The Economics of Scale: Using Autonomous Underwater Vehicles (AUVs) for Wide-Area Hydrographic Survey and Ocean Data Acquisition

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Key words: Autonomous Underwater Vehicles: AUV; UUV; Hydrography; Oceanography; Ocean Research.

ABSTRACT

This paper discusses the use of the Autonomous Underwater Vehicle (AUV) for hydrographic surveying and environmental data acquisition. The AUV is an augmenting technology that offers real potential to increase cost-effectively the quantity of ocean data acquisition while significantly improving data quality.

The paper provides an appropriate introduction to AUVs, with examples of some of the many commercial vehicles in use. Contemporary vehicles are discussed together with some of the more relevant research and developments that are taking place. An overview of the ocean survey public sector and the commercial market is considered as a means of providing a scale for assessing the impact of AUV technology. Each of these sectors is discussed and areas identified where AUVs can offer cost savings, the benefit of efficient wide-area acquisition, for ocean monitoring and as augmenting/facilitating technological solutions to solve challenging problems.

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1. OVERVIEW

In the commercial sector of the hydrographic surveying industry, the AUV is already making a significant impact. Technical dependability and cost-efficient solutions are high priorities in this sector, especially in those activities where conventional acquisition methods have reached maturity, or are unable to deliver the crucial information upon which engineers depend.

The commercial importance of hydrography to the interests of many nation states is, without doubt, considerable. Key to these activities are surveying for natural resources, environmental impact assessments and climate change, and offshore engineering, all of which can benefit from the capabilities of autonomous underwater robotics.

However, private industry is not the largest sector that could, in the future, take advantage of the new technology. Of the 1,400 survey and research vessels in service world-wide, some 25% are engaged in hydrographic surveying of one sort or another. Their work is principally focused towards charting for navigation, for military and defences applications, for environmental assessments and monitoring and for national economic exploitation. Over a half of the world's entire marine data acquisition effort is concentrated within this range of activities; it is not surprising, therefore, that much of the early development of AUVs was funded by the public sector.

Of the remaining half of the world's hydrographic activities, 28% are for, or within, the ports, harbours and coastal engineering sector. Traditionally, this is a fragmented and conservative industry and is unlikely, at least for some time, to embrace advanced technology on a large scale. The remaining 20%+ represents the surveying activities that constitute the offshore industry.

The activities comprising the hydrographic tasks that support the offshore industry are multitudinous. This sphere is overwhelmingly commercial in nature and work is primarily performed by organisations within the private sector. The broad divisions of the offshore industry, at this time (2001), are shown in Figure 2.

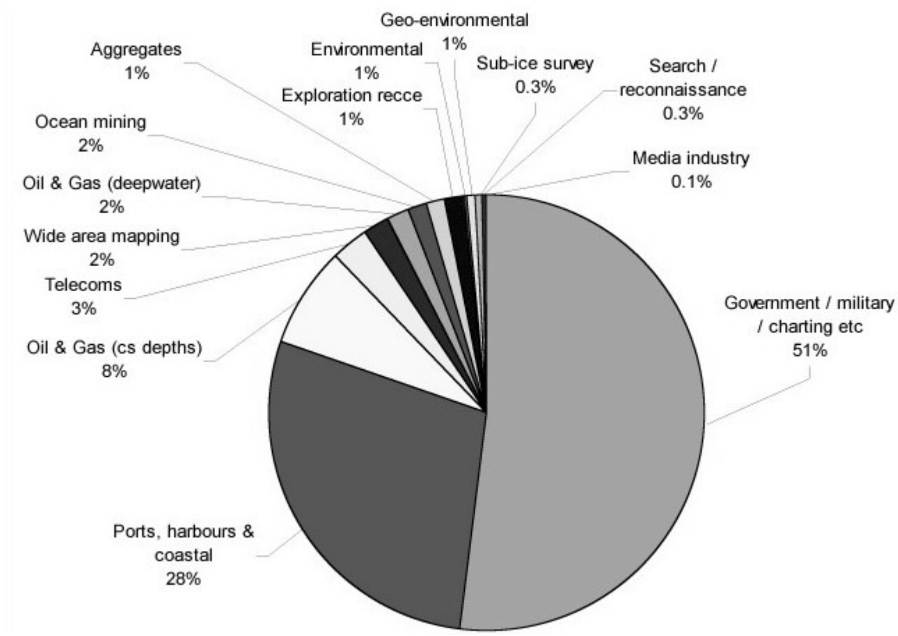

Figure 1: Hydrographic surveying by sector

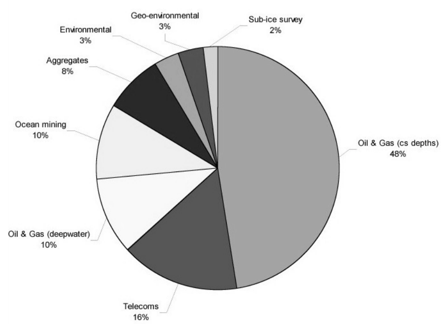

Figure 2: The sectors that comprise the offshore industry

The oil & gas sector accounts for the greatest proportion of the offshore industry, with about 83% of its activities taking place in water depths less than 300m, while the remainder is focused in the so-called deep-water areas. In the future, this ratio will change as the exploitation of hydrocarbons moves into ever-deeper waters.

Telecommunications is another sector of the offshore industry that is evolving rapidly. Its current 16% share of activities is on the increase as the demand grows for secure, robust and high-capacity telecommunication networks to link the nations of the world. Ocean mining for precious minerals and metals, is also expected to be a growth area in future as technologies are developed to harvest these products from the sea.

The oceans are still, for the most part, a mystery. While, for decades, scientists have known that the ocean drives our climate, it is only recently that politicians and the general public have come to accept the importance. Climate change and the need to understand and monitor

the ocean, as well as to assess the effects of our polluting industries and population, has already led to an increase, by progressive nations, in environmental monitoring and is slowly evolving as a market for the private sector.
The technologies and tools developed and used within the private sector are well suited to many of these vital tasks, and the commercial efficiency inured in this sector will provide cost-efficient solutions in the future. Without doubt, the AUV will be one of those tools.

2. THE VEHICLES

During the latter years of the 1990's, the commercial survey community first began investigating the possibility that AUVs could be employed to solve some of the problems then facing the oil & gas industry. The impetus came from the upstream oil & gas operators where a number of enlightened individuals were considering how best to approach surveying tasks in the deep-water blocks then being explored in the Gulf of Mexico, West Africa and offshore South America. Their contention was that, in these difficult regions, traditional surveying methods and existing technology were approaching practical limitations and that the AUV appeared to solve many of the difficulties.

It soon became apparent that the world was not short of excellent AUV development centres such as MIT's Sea Grant Laboratory, Woods Hole Oceanographic Institute and Florida Atlantic University in the USA. In the UK, the University of Southampton had developed and built its first vehicle, the *Autosub*. In all, there were nearly a hundred vehicles in existence or under development.

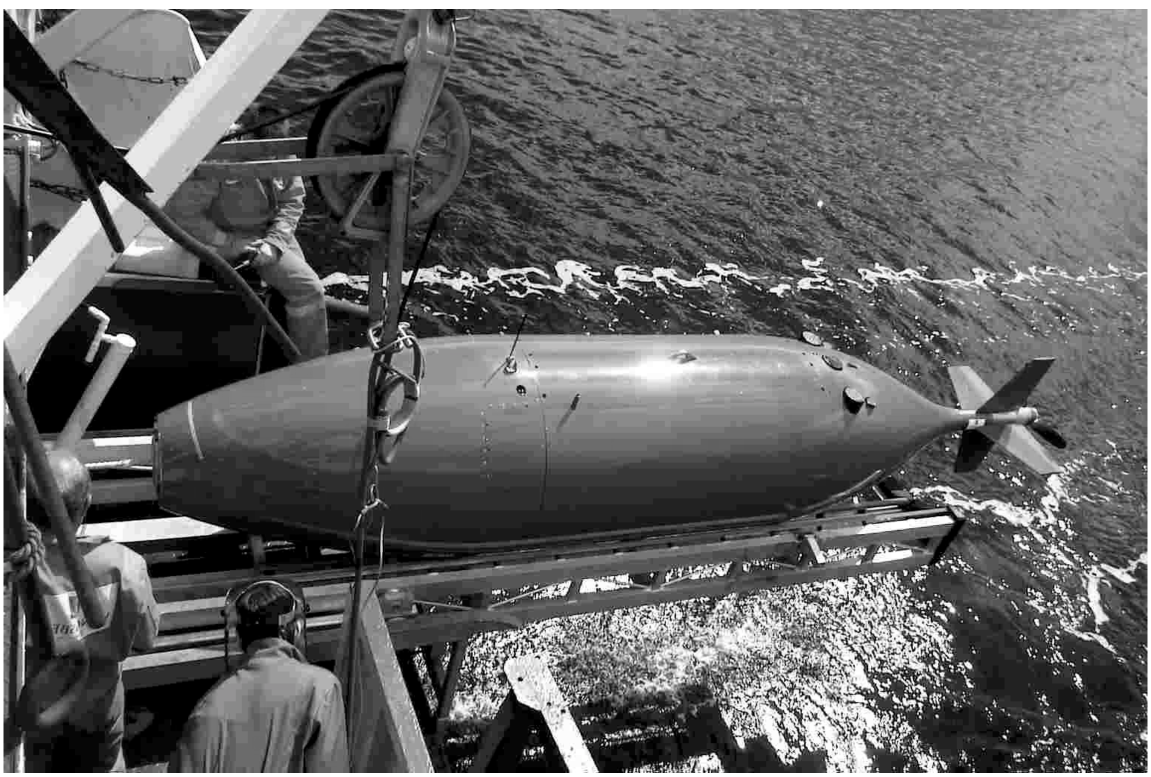

Figure 3: C&C Technologies' Kongsberg-Simrad *HUGIN III*

Of the commercial AUV manufacturers, International Submarine Engineering's *ARCS* vehicle had over 900 successful dives to its credit while its mighty *Theseus* had shown that an autonomous vehicle could lay 170 km of fibre optic cable beneath the polar ice. In Norway, Kongsberg Simrad AS and their military partners had developed the first generation of their successful *HUGIN* vehicles.

At about the same time the oil & gas industry began its study, the De Beers mining group in South Africa was also looking at AUVs as a possible improvement to their survey methods for offshore prospecting. They turned to Maridan AS, an entrepreneurial Danish company, which was then developing a AUV.
Apart from De Beers, three of the larger private survey companies embarked on the road to AUV acquisition. In the U.S., C&C Technologies were the first in the offshore sector to acquire and field a vehicle. Its choice was Kongsberg Simrad's *HUGIN III*, a deep-water vehicle targeted initially at the Gulf of Mexico market. About the same time, the U.K. based Thales GeoSolutions (previously Racal Survey) announced its intention to acquire a small fleet of *Sea Oracle* vehicles from Bluefin Robotics of Cambridge, Ma. Fugro Geoservices, the U.S. subsidiary of the Netherlands-based Fugro group, partnered with Oceaneering and the Boeing corporation to develop a large survey AUV.

Alone of the first four advocates, Thales' required that its vehicle should be small, arguing that it would be easier to handle and, by using multiple vehicles, it could meet the deep-water data acquisition needs of its customers. The other companies chose much larger configurations to cater for extended operational duration, or mission time, while carrying a full complement of survey sensors.

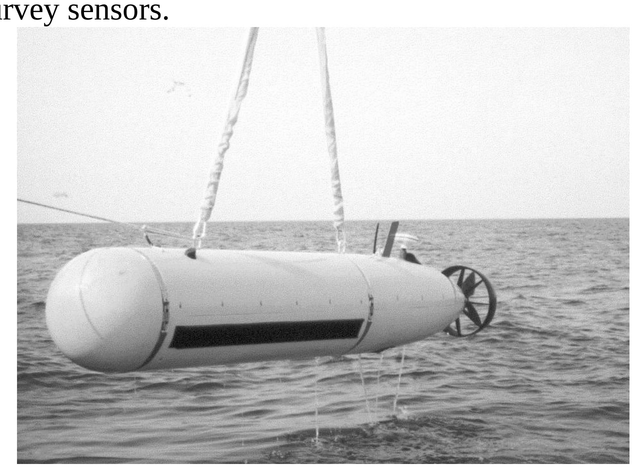

Figure 4: Bluefin Robotics / Thales *Sea Oracle* vehicle

In 2001, Halliburton's UK subsidiary, SubSea, a major offshore construction contractor, joined the race by announcing its intention to build survey class AUVs based on the University of Southampton's *Autosub* design. A net purchaser of survey services, SubSea recognised that *Autosub* could perform its own seabed surveys independently, reduce costs and enhance its products. More recently, the Norwegian organisation GeoConsult AS has announced the purchase of a *HUGIN III* vehicle for hydrographic and geophysical surveying.

There was considerable debate within the survey community on what tasks AUVs were capable of performing. Most agreed that multibeam echosounders, side-scan sonars and sub-bottom profilers should be carried; some added magnetometers to the inventory while others included some of the more exotic sensing systems. There was the issue that centred on how long an AUV mission should last. Twelve hours, twenty four, forty eight or even longer? When Fugro set out its requirements in 1998, through an invitation to tender, velocity and endurance were key commercial considerations. While no one envisioned running a vehicle for more than a few hours in the first instance, it was recognised that a 12-hour mission would not be that long in coming. However, to be commercially viable, 48 hours appeared to be the optimum and the vehicle would have to be able to perform, if not immediately, within a short time.

2.1 Hybrid AUVs

Another vehicle class, akin to the AUV, is the so-called hybrid vehicle. This centaur-like vehicle is half AUV and half ROV. As a class, the concept was stimulated by the work, among others, of the French company, Cybernetix and its *SWIMMER* vehicle, and the designs of the tripartite of International Submarine Engineering, Fugro-UDI and the Stolt Comex group. The industry's need for such a hybrid vehicle was, at first, in some dispute. While oil & gas companies saw benefit and calculated huge savings, ROV operators were more sceptical. The best, and most economically resilient use, was seen to be where ROVs were used as observation vehicles and where some 'light weight' intervention was required. The market best defining these characteristics is offshore construction support, where ROVs are routinely used to monitor pipeline installation (touch-down monitoring) and the placement of sub-sea structures such as template and manifolds.

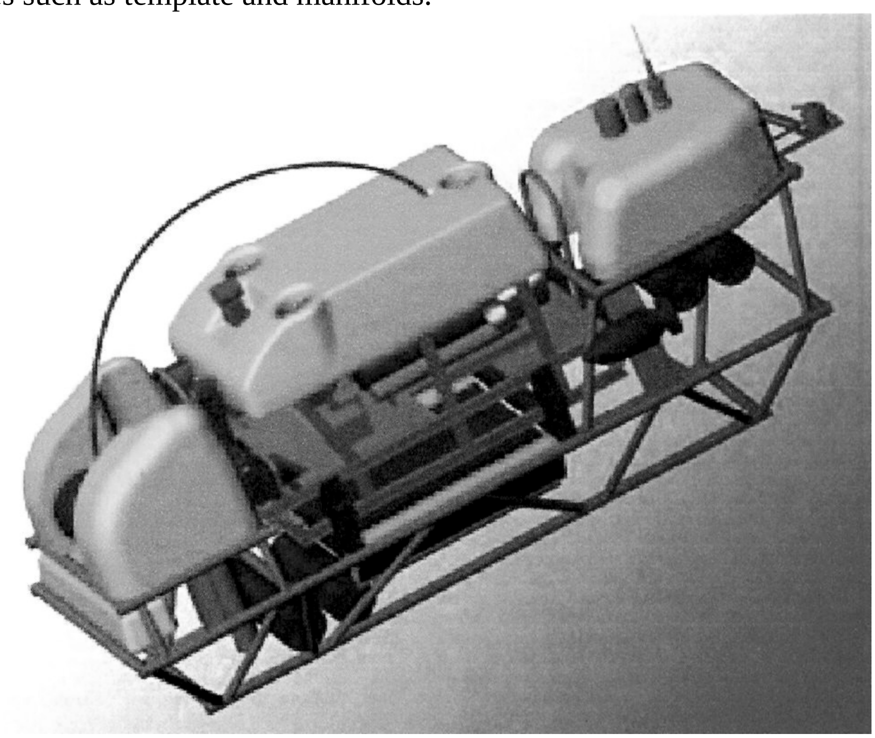

Figure 5: Cybernetix *SWIMMER* vehicle

Figure 6: International Submarine Engineering's semi-submersible *Dorado* AUV with its *Aurora* towbody

Very significant cost-savings are available to any customer who employs vehicles that do not have to rely upon specialist ROV support vessels, or whose missions are limited by weather conditions. Indeed, certain hybrid vehicle designs point towards these vehicles remaining on station, or in an oil field complex, rather than being tied to the capabilities and availability of specialist vessels. In late 2000, J Ray McDermott, one of the major offshore construction companies, announced a deal with International Submarine Engineering for such a vehicle, *SAILARS*, aimed specifically at meeting the demands of offshore construction support. *SAILARS* employs a variant of the company's semi-submersible AUVs from which is deployed a standard deep-water ROV. Other designs, such as *SWIMMER* and *AutoROV*, use an AUV-type shuttle to take a modified ROV to the seafloor construction site where the vehicle is mated to a power/optical fibre relay point.

3. THE ECONOMICS

Time and again it has been shown that a good survey, to a sensible specification, saves project time and money. Even civil engineers are beginning to understand the economics. Optimal structural design versus over-design saves the oil & gas industry millions every year; however, this is only workable when the engineers have the essential data they need. The AUV appeared to solve both problems – excellent data acquisition capabilities at an affordable price.

Another issue on AUV economics centred on the efficiency of vehicle operations, especially whether it was best to have one multi-role or several single-role vehicles. Several economic evaluations, based on manufacturers 1998 prices, seemed to point towards 'bigger is beautiful'; however, there is more to the answer than simple economics. Smaller vehicles are easier to handle and are more portable, can be operated from vessels of opportunity and offer some flexibility for sensor packages.

A paper by C&C Technologies (Chance, 2000) has been quoted on a number of occasions as demonstrating and illustrating the cost-effectiveness of AUV operations. Others have also evaluated the commercial economics and all agree that AUVs offer savings in time, commercial risk and operational cost.

In essence, the technical (and commercial) arguments for replacing conventional 'towed' technology with AUVs are:

- Line running direction: towed systems cannot accommodate sharp changes in direction whereas an AUV can
- Line running position: keeping a towed system on line is difficult - AUVs run on line
- Line running altitude/aspect ratio: keeping a towed system at correct depth is not easy - an AUV can fly at precisely the correct depth or height above the seabed
- End of line turns: towed systems, especially in deep water, require a long line turn (anything up to 2 hours) - AUVs turn in a very short space
- Run-ins / run-outs: towed systems require a run-in to a line and a run-out (in deep water the run-out can be six or more kilometres) - AUVs need neither
- Positioning: in deep water, positioning a towed system is problematic and, if any degree of accuracy is needed, calls for a second USBL 'chase' vessel - AUVs can run autonomously and/or be positioned by USBL.
- Survey speed: survey velocity of a towed system is a function of water depth and length of tow; the deeper the water, the slower the speed. The velocity of a deep-tow system can drop to a knot whereas AUVs traverse between 3 and 5 knots (or more), irrespective of water depth.

Undoubtedly, AUVs can offer timesaving over conventional survey techniques. To what extent these savings translate into economics is a more complex issue than is supposed. To the company amortising assets with which an AUV could, or might, compete, or even supersede, the wisdom of an investment in this technology can appear questionable. For a new-start, or a company considering expanding capability, the AUV offers an interesting and commercially attractive alternative to traditional technology.

Compared with some of the more exotic survey instrumentation, an AUV can appear to be quite expensive. However, analysis and experience of performance, capital amortisation and running costs show conclusively that AUVs can out-perform and out-price conventional data acquisition in many circumstances. It should be stressed the costs given in the following examples are by way of simplified comparative examples only and do not represent those of any particular company or organisation.

Example 1 – 25km^2 block survey

Water depth – 250m Total line distance (excl. run-in/out) - 135km		
	Vessel	**AUV**
Data acquisition time saving		8 hours
Data acquisition cost saving		Ca. $15,000

Example 2 – 25km^2 block survey (as above but deeper water)

Water depth - 500m Total line distance (excl. run-in/out) – 135km		
	Vessel	**AUV**
Data acquisition time saving		27 hours
Data acquisition cost saving		Ca. $50,000

Example 3 – 100km^2 block survey

Water depth - 500m Total line distance (excl. run-in/out) - 470km		
	Vessel	**AUV**
Data acquisition time saving		50 hours
Data acquisition cost saving		Ca. $150,000

Example 4 – 10,000km^2 survey e.g. EEZ resources study

Water depth - 500 m Total line distance (excl. run-in/out) - 22,200 km		
	Vessel	**AUV**
Data acquisition time saving		1,000 hours
Data acquisition cost saving		Ca. $1.5M

Even greater savings in time and costs are achievable when other tasks that normally accompany an acoustic survey, e.g. digital geophysics, sampling and geotechnical investigations are taken into account.

Figure 7: Maridan's M200 vehicle being prepared for launch

4. THE TASKS

AUVs are capable of performing many of the tasks traditionally associated with ship work. Assigning to AUVs tasks that could be performed more efficiently using traditional tools could cause more harm than good. Nevertheless, the most obvious application for AUV operations is that most traditional of ship based science - surveying.

Equipped with a multibeam echo sounder, sub-bottom profiler and side-scan sonar, the AUV is the 'ultimate' surveying tool. Detractors of this survey data acquisition method point out that the real-time quality control available from the vehicle while underway, from limited acoustic bandwidth, is not sufficient to ensure that data collected is adequate. However, this should not be regarded as an impediment to progress and, already, artificial intelligence is being developed that promises results better than any unaided human could maintain. It should of course be noted that UUVs (vehicles in direct acoustic link with the mother vessel) provide a substantial amount of real-time data.

4.1 Oil & Gas

The main driver for introducing the survey AUV has been the oil & gas industry's deep-water blocks off the Americas and Africa, where the costs associated with surveying, using traditional technology, appeared untenable. The alternative method for imaging the seafloor, and advocated by many in the industry, was to use reprocessed 3D seismic exploration data. Fortunately, for design engineers and the environment, most professionals disagree and uphold the value of surveys conducted using appropriate tools and quality-assured procedures. The AUV bridged the gap, offering the prospect of proper surveys performed at costs comparable to surveys conducted in more shallow water.
AUVs are not just limited to deep-water and Maridan AS, for example, produces a vehicle version specifically for shallow water. It is anticipated that AUVs will soon be a viable alternative for inshore survey and have the capability of going places that are less accessible to, or could endanger, a traditional survey operation.

For the oil & gas industry, AUVs are suitable alternatives for:

a) Geo-hazard and clearance surveys
b) Rig site surveys
c) Acoustic inspection of pipelines and sub-sea installations.Pipeline route surveys
e) Construction site surveys

It has already been noted that many of the vehicles entering the market are quite large, five or six metres LOA. Handling such large vehicles is not without its difficulties and specialist launch and recovery systems are needed. This tends to limit the sort of vessels capable of operating an AUV to the larger sort of vessel or survey ship.

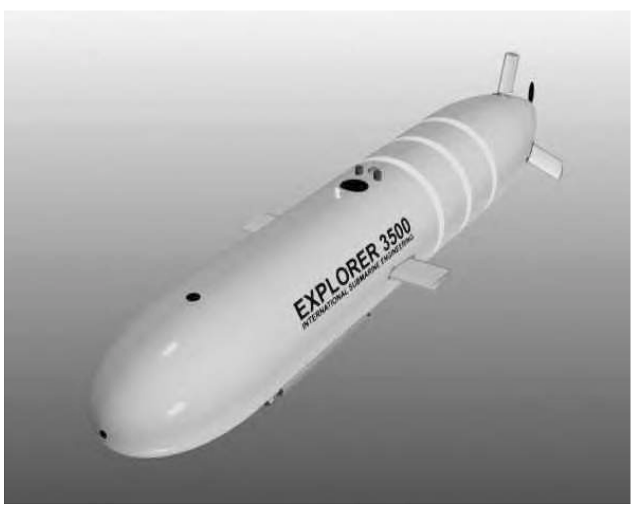

Figure 8: International Submarine Engineering's *Explorer* vehicle

The self-styled hybrid vehicle, described above, is an evolutionary line of AUVs considered by some in the oil & gas industry as one of its most exciting developments. At this time, the greatest limitations for autonomous underwater robotics (as work-class vehicles) are power and artificial intelligence. The tasks performed by ROVs are complex and, as yet, no one has been successful in replacing a human operator. It is of course only a matter of time and money, and if the commercial case for autonomous robotics is demonstrated it is very probable that hybrid vehicle developments will produce a viable alternative to the work class ROV. In the meanwhile, these sorts of vehicles have an interesting future. In oil & gas pipeline construction the traditional method of monitoring pipe laying is to use a specialist ROV vessel. The ROV monitors the pipe's touch-down point and can also be used for light intervention tasks such as wire cutting etc. The hybrid vehicle, such as Cybernetix *SPIDER* crawler AUV, can replace the ROV for much of the critical touch-down monitoring. In deep water, where there is the added difficulty that pipes tend to buckle under the extreme loads and then collapse under high pressure, this aspect of surveillance takes on even more importance.

AUVs offer very tangible benefits in pipeline route surveys, where the primary sensors are multibeam echo sounders, side-scan sonars and sub-bottom profilers. These surveys range in length from a few score metres to many hundreds of kilometres. Here the AUV has a distinct advantage because, while it collects the acoustic imagery, the mother vessel is free to perform the time-consuming and heavy geotechnical investigation work. Similarly, the vehicles can gather the shallow geophysical data for construction site surveys, while the mother ship gathers the more difficult deeper digital geophysics and performs in-situ testing for the all-important foundation studies.

Where it is expected the AUV will have a new role is as an environmental data acquisition tool. In the deep-water regions, where much is still unknown, the vehicles can study and monitor environmental conditions, observe shallow water flows and measure the strength of currents throughout the water column. It can also be used as for environmental protection detecting and observing protected benthic populations and other ocean floor phenomena.

4.2 Telecommunications

In common with the oil & gas industry, route surveys are also the principle interest of the submarine telecommunications sector. Here the AUV is particularly well suited to continental shelf operations where fielding a specialist survey vessel to a remote location can be expensive. The cable industry, attracted by the prospects of rapid deployment and efficient data collection, has showed considerable interest in AUVs. It has even been suggested that an AUV could perform short cable crossings and inter-connector route surveys entirely autonomously, launched from a shore facility.

While it is unlikely that AUVs will find a role off the continental shelf for some while, there is a requirement for the more difficult shore approaches. In this zone, typically water depths less than 30m where ocean going vessels cannot manoeuvre, surveys are generally conducted from an in-shore vessel. AUV performance competitions in the U.S. have shown that some vehicles are particularly good when operating in these difficult, close to shore and dynamic conditions.

Figure 9: International Submarine Engineering's *Theseus* cable laying AUV beneath the polar ice

The other obvious use of the AUV is as a cable layer, which has already been shown to be practicable by International Submarine Engineering, whose Theseus vehicle laid some 175km of fibre optic cable beneath the polar ice.

4.3 Minerals and Mining

In the search for seafloor minerals, the AUV has already made its appearance. De Beers' acquisition of a Maridan vehicle was for just this purpose and their arguments for going the AUV route were purely commercial. Augmenting their surface fleet with AUV capability has significantly increased the amount of ground they can cover each day in their search for precious stones.

The sub-sea mining industry will undoubtedly be a growth area of the future. The AUV is a logical tool for mapping, for example, manganese nodule fields and, perhaps, versions of the hybrid class of vehicles will be employed for the mining and monitoring.

Figure 10: Maridan's *M600* vehicle ready to dive

5. AUVs FOR SCIENCE

Autonomous underwater and semi-submersible vehicles, be they AUVs, UUV or hybrids, have important roles to play in the offshore environment. They may not yet be a complete substitute for many traditional ship-based methods of data acquiring, or replace the ROV as a construction support and intervention vehicle, but they do hold the prospect of becoming an indispensable tool for engineers and surveyors alike.

AUVs also offer the prospect of augmenting much traditional data acquisition for charting and navigational surveys and for surveying the resources within national economic zones. Already military and defence organisations have recognised the value of autonomous robotics in such areas as mine counter measures, a subject outside the scope of this paper, and much of the research in this area is exportable to more peaceful applications.

As has already been stated, much of the world's seas and oceans remain something of a mystery. Here the AUV has perhaps its most important role, as a science platform, to gather information on the properties of the oceans and as an observer of the dynamic events that take place beyond the view of humans. In the realm of fisheries research, *Autosub,* for example, has demonstrated that an AUV can follow schools of fish and observe their natural movements that cannot be observed with more intrusive technology.

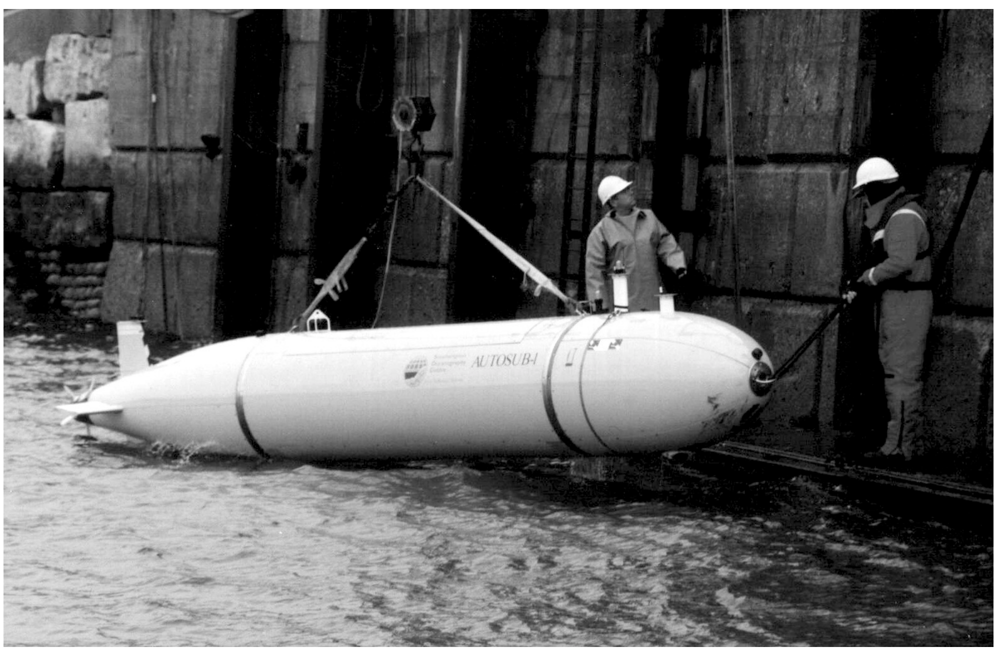

Figure 11: University of Southampton's *Autosub* vehicle

The AUV is a unique vehicle class, it comes in many shapes and forms, and operates in ways similar to unmanned space probes; they are, in fact, inner-space probes. As tools to collect data from the medium that covers the majority of our planet, the environment that drives

much of our fragile climate, they are the most logical and most efficient machines capable of collecting data from the sea surface to its greatest depths.
Research around the world continues apace, developing ever-better autonomous systems and improving the range of sensors that science demands. A great deal of effort has been, and continues to be, focused on better and more efficient energy sources that allow the vehicles to stay at sea for longer and to power more sensors.

Some AUVs are being developed to harness power from the sea itself and others, such as the Webb Research Corporation's *SLOCUM*, use advanced hydrodynamics to glide around the ocean and which offer the possibility of year-long data gathering missions.

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BIOGRAPHICAL NOTES

Edwin Danson is a Fellow of the Institution of Civil Engineering Surveyors, Chairman of the Hydrographic Survey panel and member of the Geomatics Engineering Practices Committee. He is also a Chartered Surveyor and an authority on Autonomous Underwater Vehicles. His professional career spans some 35 years during which time he has had the privilege of participating in the development of many of the fundamental technologies that have revolutionised surveying both on land and at sea. Edwin Danson is a member of the underwater robotics group of the Society for Underwater Technology and also a member of the Training, Certification and Personnel Competency committee of the International Marine Contractors Association. He has written and presented numerous papers on surveying and its commercial environment.