M B A R I

AUV Technology and Application Basics

Section 2

William Kirkwood, Mark Sibenac,

Hans Thomas, and Dr. James Bellingham

Monterey Bay Aquarium Research Institute

7700 Sandholdt Rd.

Moss Landing, Ca. 95039

www.mbari.org

AUV Technology and Application Basics

Mechanical Systems and Vehicle Handling

- Basic Architectures
- Payload Configuration
- Propulsion
  - Drag and Efficiency
  - Some Examples
- Things That Effect Control
- At Sea Operations

Basic Architectures

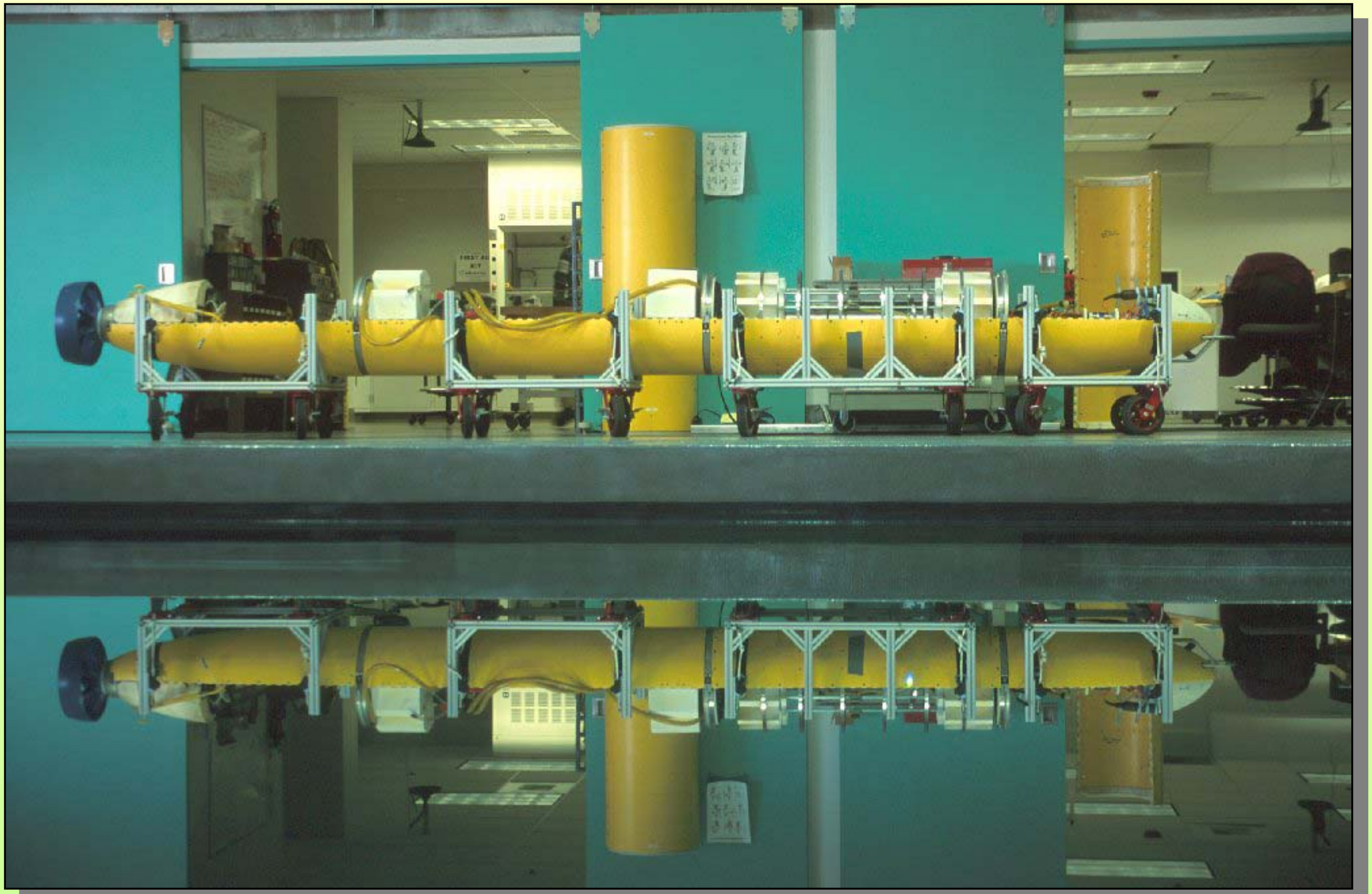
- Basic Architectures
  - Single Purpose
  - Fixed Hull Multi Purpose
  - Modular

Torpedo image from U.S. Navy web page: www.chinfo.navy.mil

Odyssey IIb image from MIT Sea Grant AUV Lab web page: http://auvlab.mit.edu

AUV Technology and Application Basics

- Basic Architectures
  - Modular



Picture: Courtesy of Todd Walsh - MBARI

What do you gain or loose by selecting one vehicle type of another?

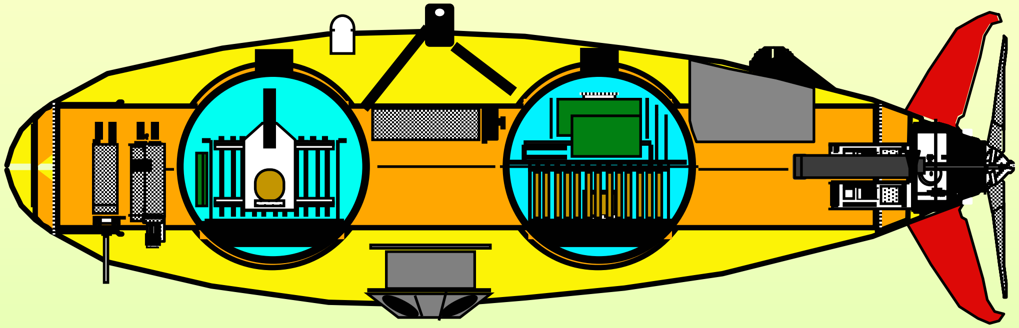
Single Purpose Architecture:

- ***Gains***
  - Reliability
  - Size and Weight (Maybe)
  - Cost
- ***Losses***
  - Flexibility
  - Opportunity
  - Capability

Great for the military (industry ?) but not what many scientists need.

AUV Technology and Application Basics

- Basic Architectures
  - Fixed Hull Multi Purpose



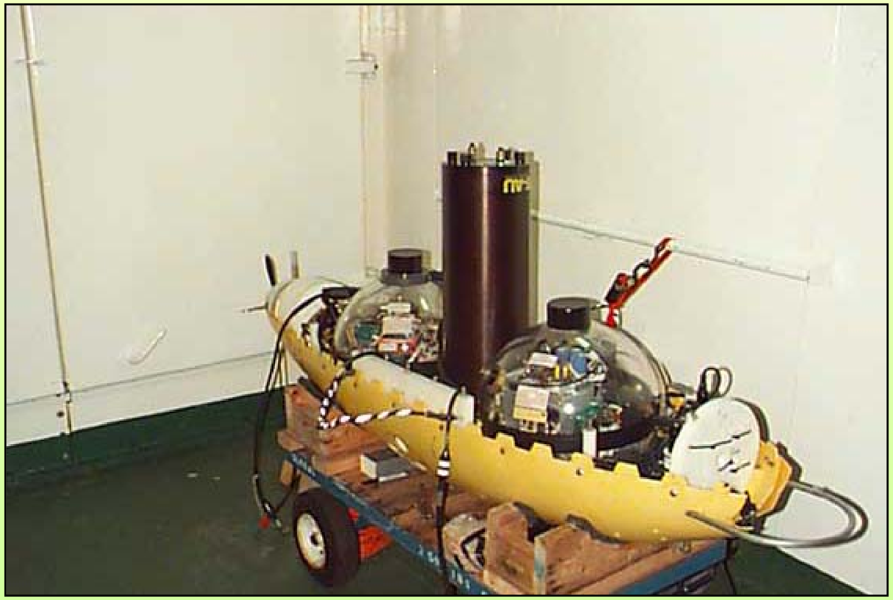
picture: courtesy J.G.Bellingham - MBARI

Odyssey IIb images from MIT Sea Grant AUV Lab web page: http://auvlab.mit.edu

What do you gain or loose by selecting one vehicle type of another?

Fixed Hull Multi Purpose:

- ***Gains***
  - **Some Flexibility**
  - **Size and Weight (Maybe)**
  - **Added Capability**
  - **Added Opportunity**
- ***Losses***
  - **Entire Vehicle Involved**
  - **Expert Users**
  - **Payload Size Sensitive**

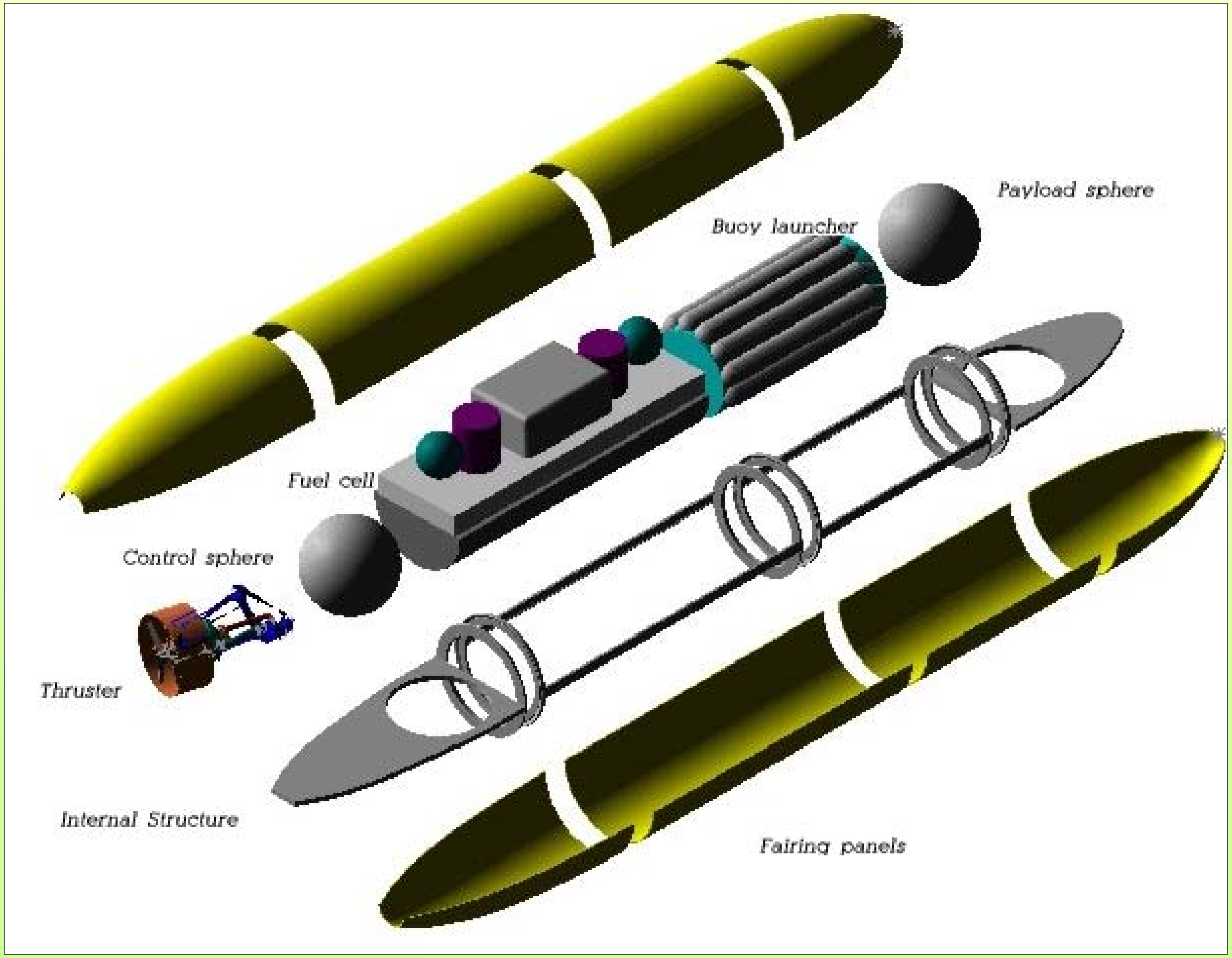


Odyssey IIb image from MIT Sea Grant AUV Lab web page: http://auvlab.mit.edu

Better but still not what many scientists need.

AUV Technology and Application Basics

- Basic Architectures
  - Modular



Picture: Courtesy ALTEX development team

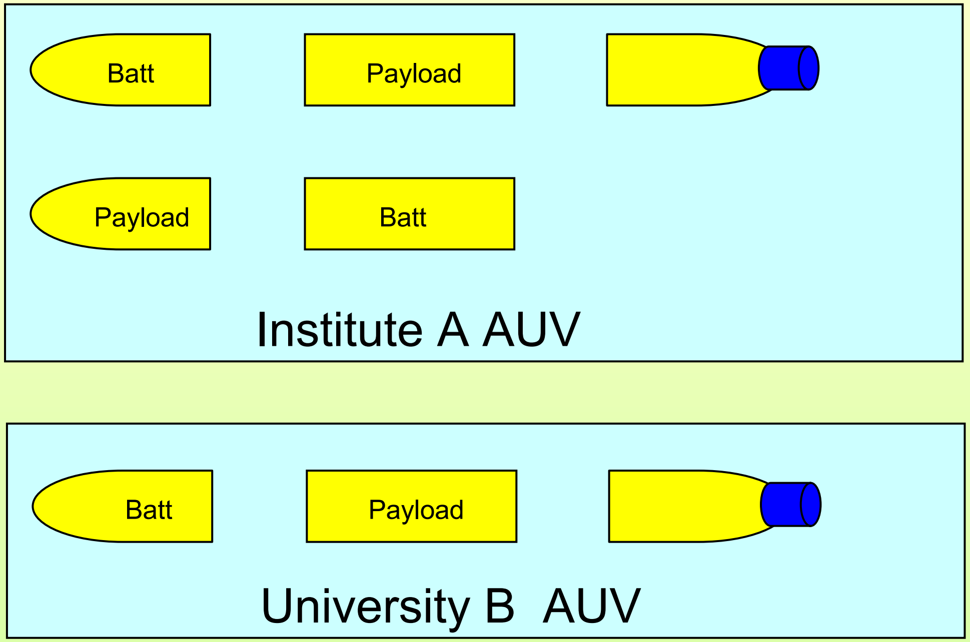
What do you gain or loose by selecting one vehicle type of another?

Modular Architecture:

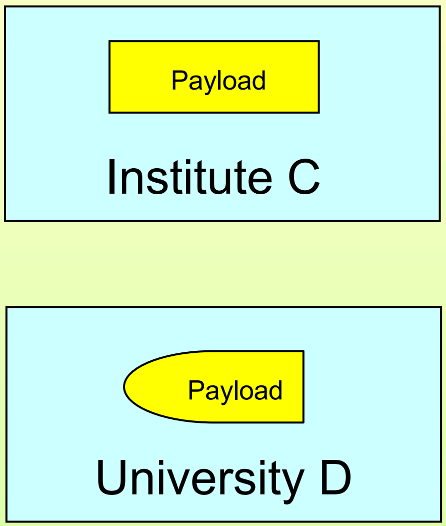
- ***Gains***
  - Lots of Flexibility
  - Payload Options
  - Lots of Capability
  - More Opportunity
  - Easier Maintenance
  - Larger User Base
  - Reliability
- ***Losses***
  - Weight and Size
  - Additional Cost Initially

A vehicle for many science applications.

Modular Architecture – what does that mean for my payload?



Note:
Tailcone and batteries are amortized over many missions and payloads versus each user supplying their own: <u>highly cost effective</u>



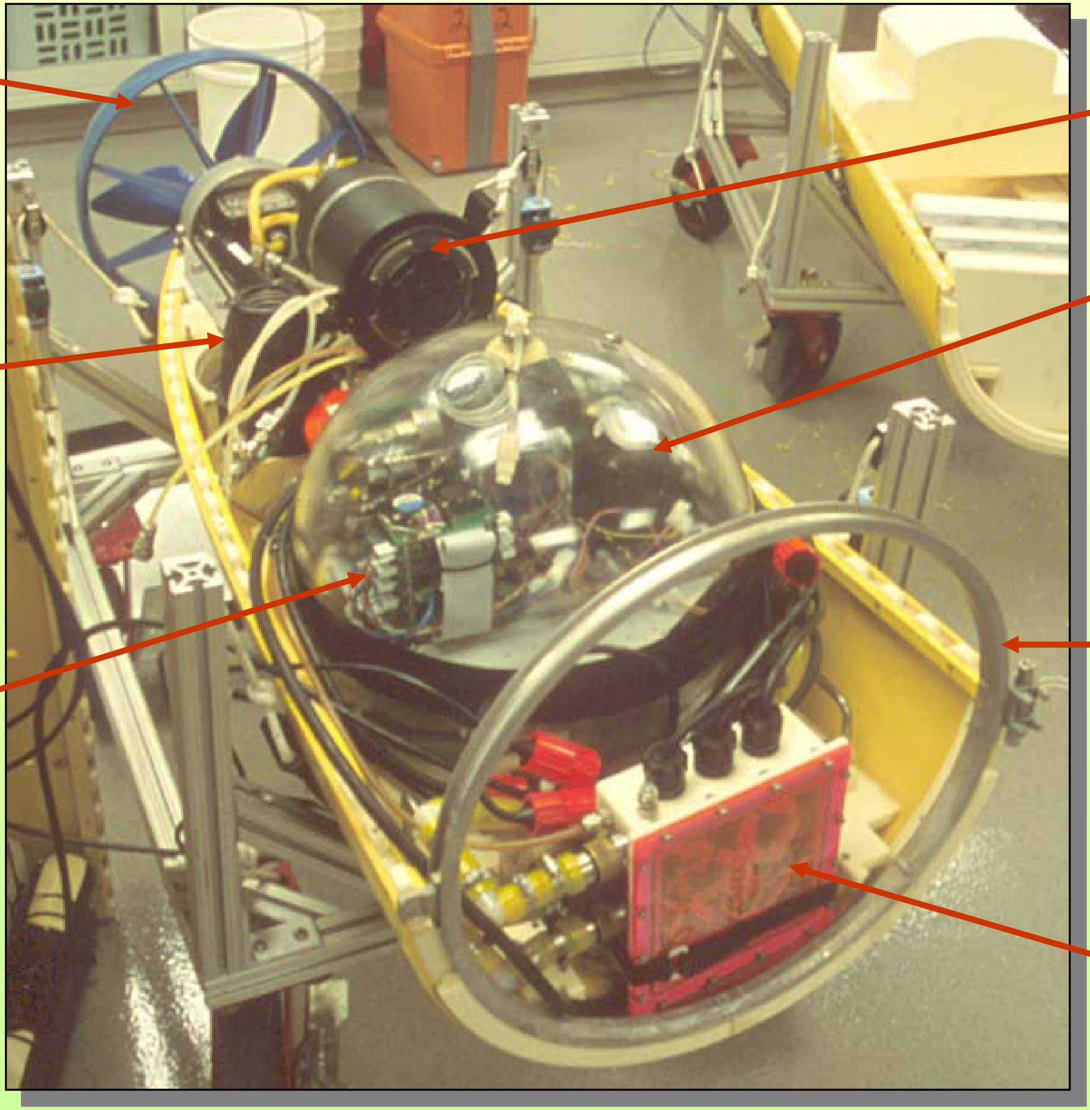
Modular AUV designs are a cost effective way to accomplish science when the missions will vary in type and complexity. Particularly when multiple institutions are the intended user base or the science users are developing instruments for themselves.

Tail section of Modular AUV

Modular tail for propulsion and control surfaces

Oil Compensator

Main vehicle computer housing and computer stack



Pressure tolerant electronics housing

Attitude Heading and Reference System (AHRS)

Interface as defined by the interface documentation

Oil filled J-Box

Payload Configuration

AUV Technology and Application Basics

- Payload Configuration
  - Payload Interfaces (Basic) using our M2 example

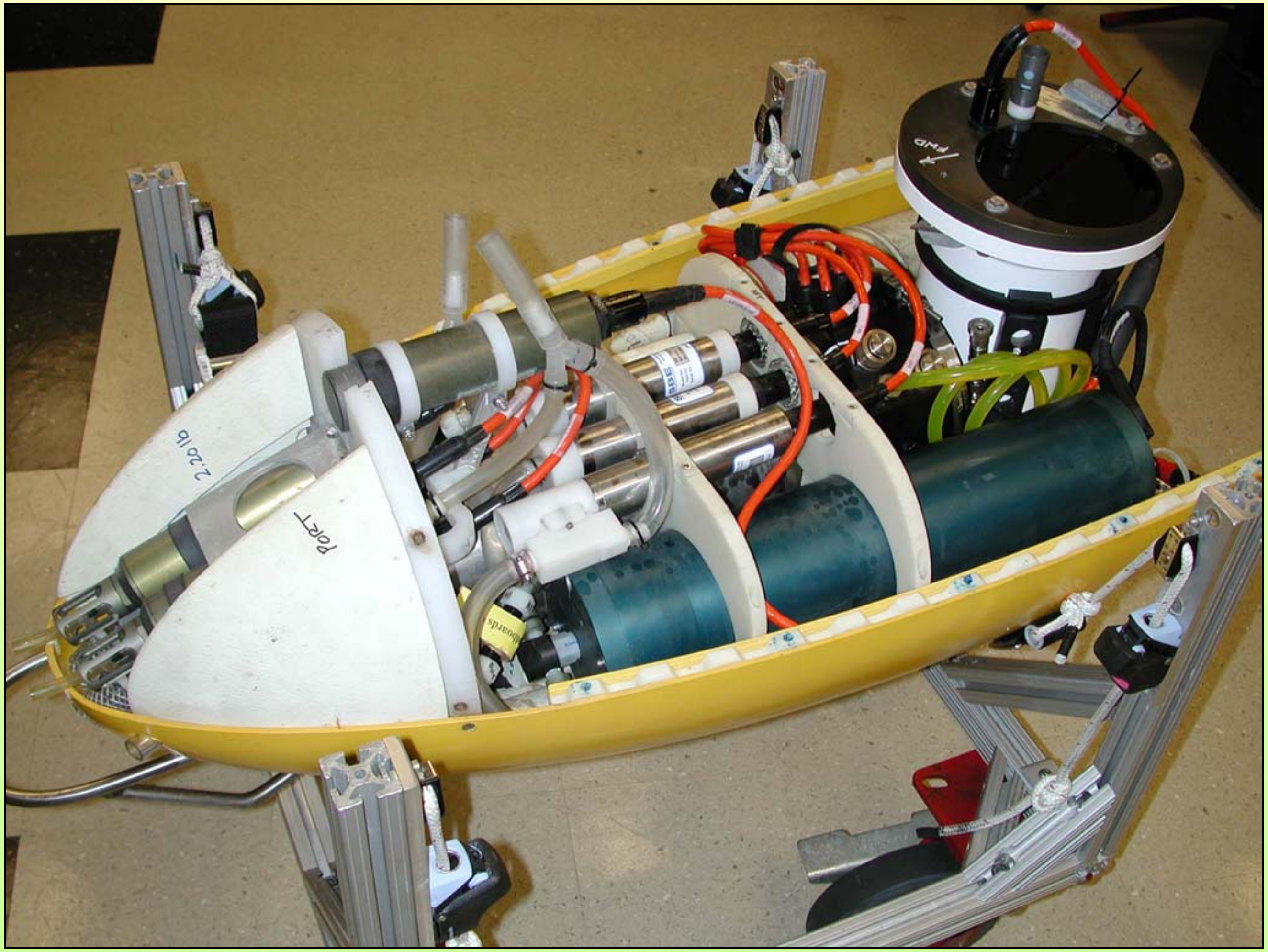


Photo from MBARI

AUV Technology and Application Basics

- Payload Configuration
  - Payload Interfaces (Basic) using our M2 example

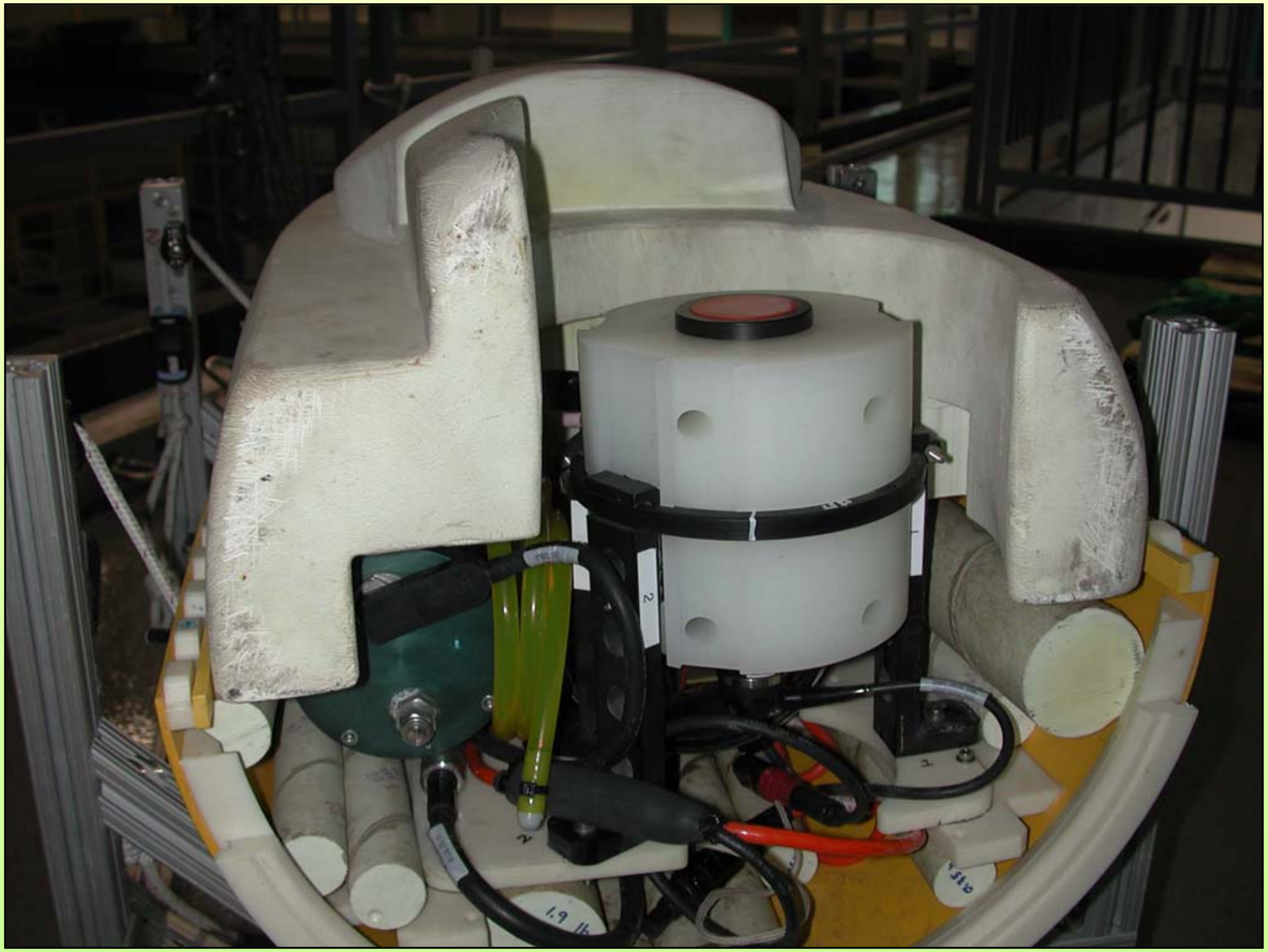
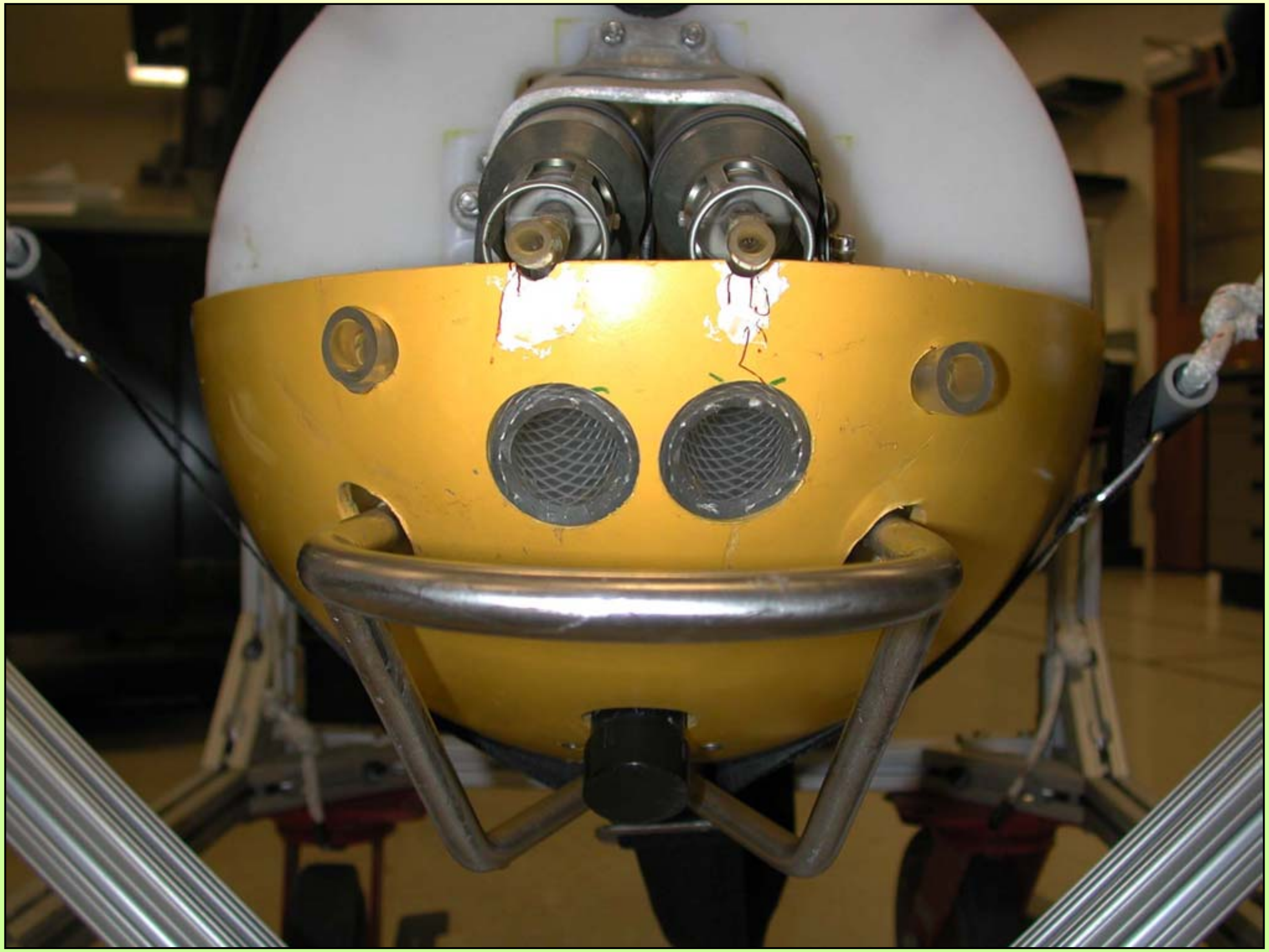


Photo from MBARI

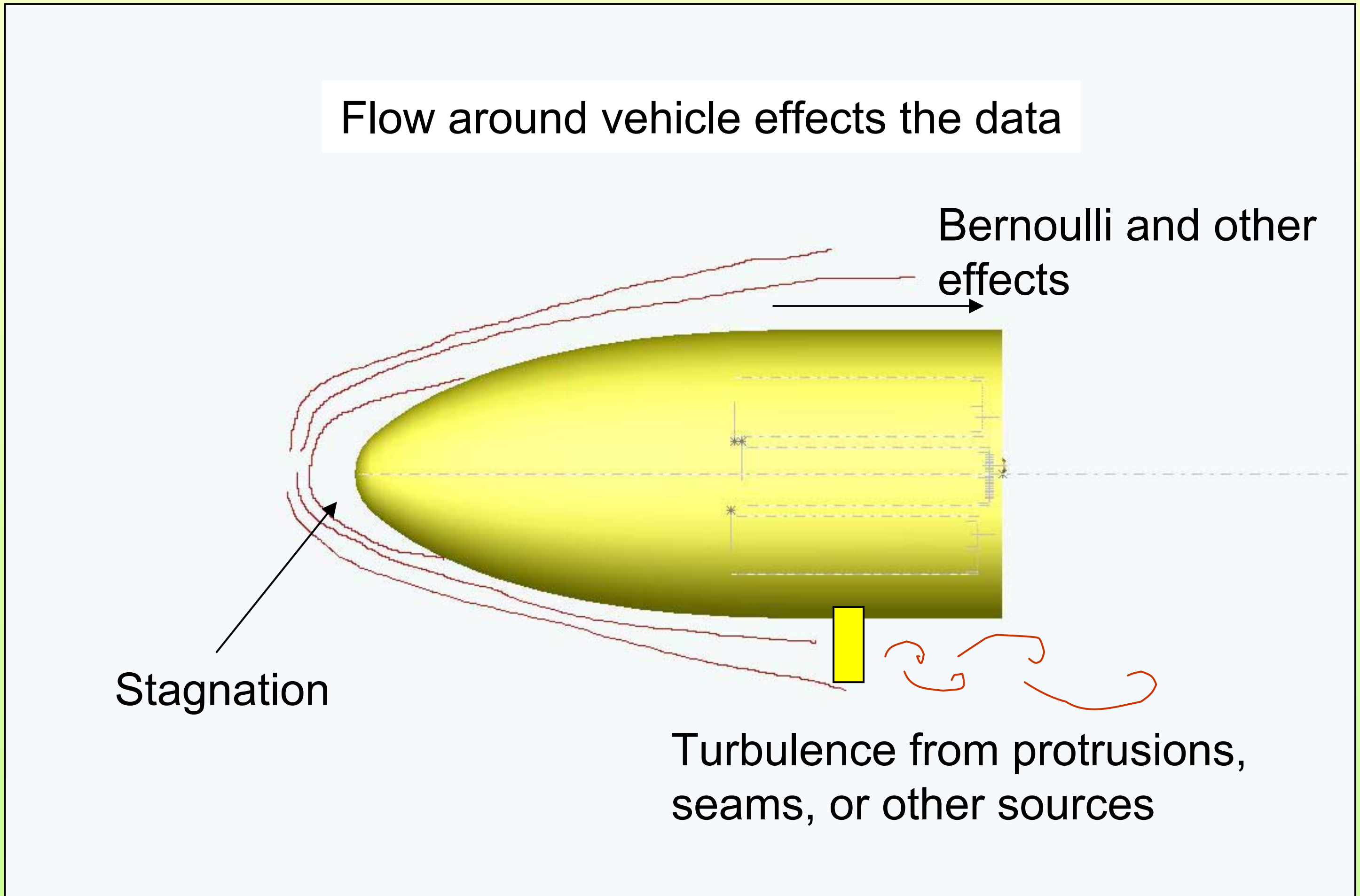
AUV Technology and Application Basics

- Payload Configuration
  - Payload Interfaces (Basic) using our M2 example



AUV Technology and Application Basics

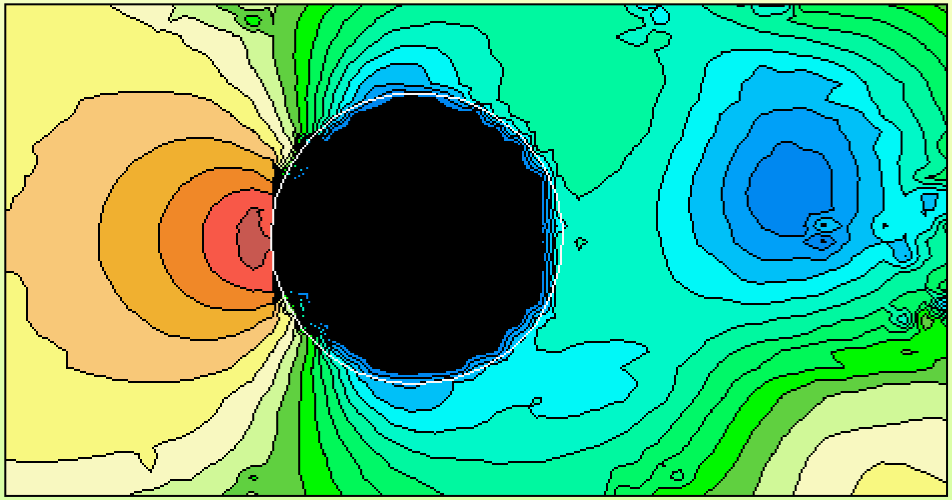
- Payload Configuration Contrast
  - Concerns
    - Placement



Flow lines not to scale

Pressure Profile

Flow from left to right past a cylinder

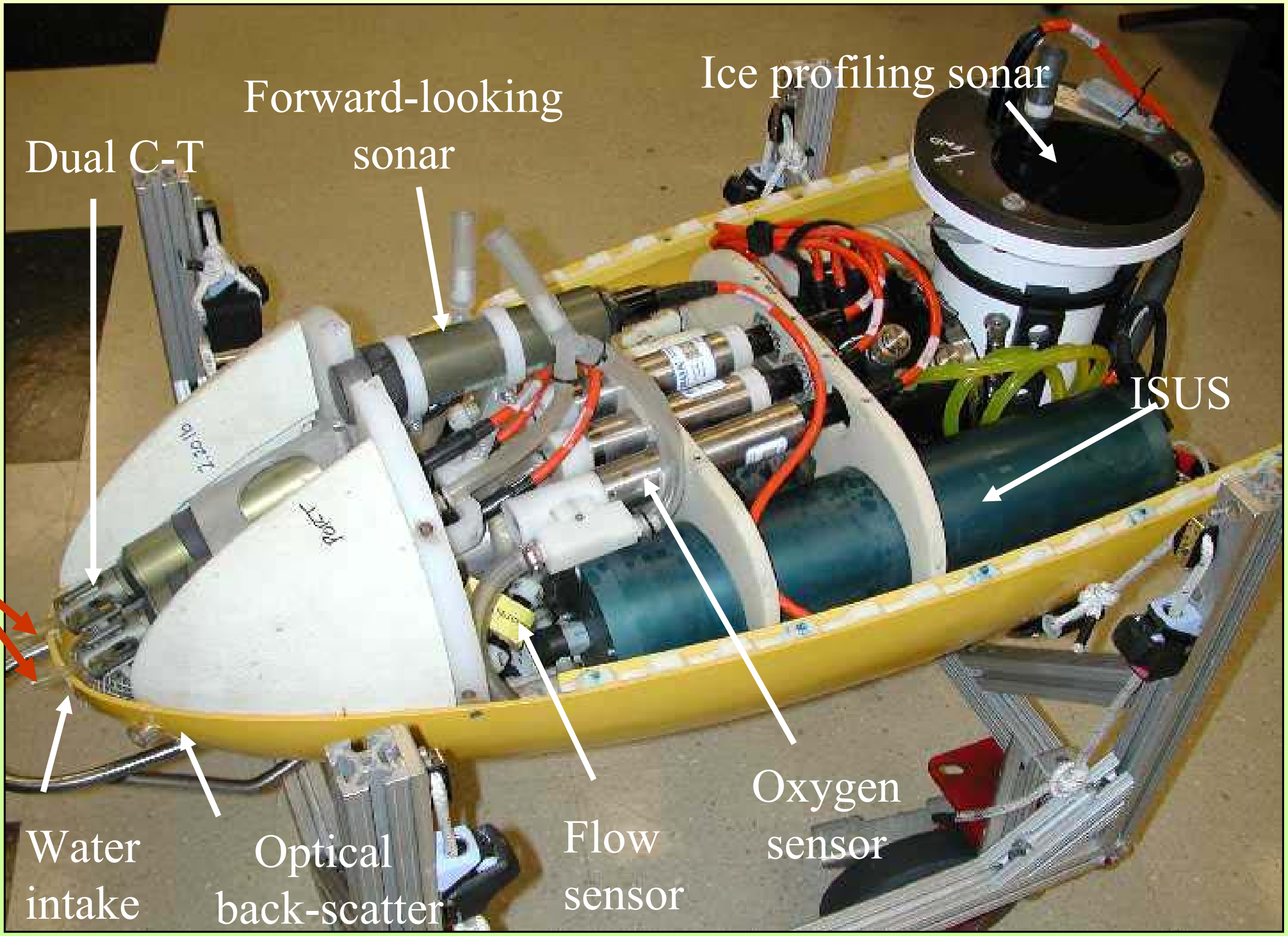


Note: stagnation zone right at front of flow area and the various pressure differences

Images from web page: www.tu-chemnitz.de/.../Von_Karman/ Von_Karman.html
Faculty of Mechanical Engineering and Process Technology, German National Science Foundation

- Payload Configuration
  - Payload Interfaces (Basic) using our M2 example

Note tubes extending outside of the boundary layer



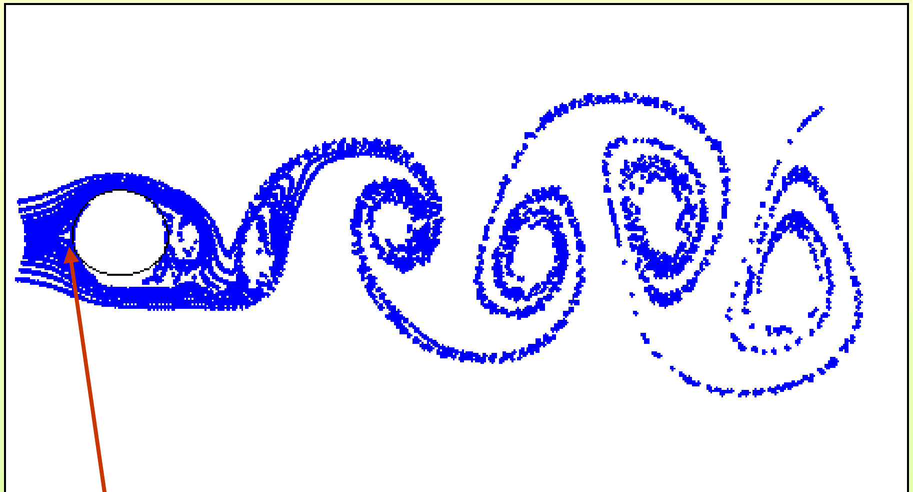
AUV Technology and Application Basics

- Payload Configuration
  – Payload Interfaces (Basic) using our M2 example

Flow data can be very important to verify your data set

This example was comes from learning on our plumbed systems for AUVs. During a science mission we sucked up jelly fish resulting in the data sets looking very strange. It took some real effort to work the data and realize something was not right!

Vortices generated by flow past a cylinder

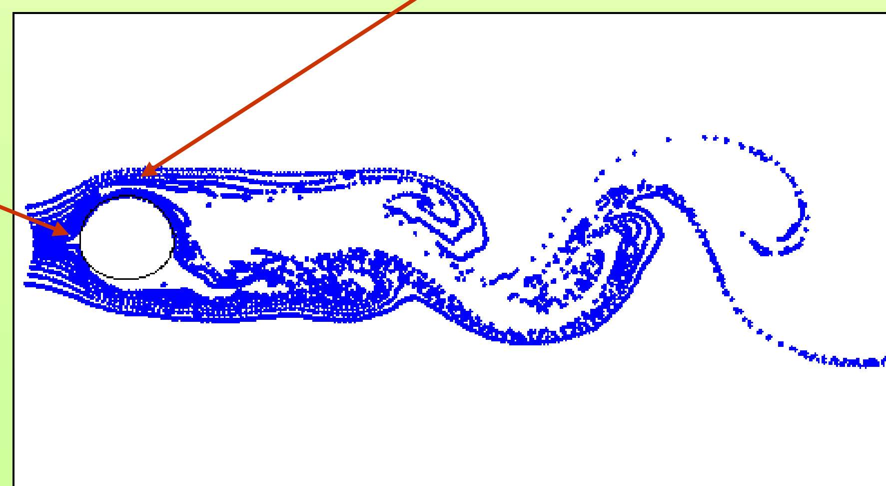


Slow to Moderate speed

Flow Separation

Stagnation

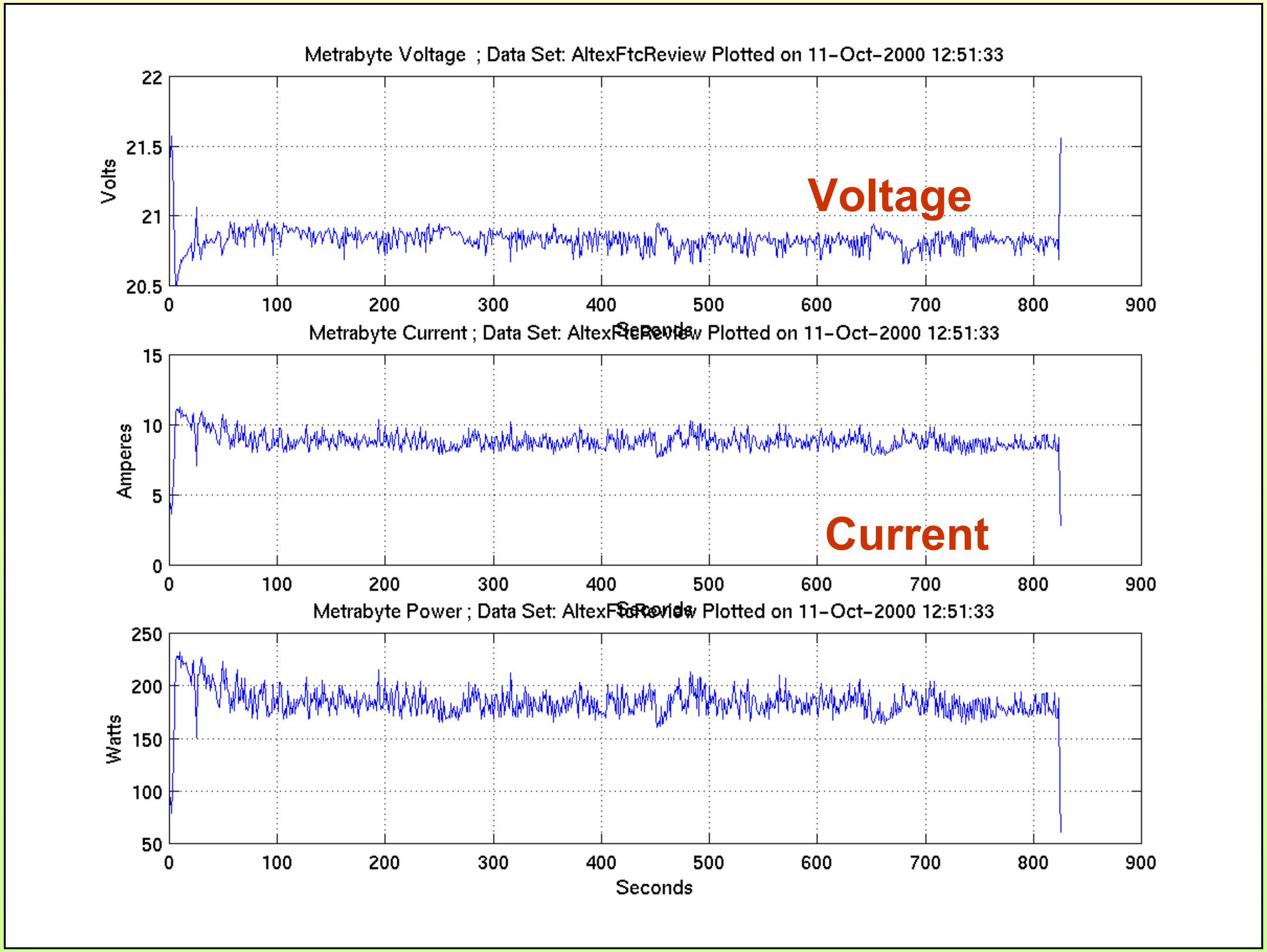
50% increase in speed



Images from web page: www.tu-chemnitz.de/.../Von_Karman/ Von_Karman.html
Faculty of Mechanical Engineering and Process Technology, German National Science Foundation

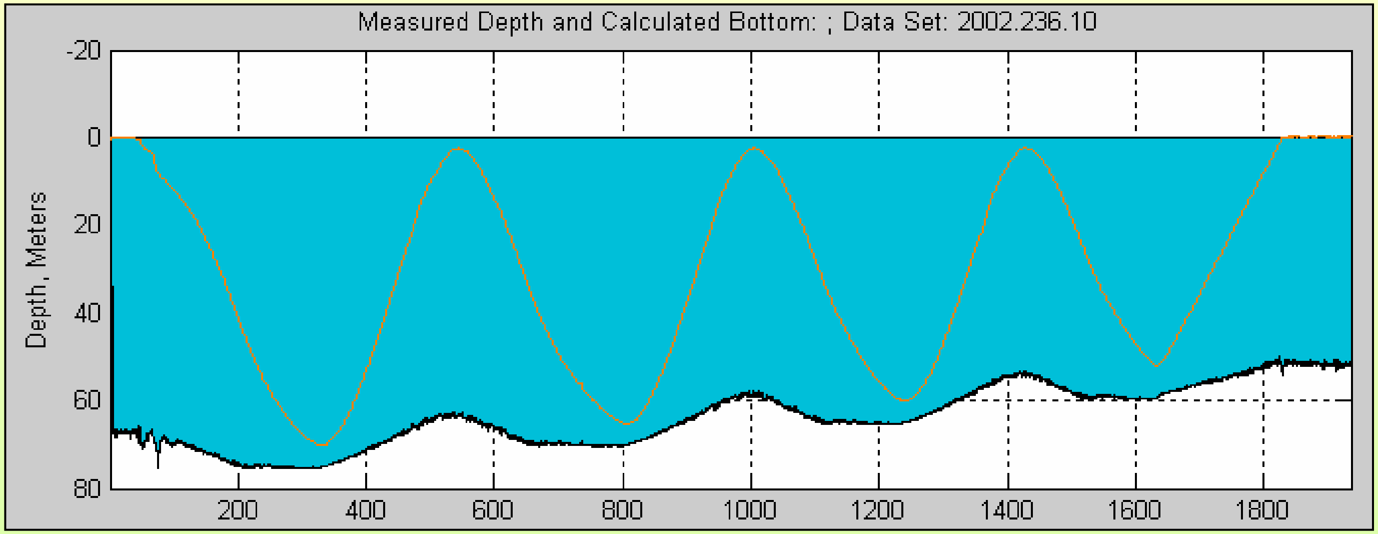
AUV Technology and Application Basics

- Payload Configuration
  - Payload Interfaces (Basic) using our M2 example



AUV Technology and Application Basics

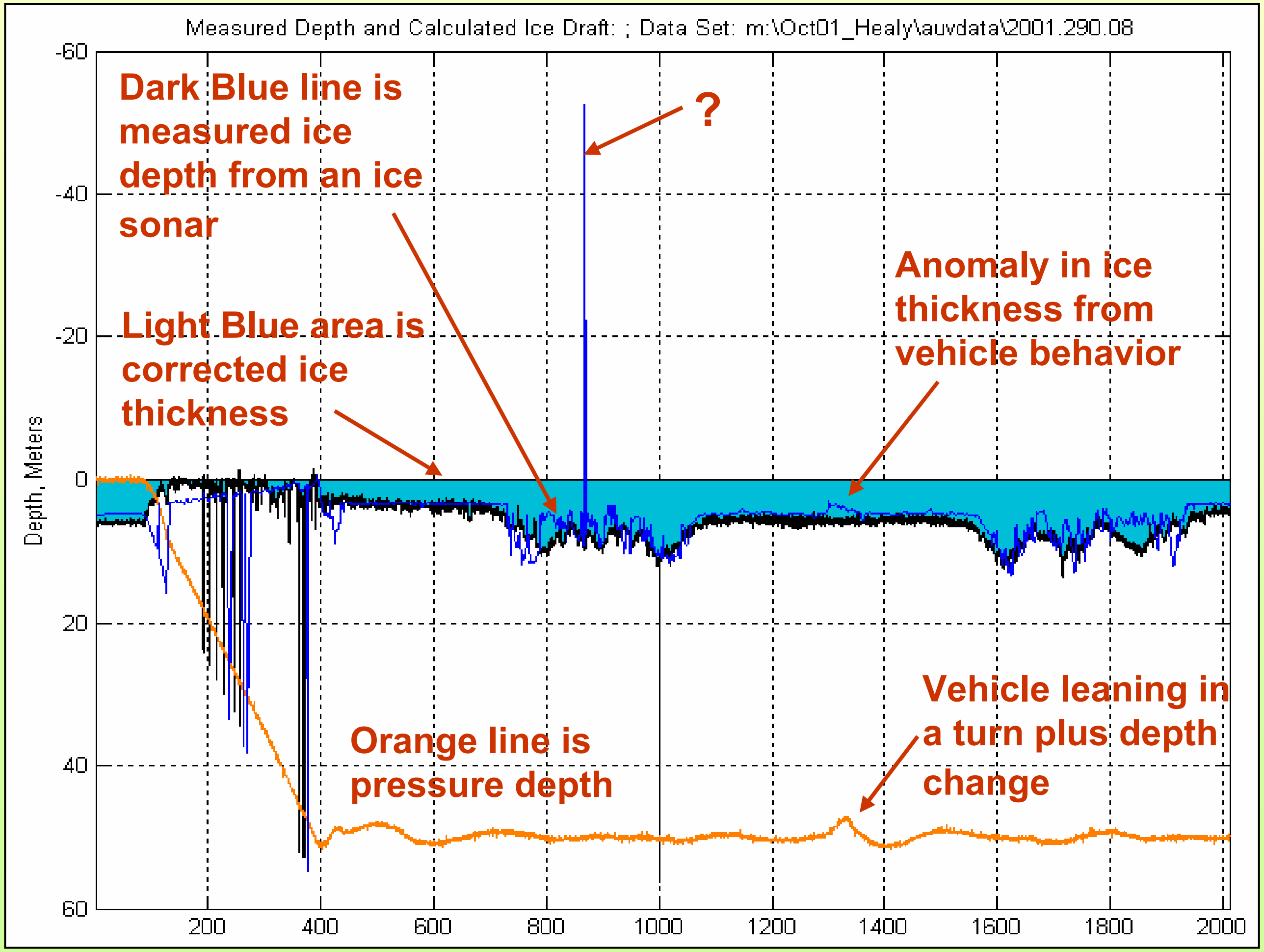
- Payload Configuration
  - Payload Interfaces (Basic) using our M2 example



Example: Altimeter data, if not calibrated, shows the bottom as having ripples when in fact it is very smooth. Altimeter geometry combined with vehicle pitch introduced anomalies in this example that must to be corrected afterwards. *Important point here is to collect all raw vehicle and raw science data for post processing and analysis.*

AUV Technology and Application Basics

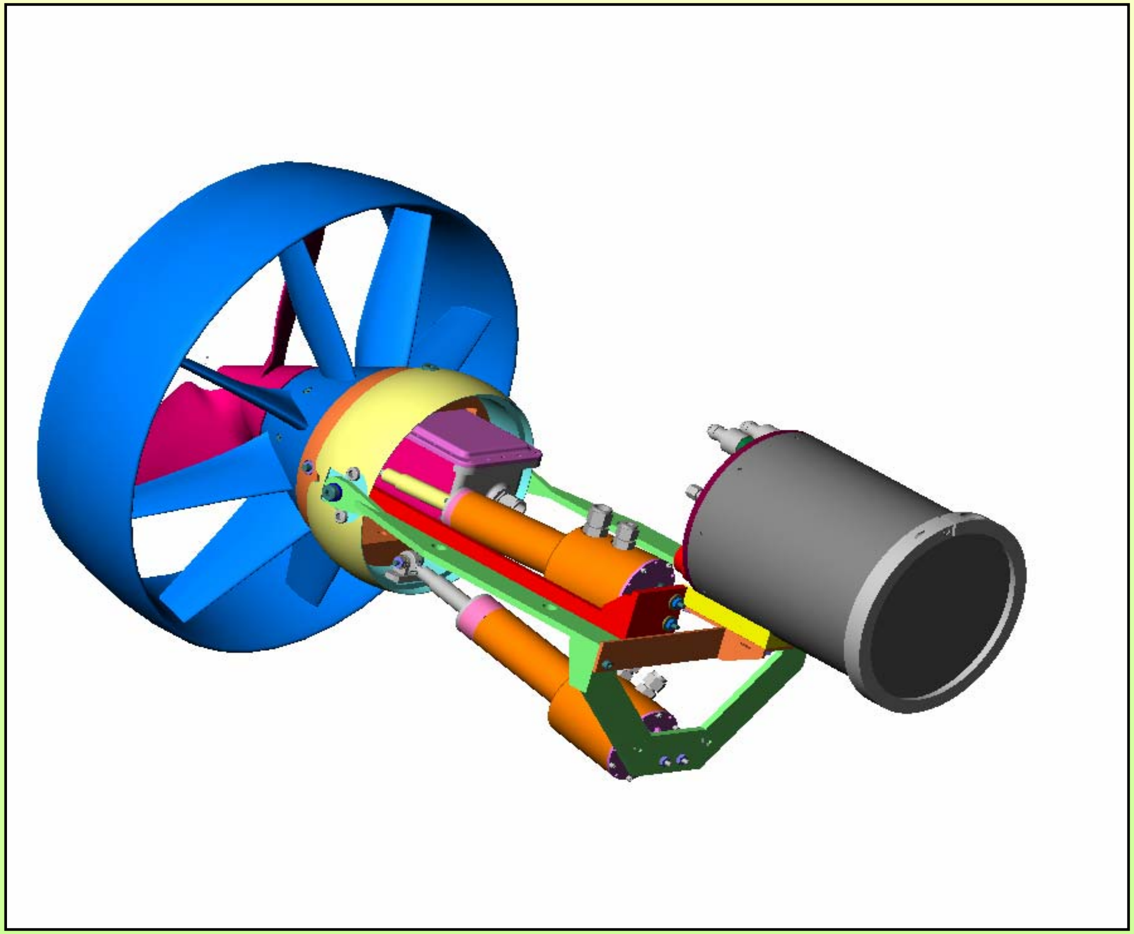
- Payload Configuration
  - Payload Interfaces (Basic) using an ALTEX example



Another simple example of vehicle data laid over ice thickness data and how vehicle motions have introduced errors.

Propulsion

Propulsion



Although there are options the most common and widely used system is a propeller and some configuration of control surface to set AUV direction

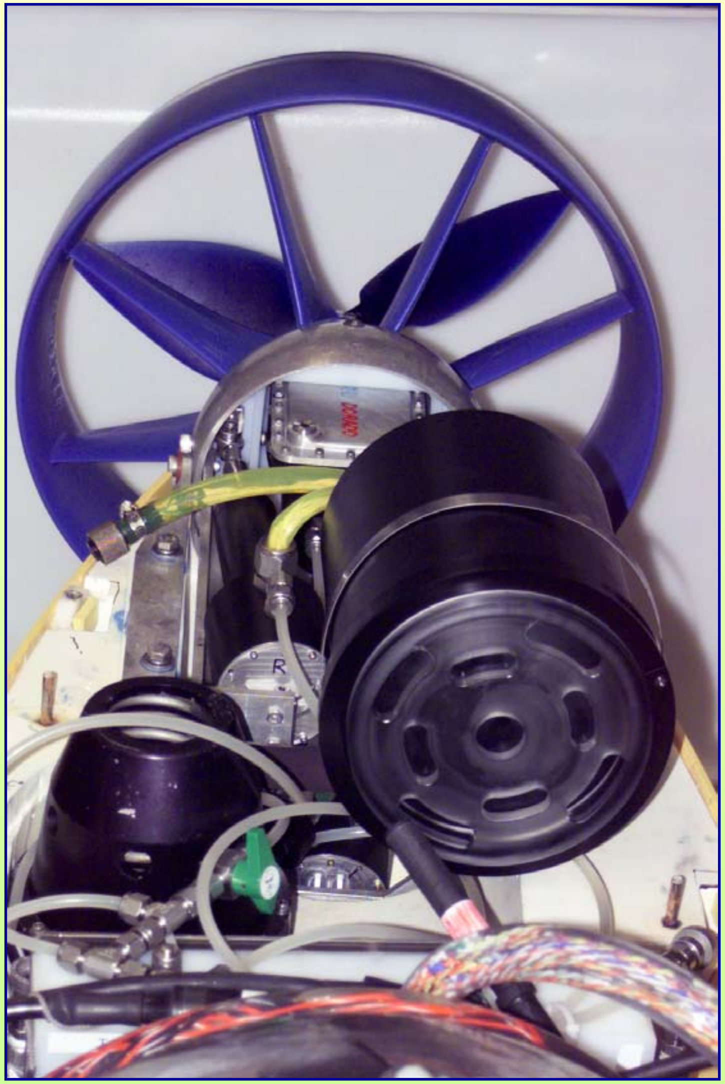
Propulsion

Some Rules of Thumb:

• Large diameter propellers turning relatively slow are more efficient

• Ducted propellers offer better efficiency

• Propellers will induce a vehicle torque roll that should be correct by ballasting or otherwise addressed in the design



Energy Calculation for Self-Propelled Vehicle

$$P = \frac{1}{2\eta} C_D \rho_{SW} S V^3$$

- *P* = power *(w)*
- *n* = propulsion effeciency (dimensionless, typically .5)
- CD = Coefficient of Drag (dimensionless)
- p_{sw} = density of seawater (1000 kg/m^3)
- *S = effective area of drag (in this case πR^2) with R =* max radius (m)
- V = velocity (m/s)

Sample Calculation of Reynolds Number

Example: Vehicle is moving at 1.5 m/sec ~ 3 knots

In sea water : rho = 1025 kg / m^3

For this example, the vehicle length is 2 meters

The viscosity of seawater = 1.61×10^{-2} gm/(cm sec)

(per our chart)

~ = .002 kg/ (m sec)

$$\mathbf{Re} = \frac{\mathbf{D.V.}\rho}{\mu}$$

Plugging in we get:

Re = (1025 x 1.5 x 2) / .002

Re = 1.5375×10^6

Using our chart the frictional drag coefficient is about .04

Image from web page: http://www.processassociates.com/process/dimen/dn_rey.htm

Drag Component of Equation

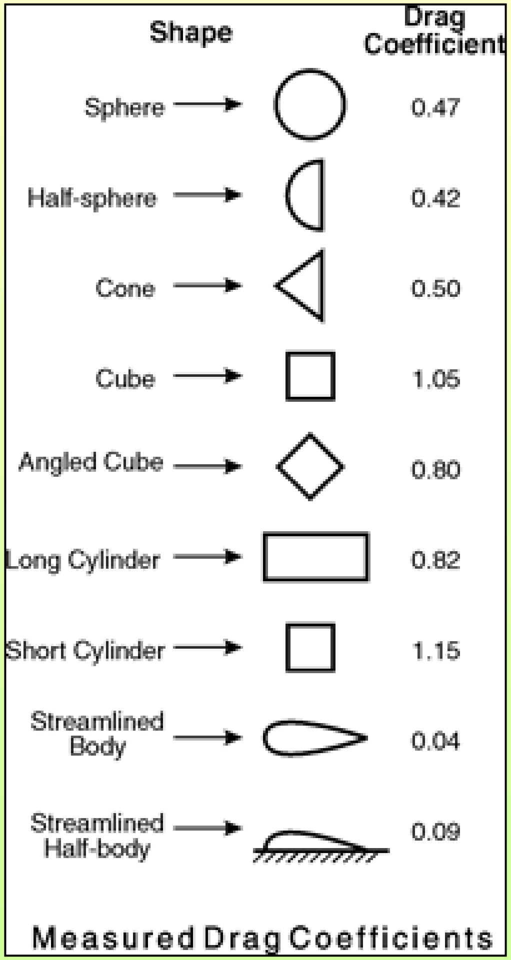


Image from web page: http://www.insideracingtechnology.com/tech102drag.htm

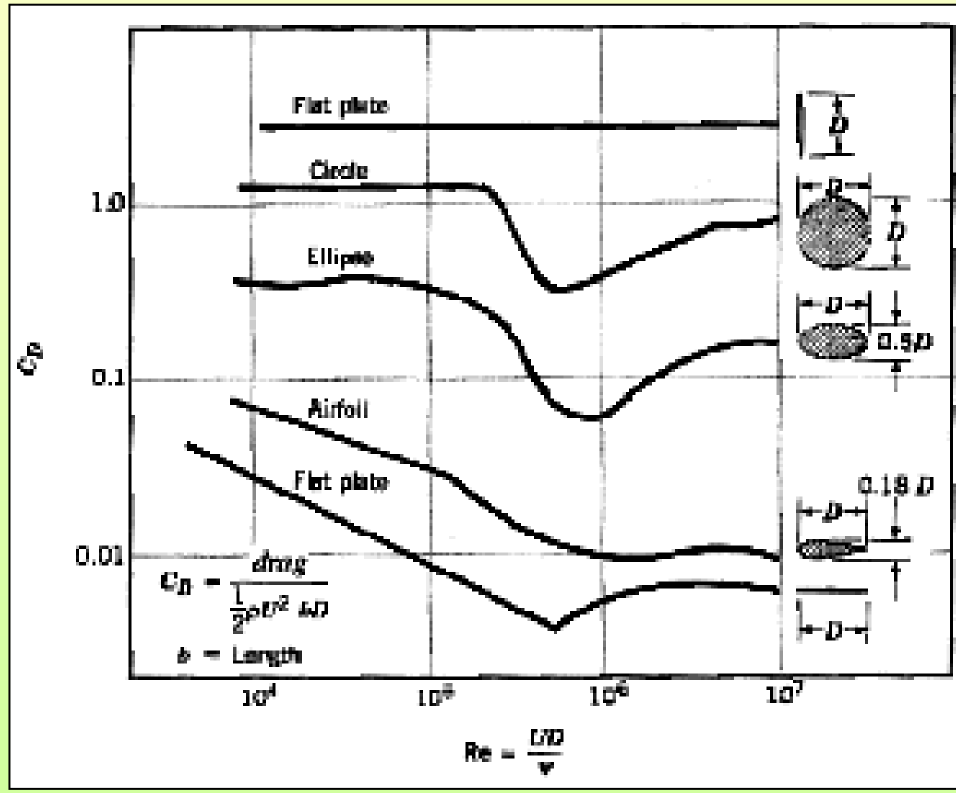


Image from web page: http://www.dopsys.com/loads.htm

Energy Calculation

$$P = \frac{1}{2\eta} C_D \rho_{SW} S V^3$$

- $S = \pi R^2$ *w/ R* = .54 m (Dorado class vehicle)
- *n* = .5
- CD = .04
- p_{sw} = 1000 kg/m^3
- V = 1.5 m/s

Substituting

P = (1/(2 * .5)) *.4 * 1000 * 3.1415 * (.54^2)*(1.5^3)

P = 123.67 watts *< But this is only the hull with nothing else!*

Energy Required for a Sample Science Appendage

$$P = \frac{1}{2\eta} C_D \rho_{SW} S V^3$$

Using the same process – let's add a 6 in. tall x 1 in. dia cylindrical probe

- ***S = 6 x 1 = 6 in^2 ~ .0039 m^2***
- ***n = .5***
- **CD = 1.2 (for a projected cylinder – SNAME)**
- **p_{sw} = 1000 kg/m^3**
- **V = 1.5 m/s**

Substituting

P = (1/(2 * .5)) * 1.2 * 1000 * .0039 * (1.5^3)

P = 15.8 watts ***< this is for one small appendage***

Energy Required for a Well Designed Antenna

$$P = \frac{1}{2\eta} C_D \rho_{SW} S V^3$$

What does the antenna from our example cost in drag and power?

- ***The main fin S_1 = 10 x . 25 = 2.5 in^2 ~ .002 m^2***
- ***The top disk S_2 = 3 x . 25 = .75 in^2 ~ .0006 m^2***
- ***n = .5***
- **CD = .04 (for a fin type body)**
- **p_{sw} = 1000 kg/m^3**
- **V = 1.5 m/s**

Substituting

P = (1/(2 * .5)) * .04 * 1000 * .0026 * (1.5^3)

P = .35 watts *< hey, not too bad compared to a short tube*

Energy Calculations Continued

123.67 watts	**Vehicle**
15.8 watts	**Probe**
0.35 watts	**Antenna**
139.82 watts	*Power for just these three items*

The take home message from here:

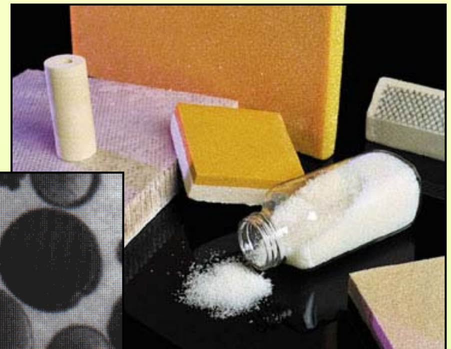
11% of the power is used just to push the probe through the water

NOTE: There is a load we refer to as hotel (P_h) that includes all those items burning power when you start up the vehicle excluding propulsion

$$P_{total} = P_{propulsion} + P_{hotel}$$

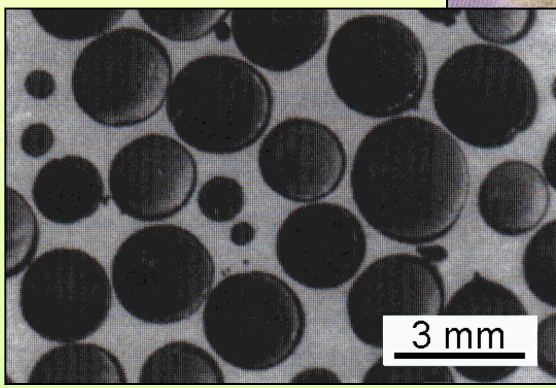
Things that Affect Control

Sidebar on Buoyancy and Housings



www.nasatech.com/Spinoff

Syntactic foam is the main flotation material we use to offset vehicle weight in water.

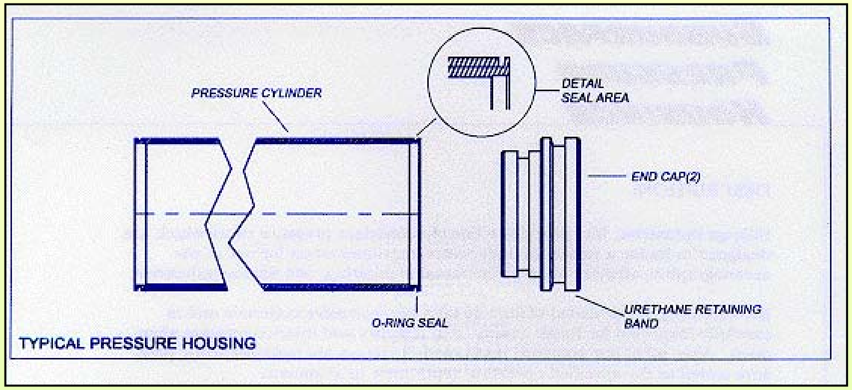


Syntactic foam is made of macro or micro spheres of various materials and bound together by a urethane or epoxy matrix generally.

http://www.benthos.com

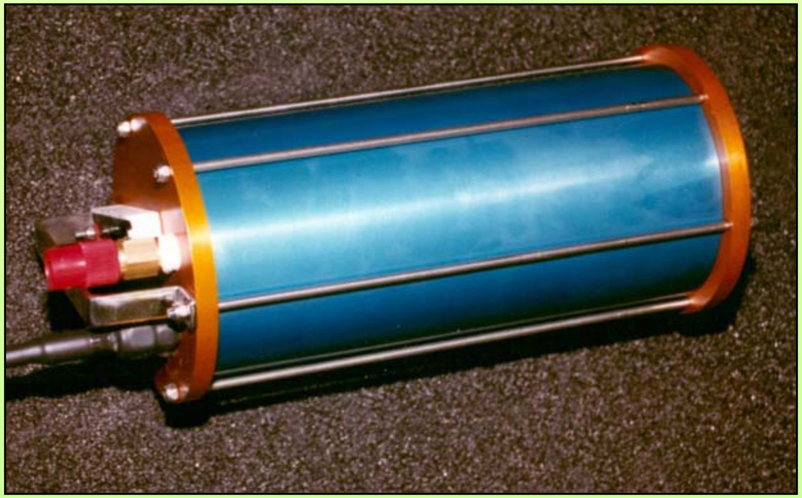
Glass spheres are commonly used for two reasons. 1st they are inexpensive pressure housings and 2nd they are the most efficient buoyancy module against weight in water. They also generally are rated very deep for no additional cost.

Sidebar on Buoyancy and Housings



http://www.o-vations.com

Sometimes pressure housings are required when pressure balanced oil filled boxes won't work.



http://www.patchambers.com

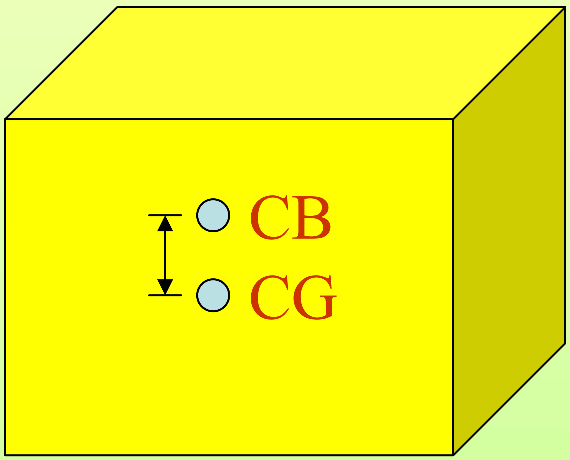
These are often metal but more and more they are composite. The design depends on requirements and costs, but wound glass (G-10) tubing is becoming a very cost effective housing material for moderate depths (up to 4000 meters).

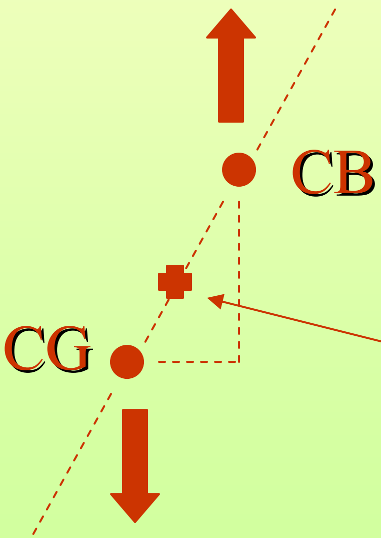
More on pressure housings is available in the Appendices

AUV Technology and Application Basics

- Things that affect control
  - **CG-CB**

Stability → CB - CG Separation

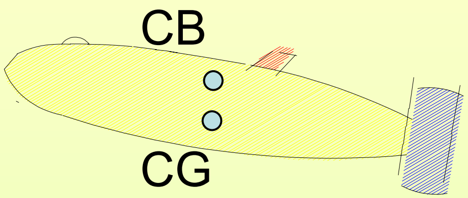




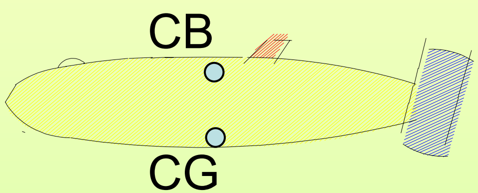
Meta-Center
This is the point that the various forces work around

AUV Technology and Application Basics

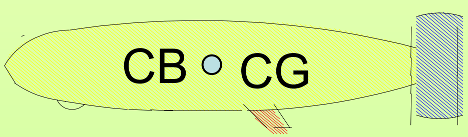
- Things that affect control
  - **CG-CB**



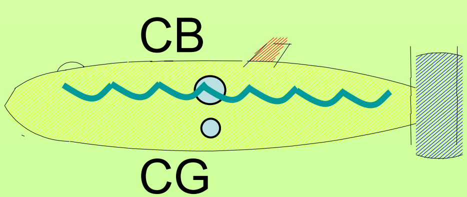
CB-CG horizontal offset causes vehicle to fight, increasing drag and making straight and level flight troublesome



CB-CG vertical offset makes diving and altitude control difficult, control inputs have diminished effectiveness



CB-CG coincident makes vehicle unstable causing control loop problems with gains and cross coupling of controls if vehicle rolls to side



CB too large makes diving and altitude control difficult, causes pitch control oscillations

I'm assuming I don't need to cover too large a CG

AUV Technology and Application Basics

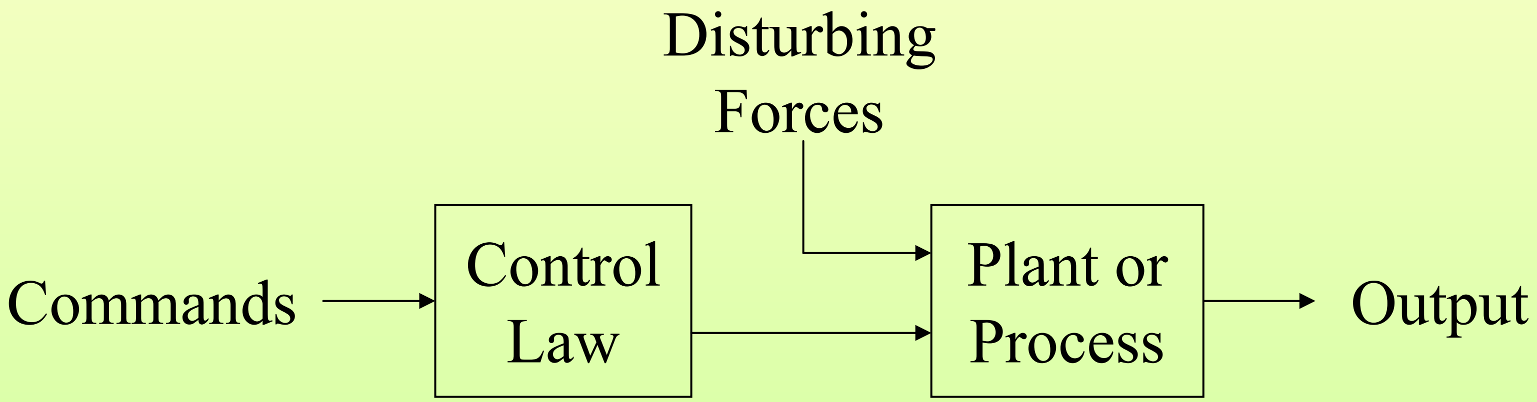
- Things that affect control
  - Weight and Balance

SI units x is from the nose						
Item	Weight	Displacement	Buoyancy	Displacement total	W x-mom	B x-mom
	(N)	(m^3)	(N)	(m^3)	(N-m)	(N-m)
2Kw/Hr Battery	254.1771	0.01547	155.5547175	0.04641	727.1117211	444.9876026
Spacer, Center Battery	0.4299723	0.000044	0.442431	0.000044	0	0.51576792
Bulkhead, Forward	4.8895983	0.00052	5.22873	0.00052	3.187529132	3.408609087
Spacer, Forward Bulkhead	0.4371336	0.00005	0.5027625	0.0002	0.52456032	0.603315
Bulkhead, Aft,Aft	5.4603441	0.00058	5.832045	0.00058	6.242265375	6.667193844
Bulkhead, Aft	5.4603441	0.00058	5.832045	0.00058	4.95731536	5.294773686
SBE-49 CTD	26.487	0.00114	11.462985	0.00114	11.38941	4.92908355
CTD Acrylic Shroud	2.9674269	0.0003	3.016575	0.0003	0.59348538	0.603315
Washers	0.04905	0.0000004	0.0040221	0.000012	1.015335	0.08325747
Compression Ring	3.50217	0.00013	1.3071825	0.00013	5.4633852	2.0392047
Shell Splice Joint	7.047504	0.00069	6.9381225	0.00138	16.86298567	16.60126199
Cables w/ connectors	7.3575	0.00021	2.1116025	0.00042	14.582565	4.185196155
TOTALS				**0.18965682**	**1483.2321**	**1544.6917**
Balance Point from Nose (m)	**0.8099915**				**0.8573902**	**0.8099915**
Total Dry Mass of Nose (kg)						
Dsplcmt of Nose (m^3)						
Net Buoyancy (N)						
Cb - Cg (m)						

Note: this sheet has hidden columns – see handout or appendices for the complete sheet

- Things that affect control
  - control loops

Open-Loop Control

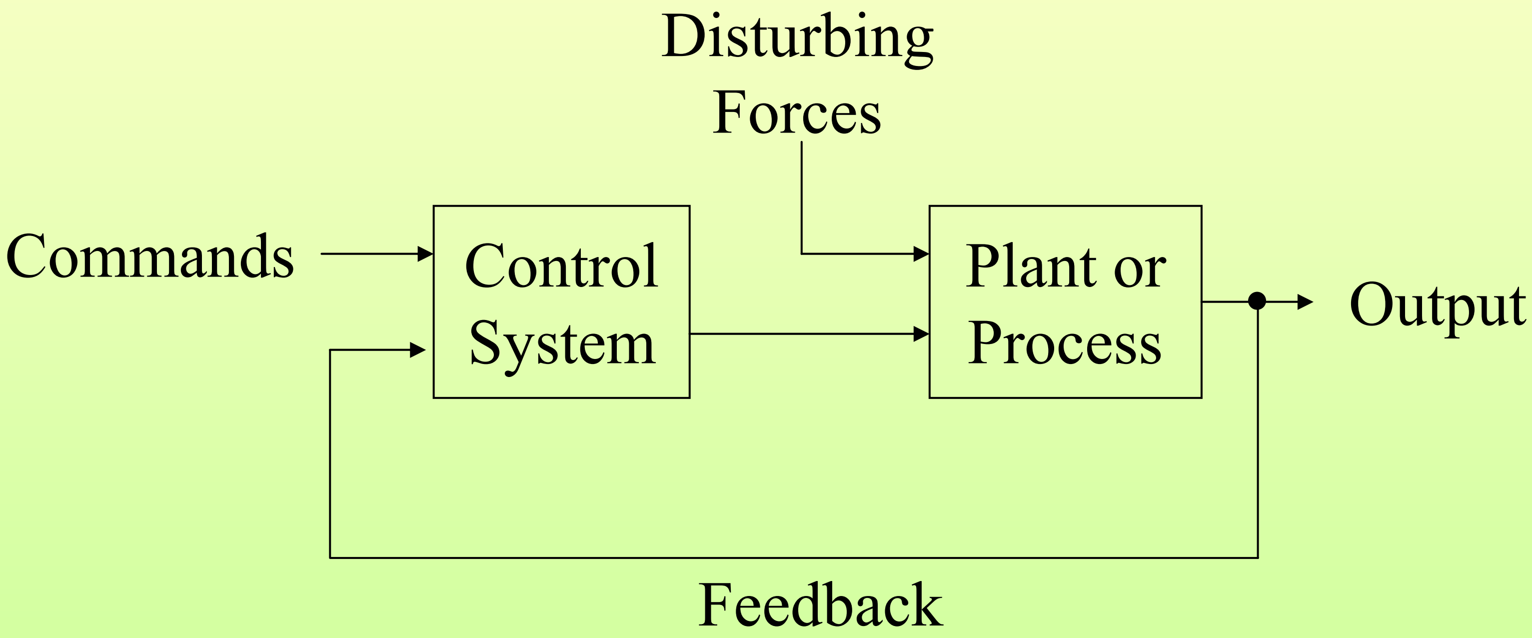


Example: A running propeller

images courtesy of P.McGill_MBARI

- Things that affect control
  - control loops

Closed-Loop Control



Example: A running propeller with velocity control

Note: AUVs tend to be underdamped and easily perturbed

Note: See appendices on controls for more info.

images courtesy of P.McGill_MBARI

Depth Control

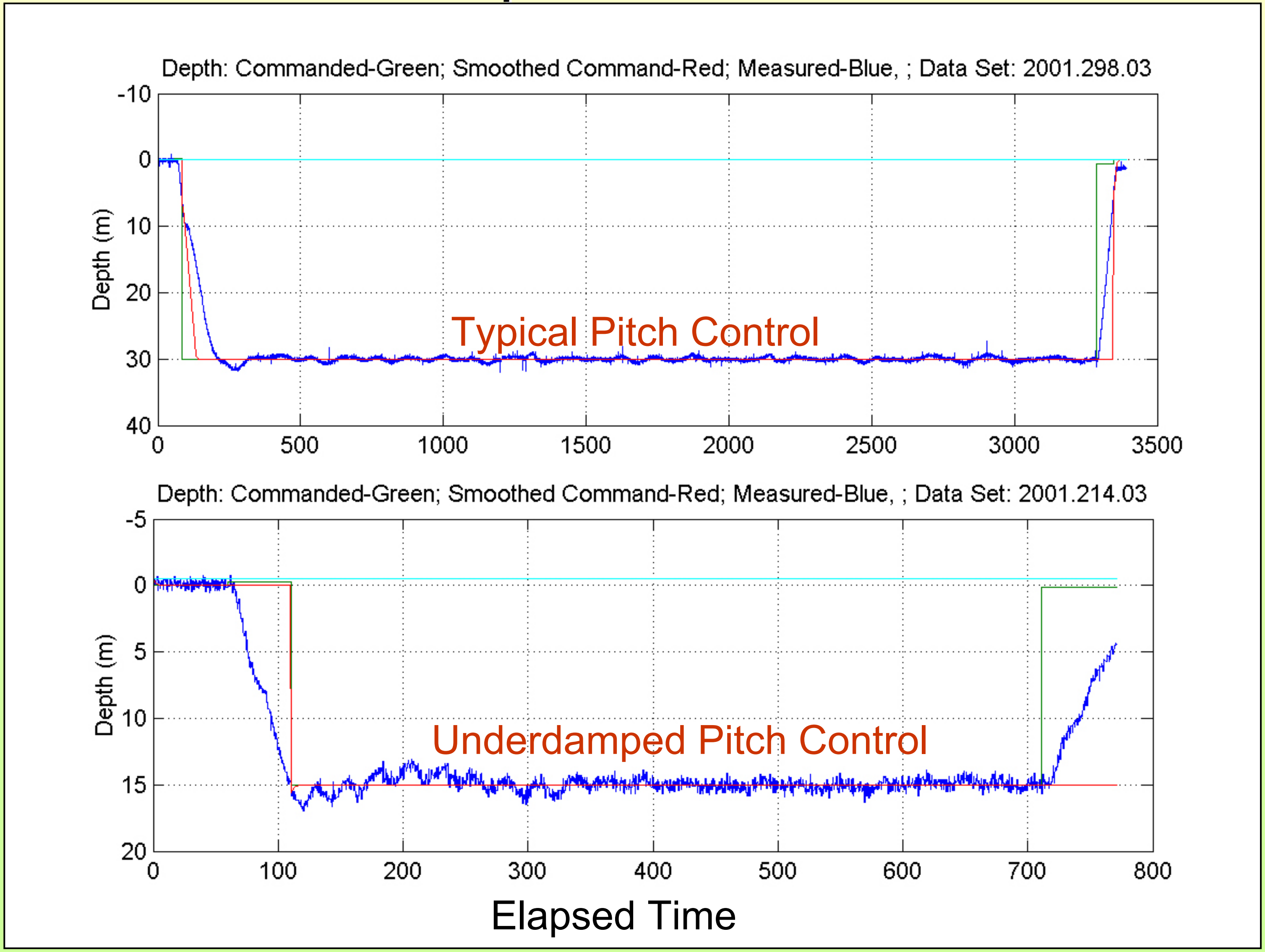


Image courtesy of Rob McEwen- MBARI

At Sea Operations

AUV Technology and Application Basics

- Launch and Recovery

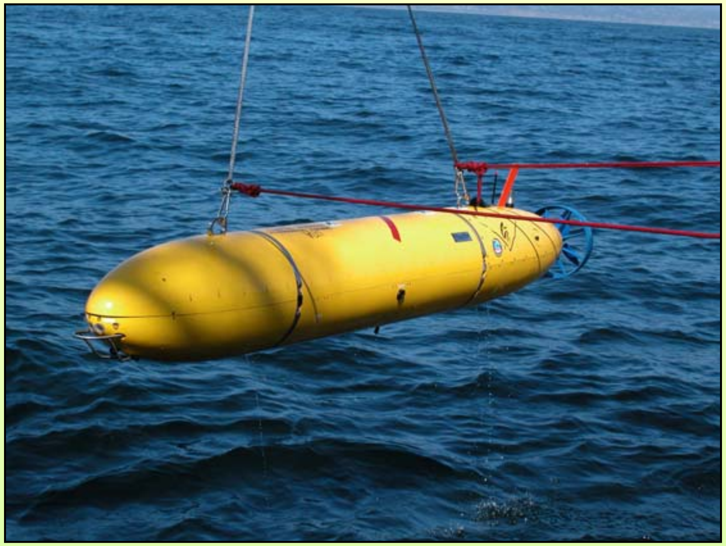
Ramp

- Generally good for low freeboard
- Low Cost
- Requires instruments to be protected from rollers

Images from MBARI

- Launch and Recovery

Overboard Crane



Very simple and effective for ships of opportunity with minimum freeboard. Pull releases required to let vehicle go on launch.

Recovery is a bit more work. A pole is used to attached a nose tagline and then a second one to the aft section. The crane lifts vehicle up at a distance and swings it back on board. This requires several people but more than that a ship driver paying attention!

Images from MBARI

AUV Technology and Application Basics

- Launch and Recovery

A – Frame

Similar process to overboard crane:

Launch with a little forward way, pull release line

Recover with taglines, pull forward with a little forward way and get at least 2 lines on vehicle for control. Lift the vehicle with A-frame and swing in. This requires the line handlers to constantly adjust as A frame changes position.

Images from MBARI

- Launch and Recovery

Spreader for Longer Vehicle Configurations

Same procedures as the regular overboard crane or A-frame approaches but requires even more diligence to prevent vehicle damage. <u>Plus you need a boat in the water!</u>

This is not something I recommend until your team has some sea experience with Launch and Recovery!

Images from MBARI

- Launch and Recovery

Specialized L and R systems

By far the best systems are purpose built. They solve a specified set of conditions which the users can control. They can be complex or relatively simple as requirements dictate. They can also be fly away or permanent installations.

Image from Bluefin Robotics, Inc.

Image from MBARI

• Launch and Recovery

Some basic notes on L n R

The worst of all options is man in the water or boat in the water launch and recovery. We have only had to do this for ships with extremely high freeboard (like ice breakers) and the long spreader bar scenario.

- Plan this function as part of your science mission to protect your instrumentation.
- Practice the plan at the dock before leaving for sea.
- Besides the common sense safety rules we recommend getting expert help to work out your operation

AUV Technology and Application Basics

- Operational Location Devices
  - Some of the things we use

GPS and Radio modem used in combination which enables the vehicle to surface, take a GPS fix, and transmit it's exact location. This is our primary engineering method for location on the surface.

Ultra-short baseline tracking for locating the vehicle during the operation and following

Long baseline tracking for vehicle navigation and modem communications

AUV Technology and Application Basics

- Emergency Location Devices
  - Some of the things we use

Novatech Radio Beacon (RDF)

To help locate submersible equipment returning to the surface for up to 8 day operation. Range up to 4 to 8 miles to a vessel. Pressure Switch turns unit ON at the surface, OFF when submerged

Novatech Strobe

Useful for limited space or ROV/ AUV applications for up to 15 day operation. "DOUBLE BURST FLASH" to enhance visibility. Auto "Daylight Off" with 35 Candelas output for up to a 4 mile range. Pressure Switch units ON at the surface, OFF when submerged.

NOTE: Working at night is often preferred because this beacon makes it's very easy to find the vehicle. Particularly with low lying cloud cover.

Sonardyne HomerPro

Operating Frequency Range35-55 kHz with a source level >183 dB. The receive sensivity <110 dB re 1µP at 1 meter. Listening life of 2 years.

NOTE: Not that you plan on bad days but this is a great device for locating on the bottom

Questions?