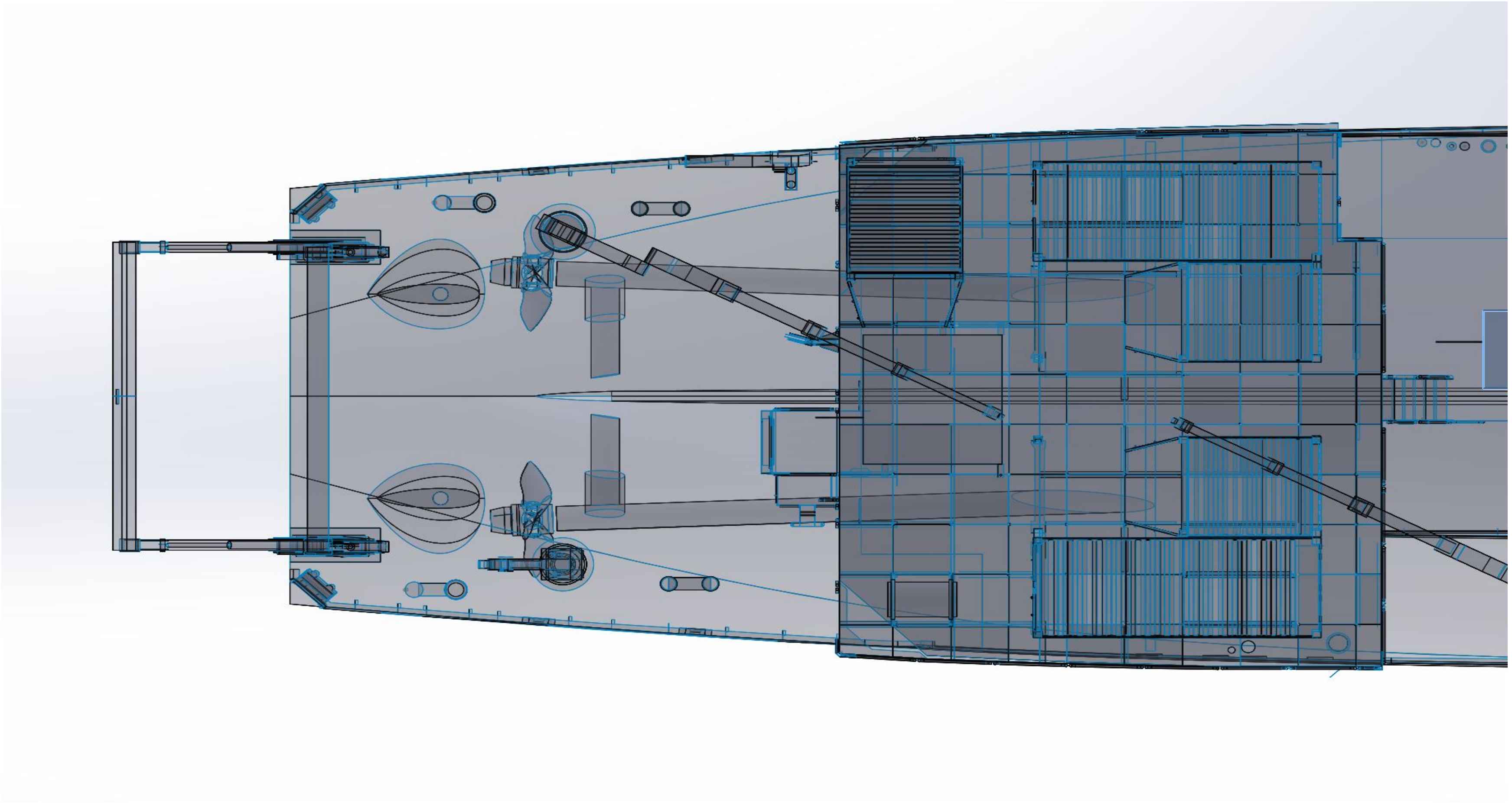


Falkor Rear View

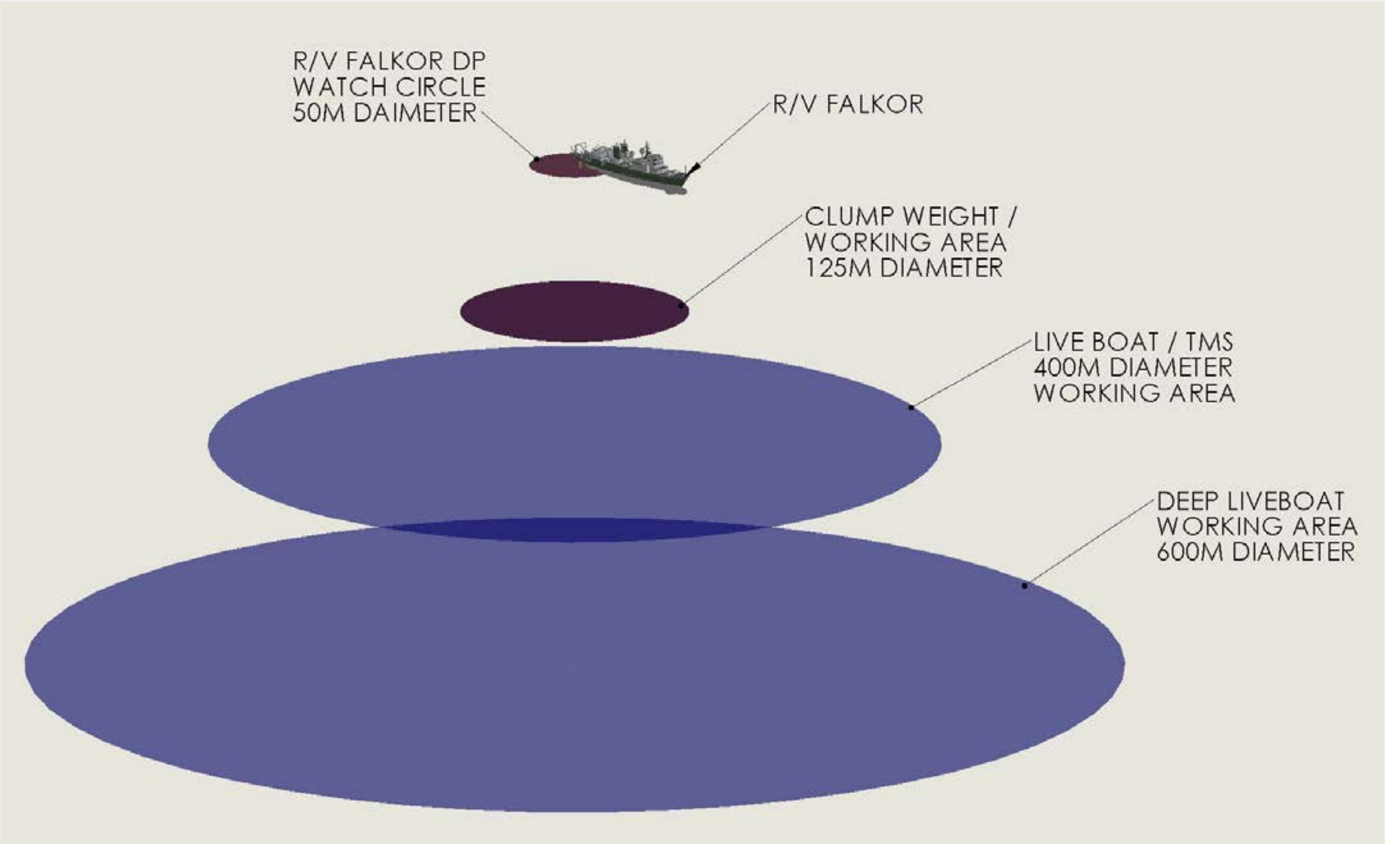


R/V Falkor

R/V Falkor Deck View



R/V Falkor



Single Body System

Excursion Distance Diameter 600m

Falkor Watch Circle radius approx 50m

Effective working Diameter 400-600m at 2000m – 5000m depth

2 Body System (Clump)

Assume 75m tether

Falkor Watch Circle Diameter approx. 50m

Effective working diameter 25m – 50m

Operational Description (Mode 1)

Launch

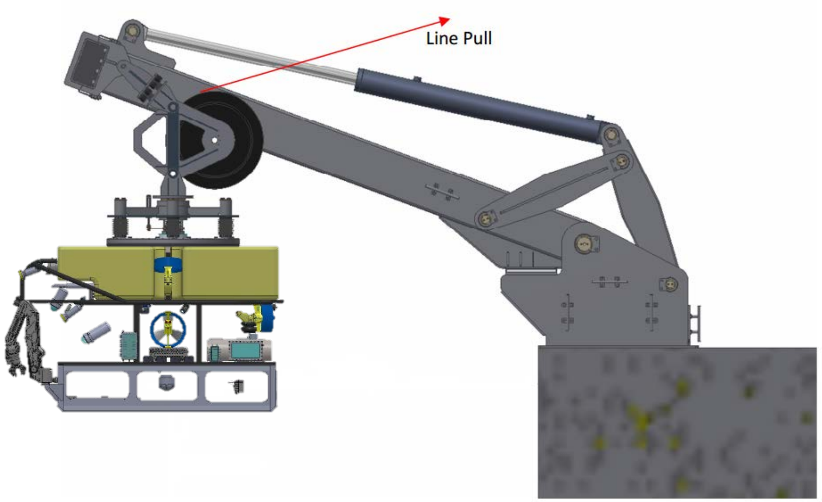
1. A-frame inboard, winch used to pick up vehicle (option: A-frame pickup)
2. Umbilical mechanical termination ‘captured’ by DH latch. Vehicle Secured.
3. A-frame luffing to outboard position
   - *Taglines used to control vehicle motion*
4. Winch builds tension on umbilical to remove load from Docking head latch
   - *Taglines removed*
5. Vehicle unlatched from DH (air operated), lowered to water surface.
6. Winch pays out, DH slack drive system activated (air operated)
7. Vehicle positions away from ship, starts descent.

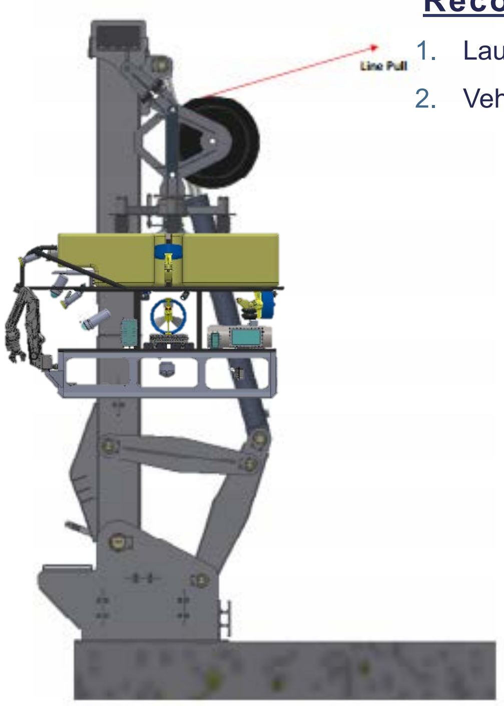
Float Installation

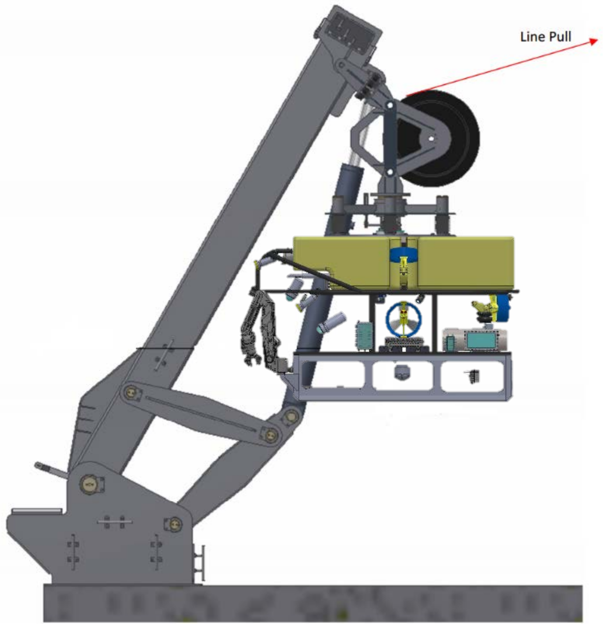
1. Vehicle descent to ~20m – Stop. Aframe moved to ~75° posn.
2. Two umbilical floats installed ~2m apart.
3. Vehicle descent to ~50m. 20x floats installed every 2m.
4. Vehicle full descent

Recovery

1. Launch in reverse.
2. Vehicle wil



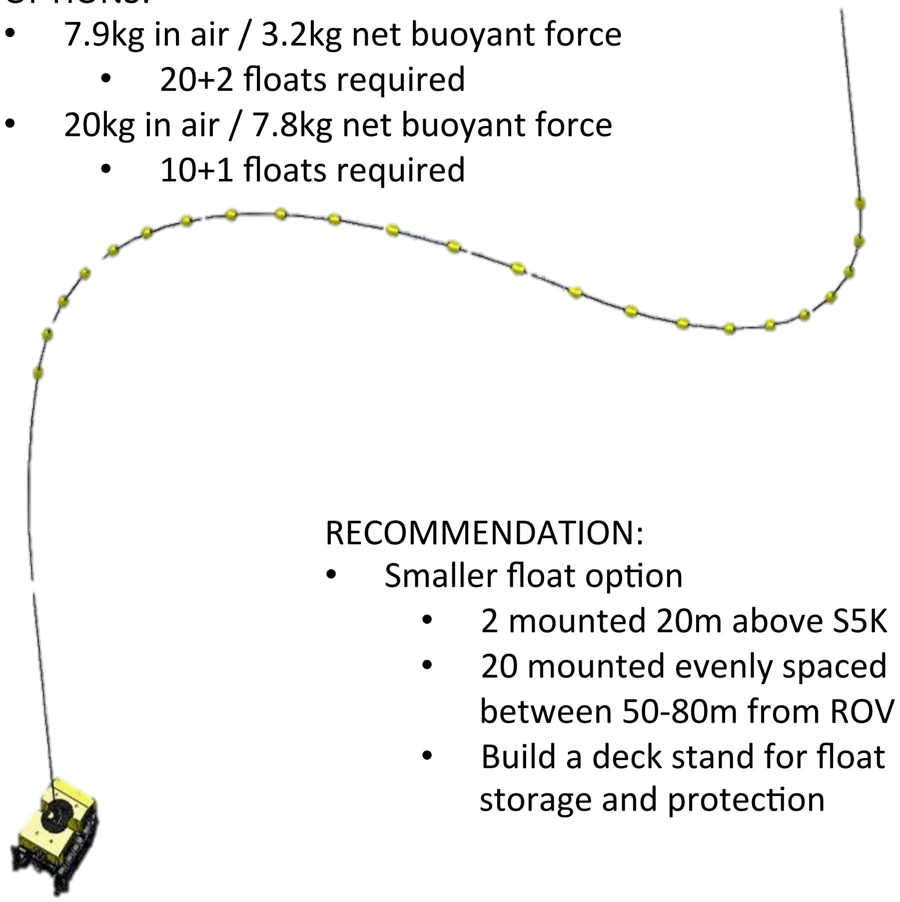




Catenary Floats

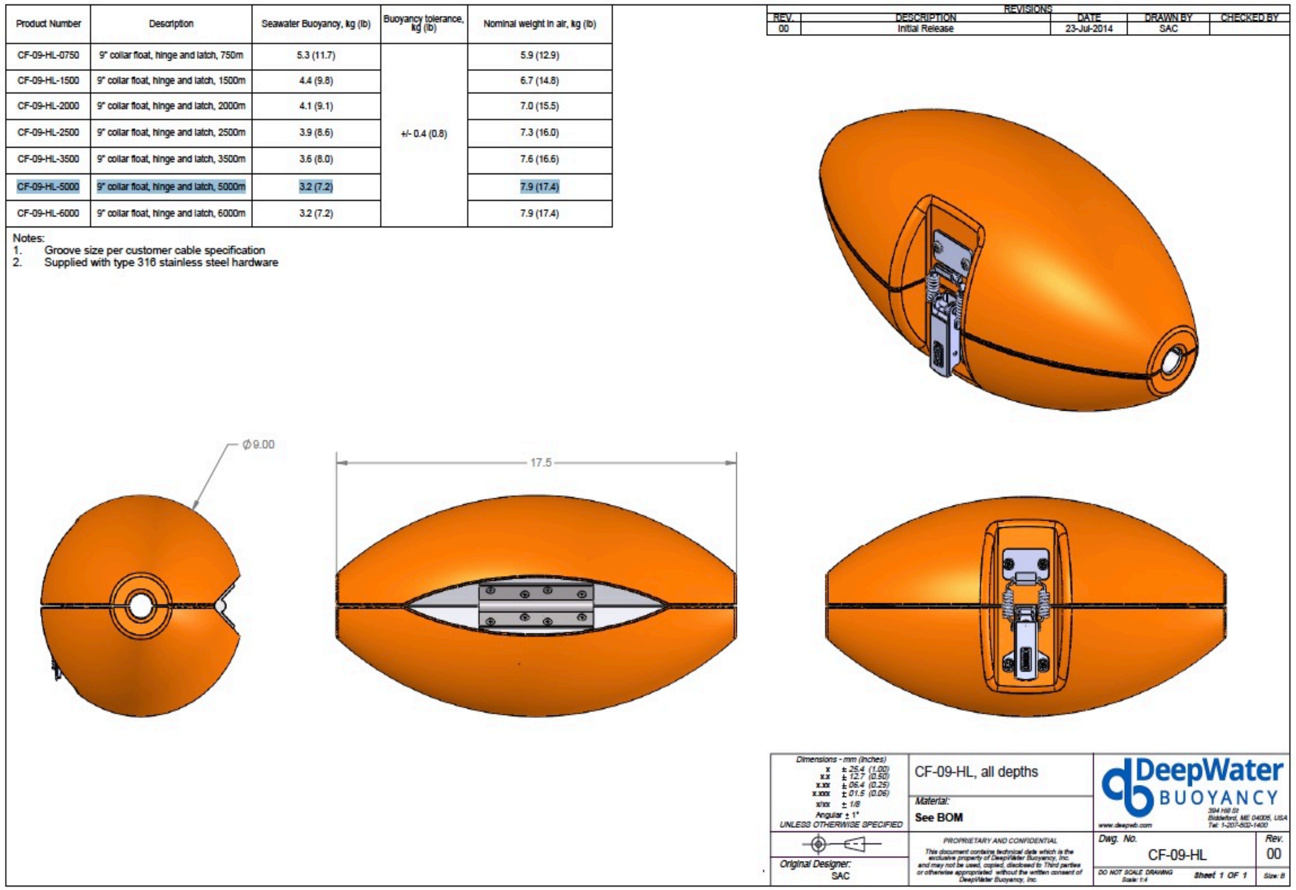
OPTIONS:

- 7.9kg in air / 3.2kg net buoyant force
    - 20+2 floats required
- 20kg in air / 7.8kg net buoyant force
    - 10+1 floats required



RECOMMENDATION:

- Smaller float option
    - 2 mounted 20m above S5K
    - 20 mounted evenly spaced between 50-80m from ROV
    - Build a deck stand for float storage and protection



Product Number	Description	Seawater Buoyancy, kg (lb)	Buoyancy tolerance, kg (lb)	Nominal weight in air, kg (lb)
CF-09-HL-0750	9" collar float, hinge and latch, 750m	5.3 (11.7)	+/- 0.4 (0.8)	5.9 (12.9)
CF-09-HL-1500	9" collar float, hinge and latch, 1500m	4.4 (9.8)		6.7 (14.8)
CF-09-HL-2000	9" collar float, hinge and latch, 2000m	4.1 (9.1)		7.0 (15.5)
CF-09-HL-2500	9" collar float, hinge and latch, 2500m	3.9 (8.6)		7.3 (16.0)
CF-09-HL-3500	9" collar float, hinge and latch, 3500m	3.6 (8.0)		7.6 (16.6)
CF-09-HL-5000	9" collar float, hinge and latch, 5000m	3.2 (7.2)		7.9 (17.4)
CF-09-HL-6000	9" collar float, hinge and latch, 6000m	3.2 (7.2)		7.9 (17.4)

Notes:
1. Groove size per customer cable specification
2. Supplied with type 316 stainless steel hardware

ROV General Assembly Design – Constraints

Constraints:

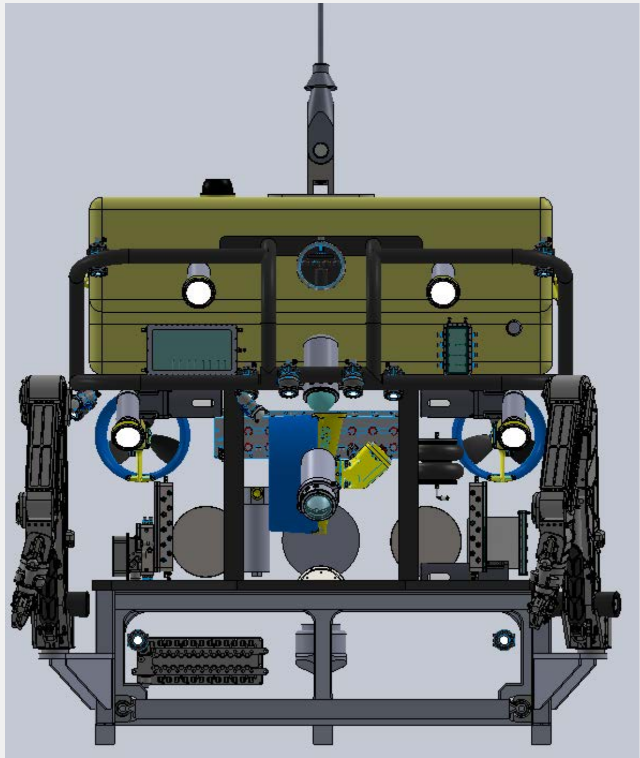
1. Staging bay opening WxH, (2450mmx 2312mm)

2. Standard transport container spatial constraints.
   - High cube container.
   - Container will also have docking head, and possibly other equipment.

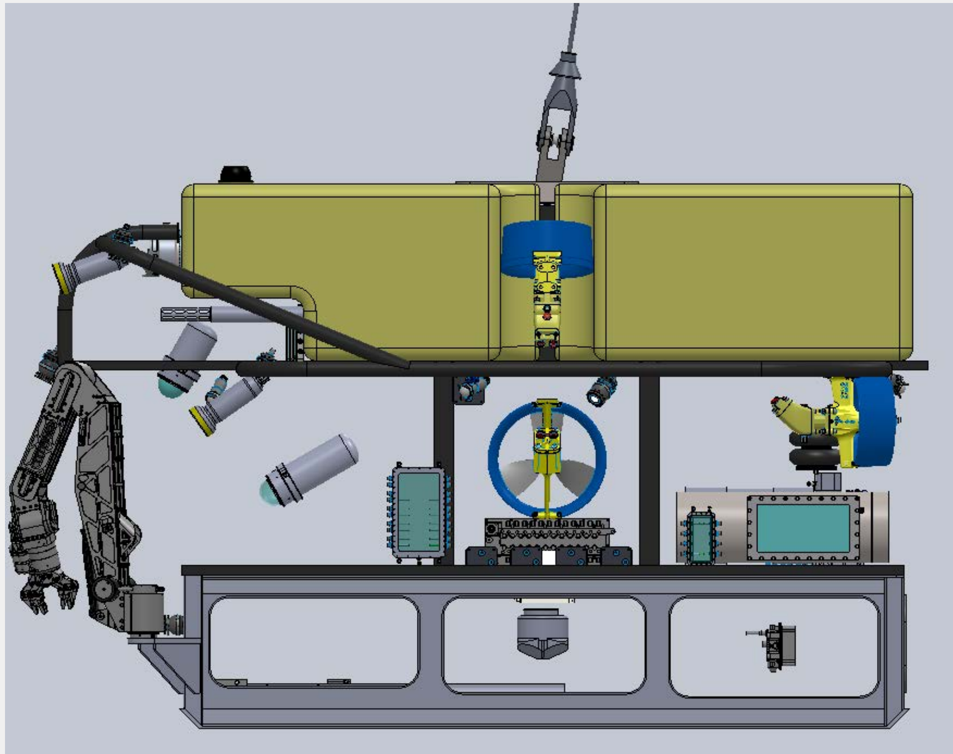
3. A-frame allowable WxH (6.96m x 6.15m)
   - Vehicle must travel over umbilical float installation railing (~1.118m high)
   - Maximum A- frame load capacity – Max vehicle weight set at 3200kgf (luffing)

SOI 4500m ROV – Vehicle Current Layout

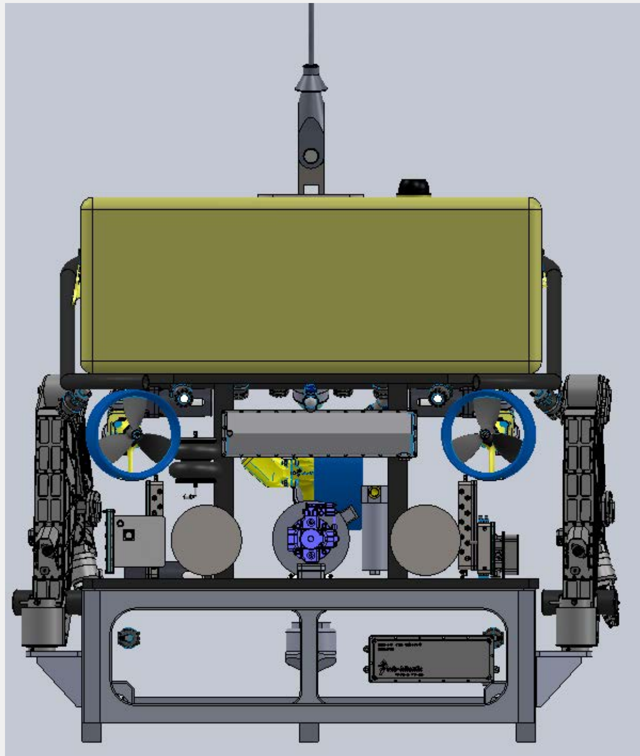
Front View

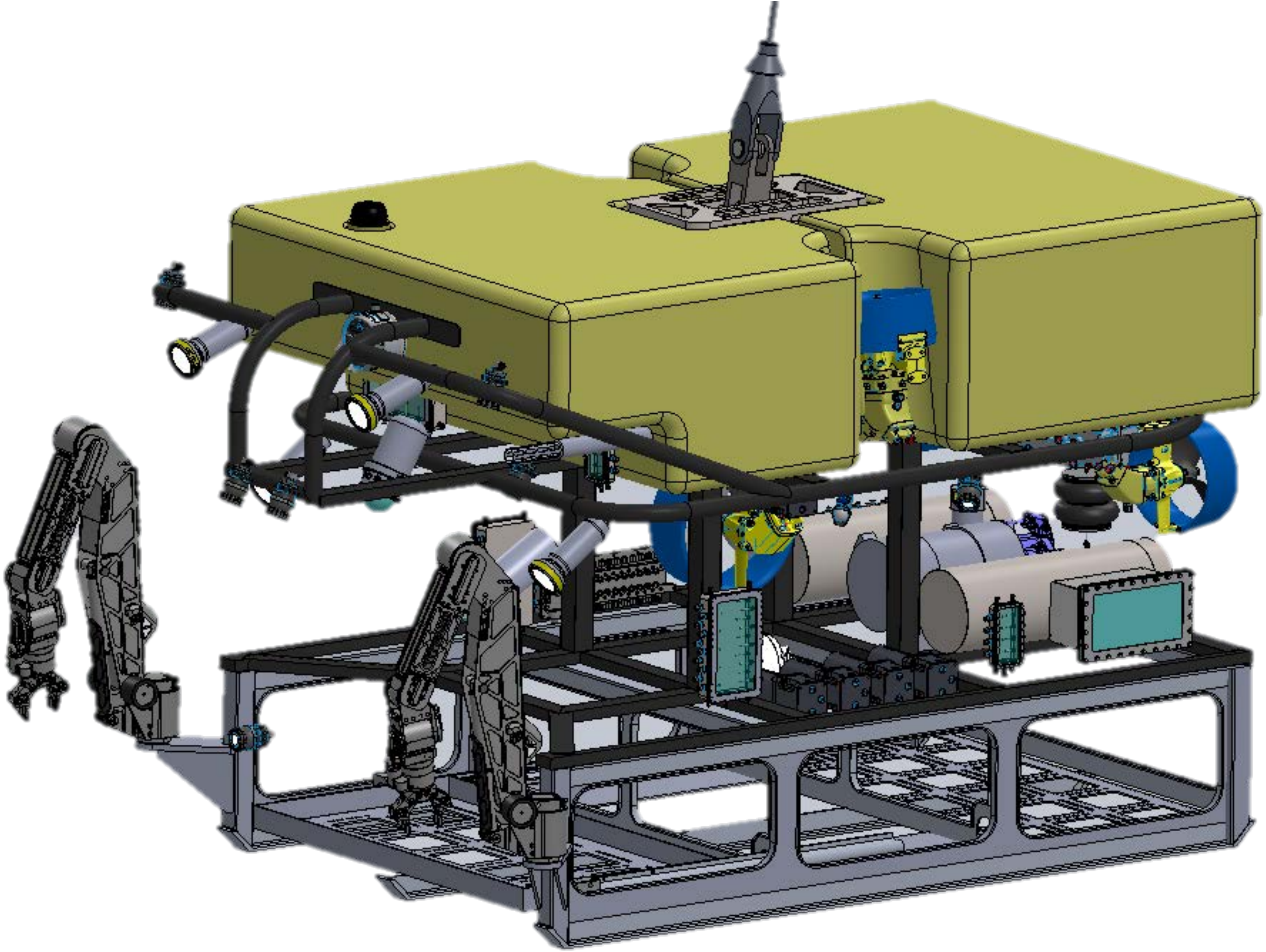


Side View

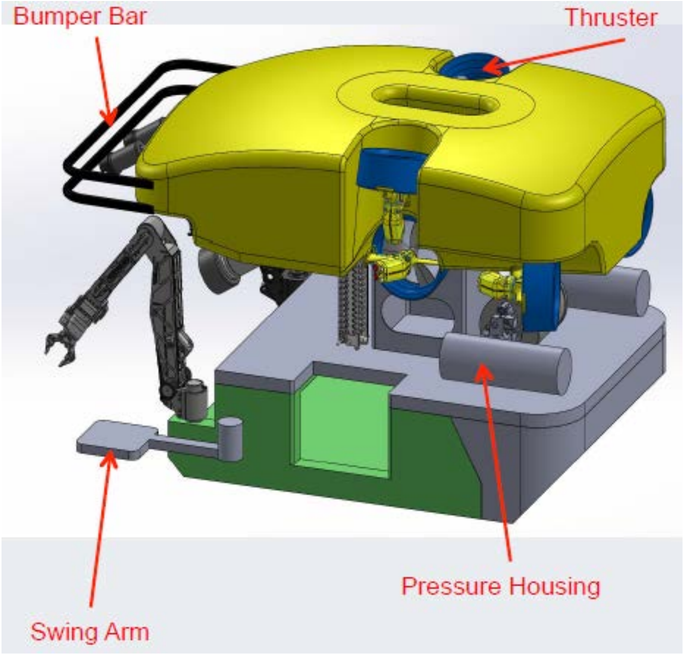


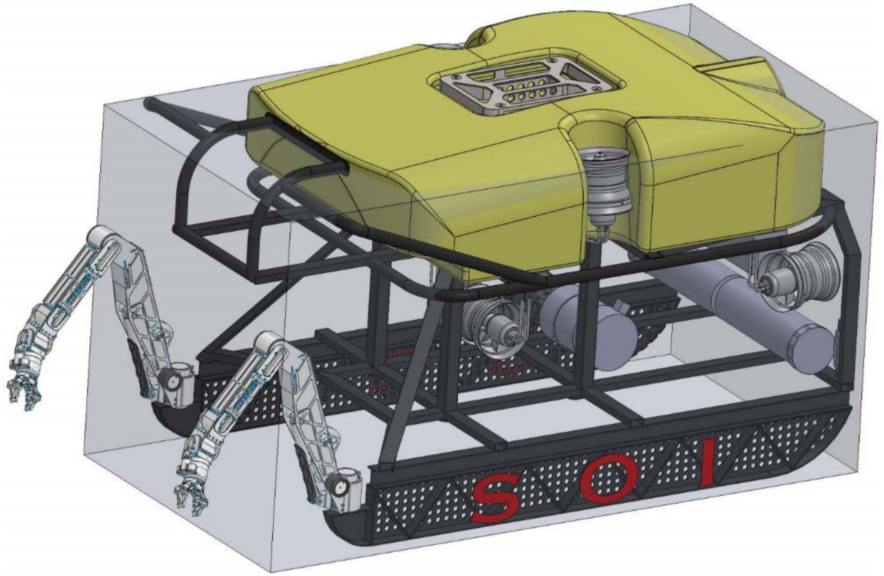
Back View

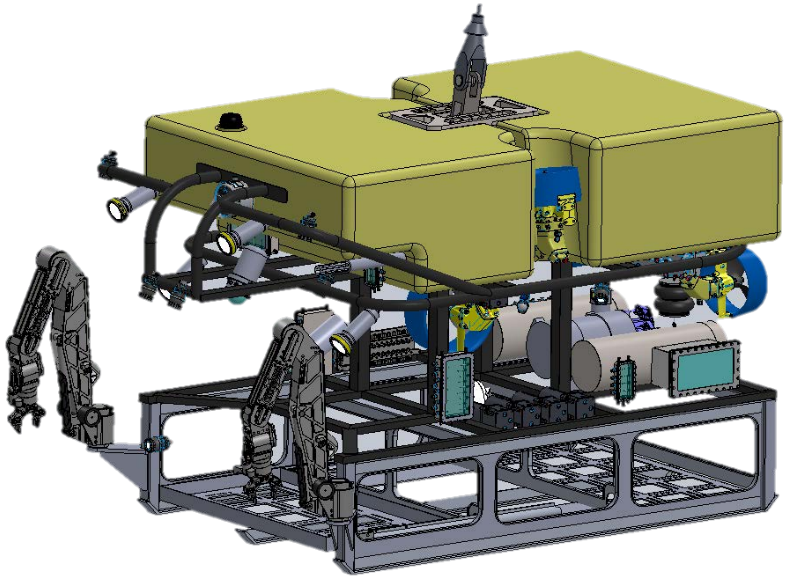


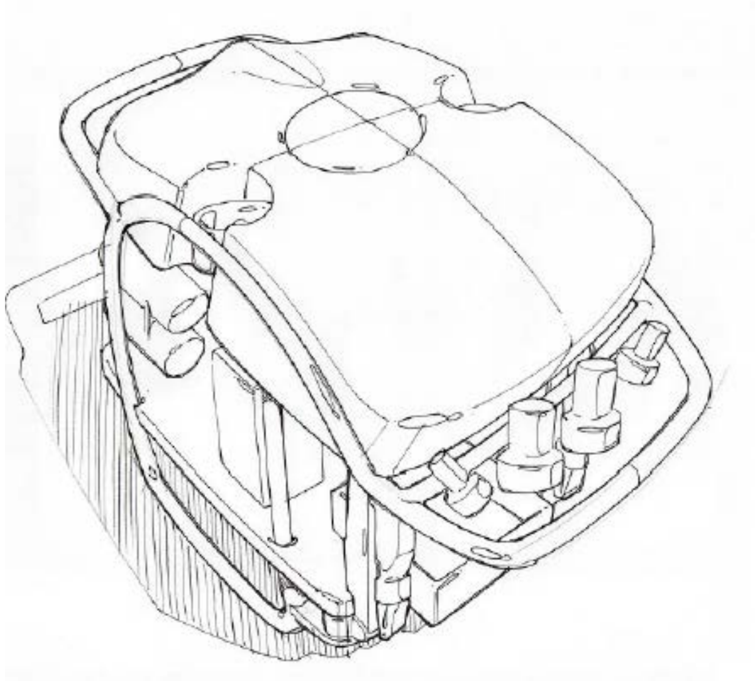


4500m ROV









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ROV Form Evolution