Technological Needs for Autonomous Underwater Vehicles

A requirements-driven approach

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UK

Caveats ...

- Beware of predictions -
    - Gottlieb Daimler predicted a world market for motor vehicles of 1 million
        - Based on estimate of number of people that could afford chauffeurs
- Technology often starts as bigger, more complex but real success comes with inexpensive technology in mass markets
    - Thomas Watson of IBM predicted computers would become so powerful
        - That only five would be needed for the whole world

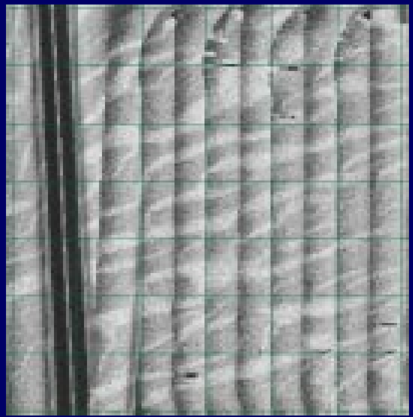
So we will only consider short & medium term needs ...

AUV Applications

- Marine Science Research
- Routine Ocean Observations
- Offshore Oil & Gas
  - Seabed Survey
  - Pipeline Survey
  - Environmental Obligations
  - Intervention
  - Iceberg Reconnaissance
- Defence
- Fisheries
- Wreck Reconnaissance
- Customs

European Leadership in AUVs

Martin



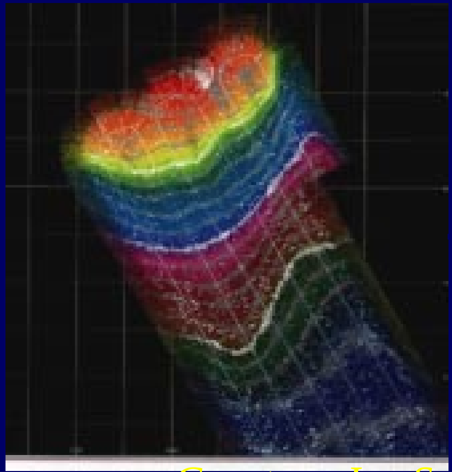
Mosaic from tracks ~ 40 m apart
Fully Autonomous site survey
Courtesy Anders Bjerrum

Autosub

Also:

Sara Caravela
Sirene Redermor
Taipan ...

Hugin

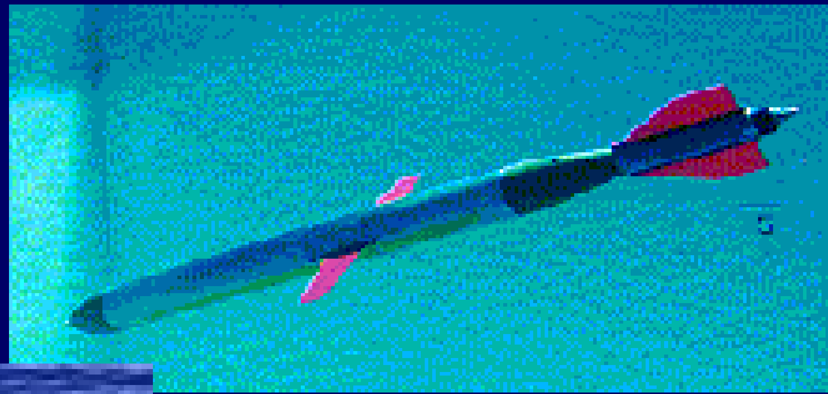


Courtesy Jan Sortland

Other types of AUVs ...

Moored Profilers
courtesy D Frye & R Lampitt

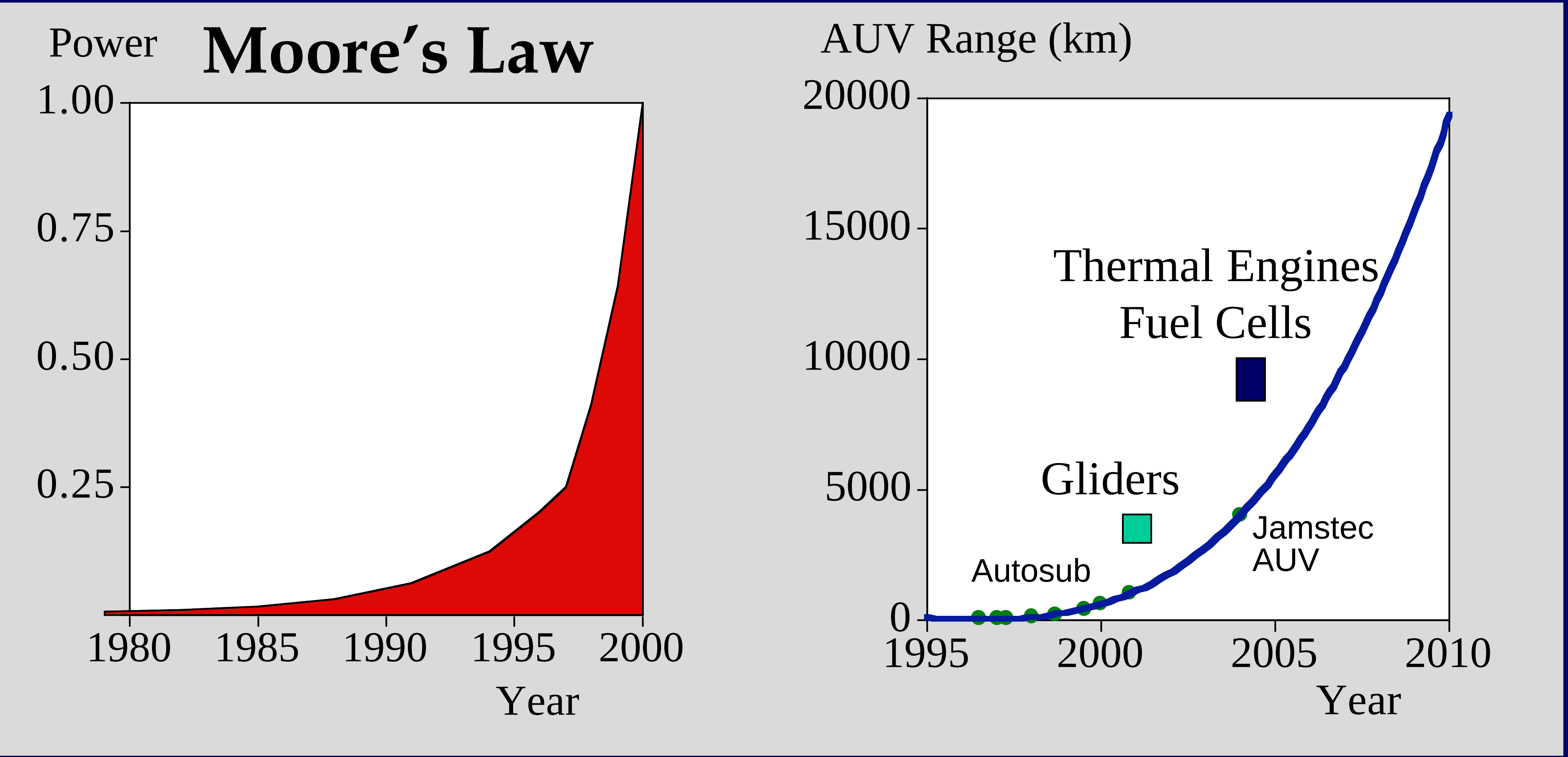
Autonomous Surface Craft
courtesy A Pascoal



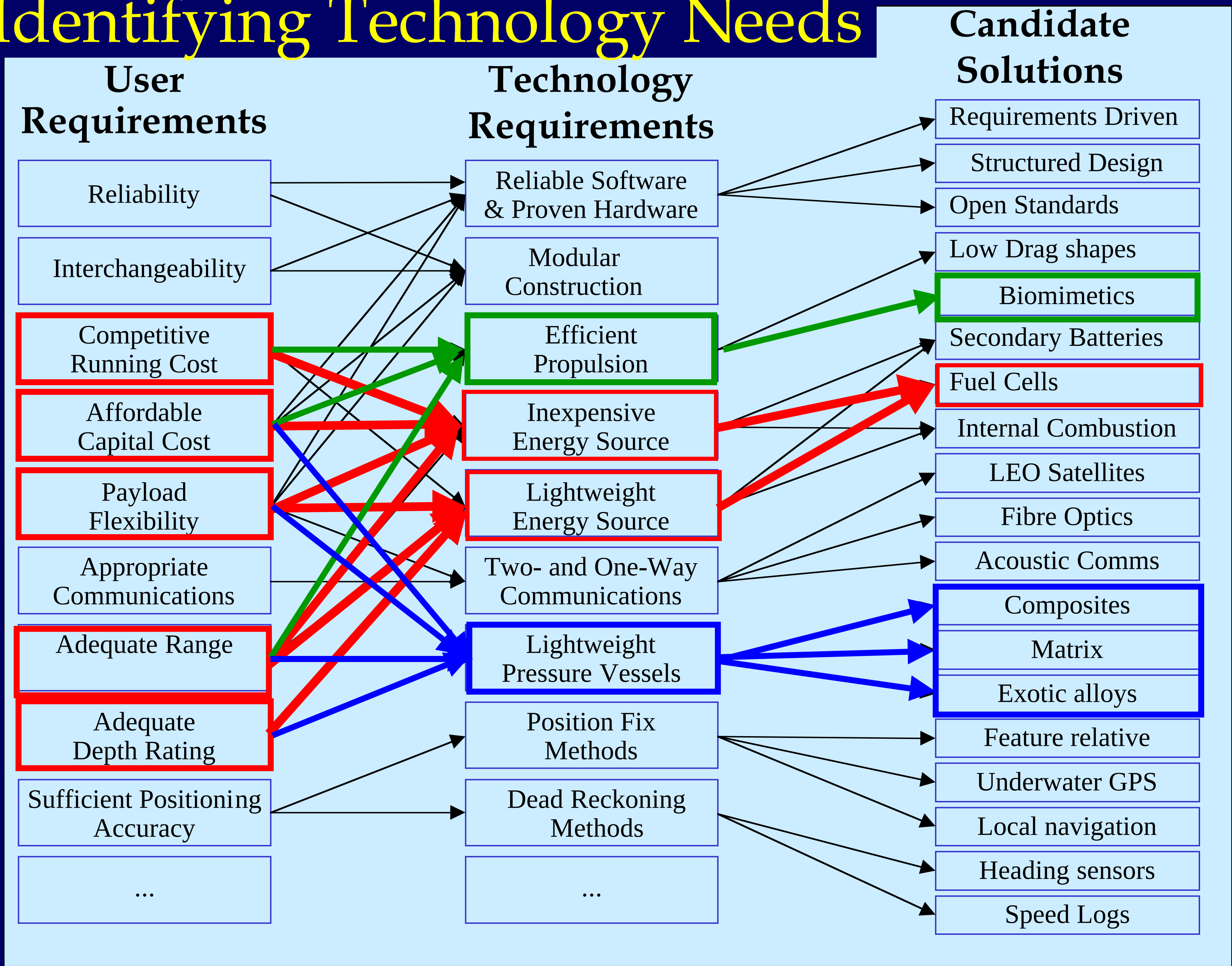
Gliders
courtesy D Webb & C Eriksen

Pace of Change

AUV Range Prediction 1995-2015



Identifying Technology Needs



Key User Requirements

- ❑ Competitive Running Cost
- ❑ Affordable Capital Cost
- ❑ Adequate Range & Depth
- ❑ Payload Flexibility

Energy Source

- ❑ Competitive Running Cost
- ❑ Affordable Capital Cost
- ❑ Adequate Range

Propulsion Efficiency

Energy Supply

- Needs
  Light, inexpensive, reliable, easily available energy source

- Technology Transfer?
  Where should we look?
  Depends on application

  Consider ...

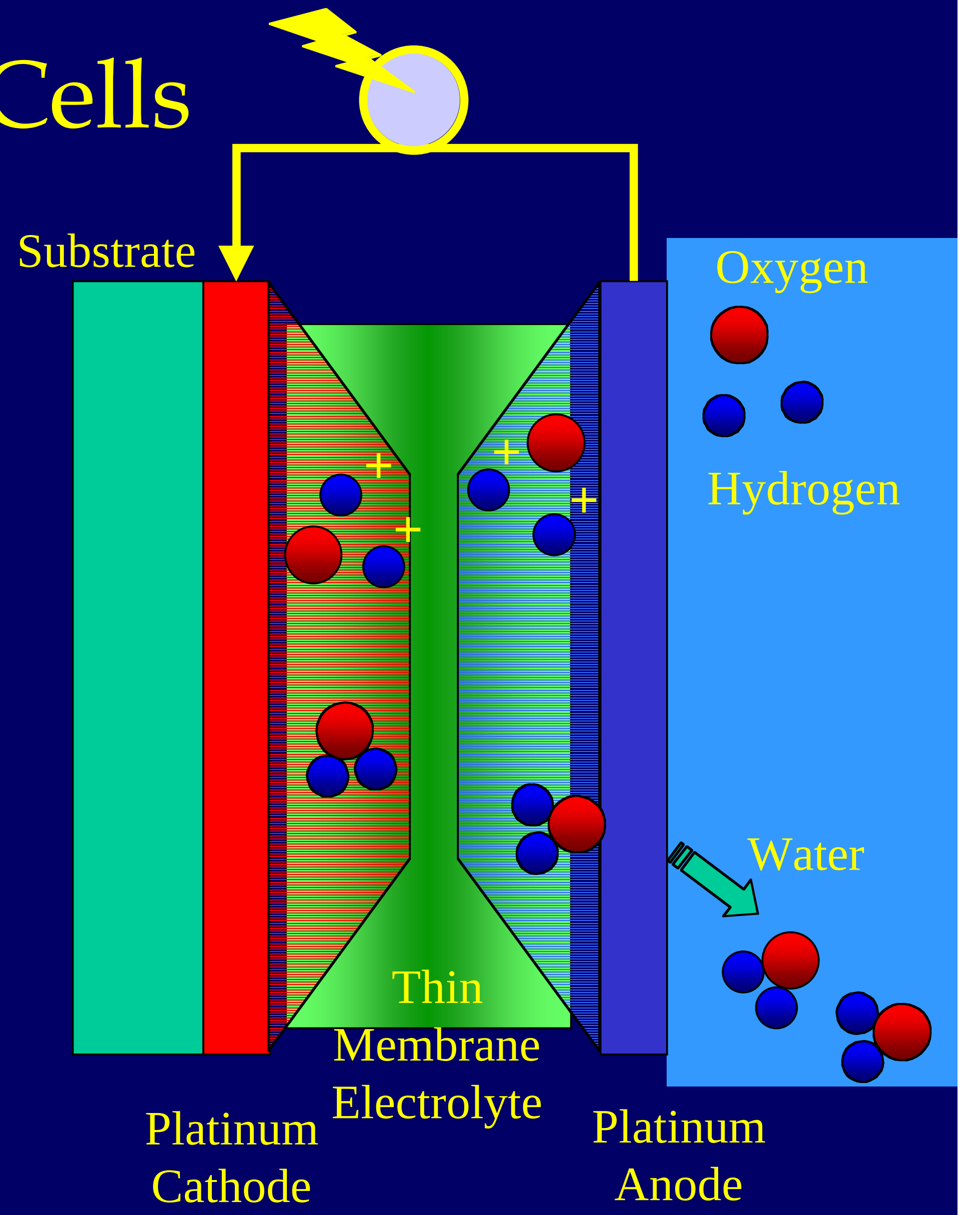
Mobile Phone	Micro AUV	Small AUV	Large AUV	Automobile
1 W	3 W	30 W	1 kW	50 kW

Acceptable Cost

€ 100 / Watt — € 0.01 / Watt

Fuel Cells

- Batteries: Reactants stored internally
- Fuel Cells: Reactants stored external to the cell
- ***Both*** are excellent at extracting electricity from chemicals
- ***But,*** fuel cells can use reactions that liberate far more electrical energy
- Issues are cell design and storage of reactants



Thin- Film fuel cell design

Fuel Cell Reactants & Storage

- Benchmark:
  Primary Manganese Alkaline
  ~ 120 Watt Hours per kg

Fuel Cell Reactants	Wh/kg
Metal Hydride	370
Methanol	6,200
Hydrogen in graphite nanotubes*	~16,000
Liquid Hydrogen	33,000

Source: Dyer, Sci. Am., 281(1), 1999

Propulsion Efficiency

- Perfect-World
  - Low Drag form
  - Low drag **maintained**
  - Few protrubances
  - Little turbulence
  - No fouling or blemishes
  - Problems of access not important

- Real-World
  - 'Submarine' hull common
  - Several protrubances, drag increased
  - Blemishes, fastners and dents facts of life
  - Ready access important, need for rapid configuration changes

Fish-like AUVs - Biomimetics

- Academic & Industry Research
  eg in the USA …
  - MIT
  - Duke University
  - Naval Research Lab.
  - NUWC
  - Nekton Technologies Inc.
  - IS Robotics Inc.
  - Biomimetic Products Inc.
  - WAYA Research Inc. *etc.*
- Also in Japan
  - Tokyo Inst. Technology
  - Hiroshima University

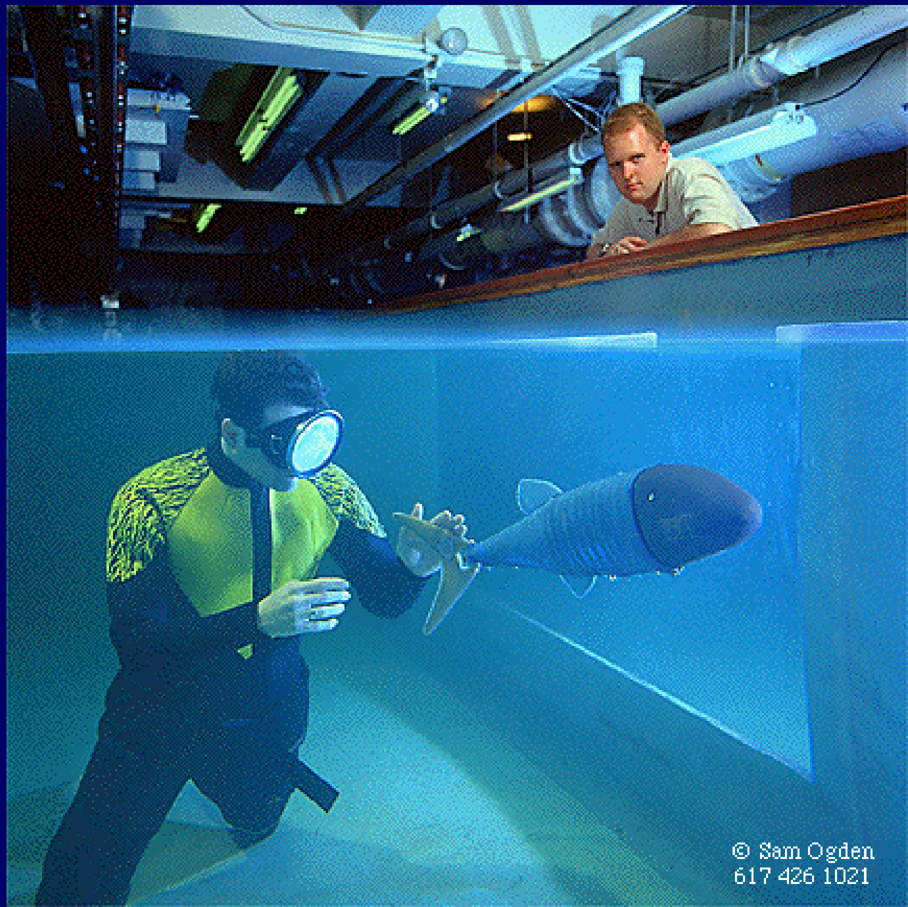


Image by Sam Ogden from MIT website

Potential of Biomimetics

- **Why use biomimetics?**
  - Increased agility and maneuverability
  - Reliable operation in high energy areas eg near shore & near surface
  - Turbulence (drag) reduction
  - Fast starting
- **Approaches**
  - Flexible foil propulsors
  - Flexible hulls
  - Body-based pressure transducers and feedback
  - Studies of swimming fish using theoretical and physical models
  - Artificial muscles

Energy from the Environment

- Solar Powered AUVs
  - 'Green' technology
  - Suitable for slow, long-endurance AUVs
  - Prototype from IMTP, Russia & AUSI, USA
  - Operating cycle depends on latitude & climate
- Wave Powered AUVs
  - Usable for moored profilers
- Thermal Engines
  - 'Green' technology
  - Suitable for Gliders
  - ***Slocum*** from Webb Research, USA
  - Minimum operating temperature gradient
  - Issues over long-term performance

Materials

- ❑ Major Factor in AUVs
- ❑ Critical Design Philosophy
- ❑ Buoyancy Provision
  - Either as Pressure Vessel(s) or
  - Distributed buoyancy
- ❑ User Needs for:
  - Low maintenance
  - High reliability
  - Affordable cost
  - ...

- Adhesives
- Buoyancy
- Compressibility
- Cost
- Pressure range
- Single or multiple sources?
- Temperature range
- Water take-up

Pressure Vessel Materials

Options for Today and Tomorrow ...

Material	**Stiffness Index** **($E^{1/3}/\rho$)**	**Strength Index** **(s/ρ)**	**Remarks**
Steel 62-45B	1.0	1.0	
Titanium 318	1.4	2.2	
Forged Aluminium 7076	2.0	1.4	
Glass Fibre RP	2.2	2.2	55° winding angle filament wound
Carbon Fibre RP	3.5	3.8*	55° winding angle filament wound based on E=470 MPa
Alumina Ceramic (*)	2.4	8.1	But limited in flexural strength. E=2500 MPa
Boralyn E15-T6	2.3	3.5	
Boralyn H35-T8	2.6	2.1	

Stiffness is limiting factor for thin walled tubes that fail due to buckling

Wide-Area Underwater GPS

- Navigation key issue for all types of AUV
- Navigation Networks
  - Self-Contained, On Board
  - Transit
  - Manoeuvring
  - Local Area
  - Regional
  - Basin-scale
  - Global
- Wide-Area Common Infrastructure
  - Timely?
  - Of value?
  - Who are the user communities?
  - Technical issues?
  - Take up?
  - Investment sources?
  - Control authority?

DR Navigation Sensors

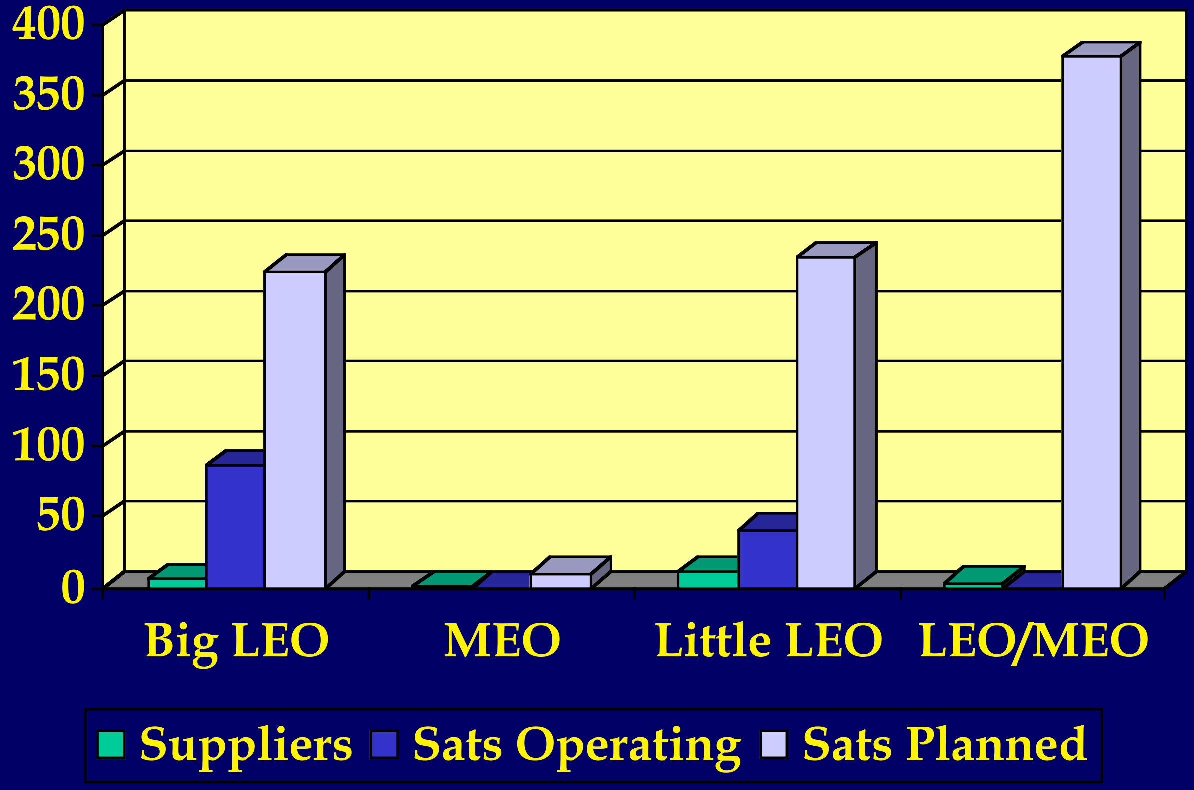
- Heading
  Issues
  - Magnetic or Gyro-compass?
  - Accuracy: Latitude, speed and heading-related errors
  - Drift
  - Integration with speed & acceleration sensors
  - Cost

- Speed over ground
  Issues:
  - Range to seabed
  - Accuracy: Bias & Random errors
  - Update Rate
  - Platform motion
  - Transducer size & weight
  - Cost

Some impressive equipment is available, but no universal solution yet

Satellite Communications

- ❑ Over next 5 years - (possibly) large choice of (low cost) satellite communications services, but
- ❑ Need for 'benign' system (quote from Doug Webb, WRC)



Big LEO & MEO
Telephony

Little LEO
Messaging

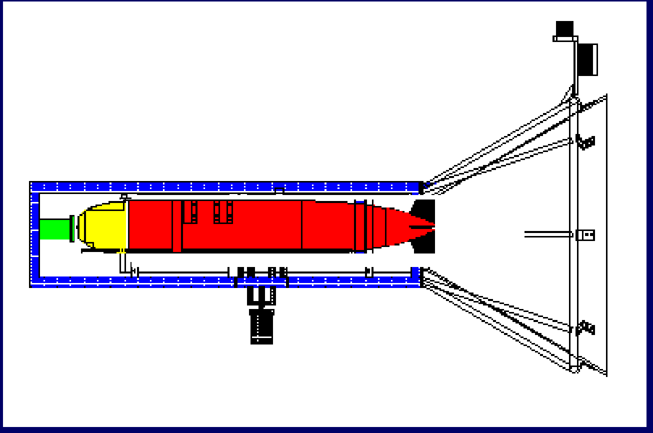
LEO/MEO
Broadband Comms

Courtesy David Meldrum, DML & ISIR Newsletter, April 99

Docking Technology

Why Dock?

- ❑ Extend endurance, down-load data, reduce launch-recovery risks …
- ❑ Step to routine use
- ❑ Essential for intervention-class AUVs



Courtesy MIT Sea Grant web site

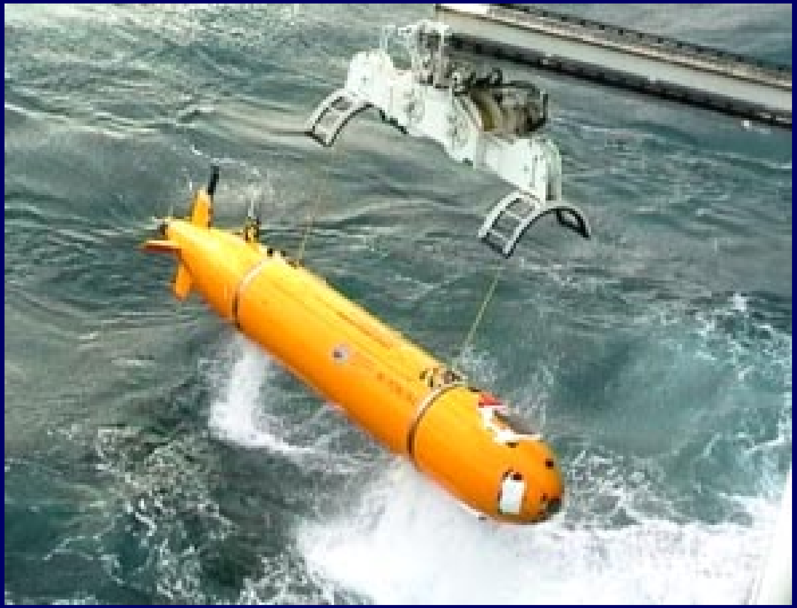
- ❑ Underway
  - ● Activity in Europe & US
  - ● Shallow water docking - almost routine
  - ● Few experiments in deep ocean docking to mooring
  - ● Military work on deployment from & docking to moving platforms
  - ● Mixed experience of docking garage recovery

Beyond Present Mission Programming

- Inter-AUV Communication
  - Is there a need for a standard AUV command and monitoring language?
  - Initiative at AUSI, New Hampshire supported by AUSI and ONR
- Adaptive and feature relative mission programming
  - Import techniques from land robotics, recognising sensor limitations: Planning-based; Behaviour-based or Hybrid systems
- Fault-Tolerant Control
  - Faults in firmware, electronic hardware, actuators/fins, propulsion
  - Failure diagnosis -> identification
  - Failure databases
- Use of Java, VRML and hardware-in-the-loop for simulation and mission planning
- Computational Power: 1 Teraflop per cubic foot available in aircraft

Interaction of Technology & Legal Issues

- ❑ Status of Autonomous Underwater Vehicles unclear in national and international law



- ❑ Liability of mission programmer?
- ❑ Piracy through 'hacking'?
- ❑ Abort criteria and actions?
- ❑ Beacons - visual, acoustic, radio, IFF: standards?
- ❑ Adaptive mission plans
- ❑ Issues when leaving harbour?
- ❑ Collision avoidance techniques?
- ❑ Built-in hazard maps?

Conclusions

- Increasing interest in AUV applications from business, defence & science communities
- Europe is a leader in innovation and use of vehicles
- User-driven requirements will increasingly focus development
- Partnerships more likely to produce business successes

If, for autonomous underwater vehicles 'Tomorrow is Today'*

Who is looking beyond tomorrow?

* James McFarlane, ISE