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# Control of remotely operated vehicles (ROVs) in the future

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## SYNOPSIS

*ROVs are now used extensively by the offshore, defence, telecommunications and leisure industries. The size and cost of these vehicles have decreased dramatically over the last decade. These vehicles have, at present, a limited range and depth capability with respect to their 'parent' vessel, as they are 'tethered' by an umbilical.*

*This paper discusses some of the technical developments necessary to make these vehicles fully autonomous, and ends by emphasising the realistic market potential for such systems.*

## INTRODUCTION

Current ROVs (Fig 1) have a range capability limited by with their support vessels. The main reason is that ROVs are tethered to the vessel by an umbilical which provides a severe encumbrance due to drag and risk of snagging when ranges in excess of a few hundred metres are attempted, particularly when there are strong tides or subsea currents. Decoupling the ROV from the mother vessel could give a significant increase in range. The commercial consequence of this should be to significantly reduce support vessel costs.

To achieve this decoupling, the ROV would have to operate without an umbilical (an autonomous ROV) or operate with a very small diameter umbilical, e.g. a fibre optic data link without power transmission (a semi-autonomous ROV).

Some of the developments necessary for a semi-autonomous or autonomous vehicle are highlighted in this paper. These include:

1. power sources
2. materials
3. information management
4. intelligent remote work systems
5. navigation and control systems

## SEMI-AUTONOMOUS ROVs (FIG 2)

An example of the need for semi-autonomous ROVs is, due the advent of subsea oil production controls, offshore platforms which have associated with them subsea installations several kilometres away, as well as export pipelines, either coupled into another pipeline system or back to shore.

A highly effective ROV inspection system, which could operate from the associated platform out to several kilometres, and operate in a subsea mode where it would be generally immune to limitations on launch and recovery due to high sea state, would offer significant advantages compared with current systems. It is proposed that this objective is best achieved by a semi-autonomous ROV. That is, an ROV system where the power is generated on board the vehicle rather than being transmitted through an umbilical cable. The vehicle is only linked to the surface by a thin fibre optic cable for bi-directional transmission of high speed data. The dimensions of the data link are designed to eliminate the problems of drag and severe sea state operations normally associated with standard ROV umbilicals.

Mr Roger Chapman has spent 9 years in the Royal Navy as a Submarine Officer (navigation specialist), 4 years as an operator of manned submersibles, 2 years as a survey manager for a manned submersibles operating company and 7 years as Managing Director of a successful ROV operating company specialising in high quality pipeline inspection. He is a Director and founder of RUMIC and is currently Managing Director. Mr Chapman is also a Fellow and Director of the Society for Underwater Technology.

Mr Kenneth London has a BSc (Hons) in Electronic/Electrical Engineering, he spent 3 years as a Submersible Engineer of a manned submersible operating company, 3 years as an operator of ROV systems and 3 years as Technical Manager of a successful ROV operating company developing an innovative payload for ROVs. Mr London is a Director and co-founder of RUMIC and is currently Technical Consultant. He is also a member of the Society for Underwater Technology.

The semi-autonomous ROV can therefore work in most weather/sea state conditions, and at extreme range from a support platform or vessel.

The presence of an umbilical between the parent vessel and the ROV in inspection operations requires the parent ship to be of a dynamically positioned (DP) type so that the umbilical deployed, and hence drag, is minimised.

By using a semi-autonomous vehicle a cheaper ship can be utilised since umbilical drag is no longer a problem. In addition, this autonomy makes feasible the use of more than one ROV at a time. The mother ship, now free from manoeuvring constraints, can shadow the operation at a distance.

A major limitation to be overcome would be the absolute positioning of such a system. An on board navigation system would be a major piece of new technology required.

## ACOUSTIC TELEMETRY

A fully autonomous ROV will require data transfer for visual and control information to the surface operator and from the surface to the vehicle. In this mode of operation the most reasonable possibility is to use an acoustic link.

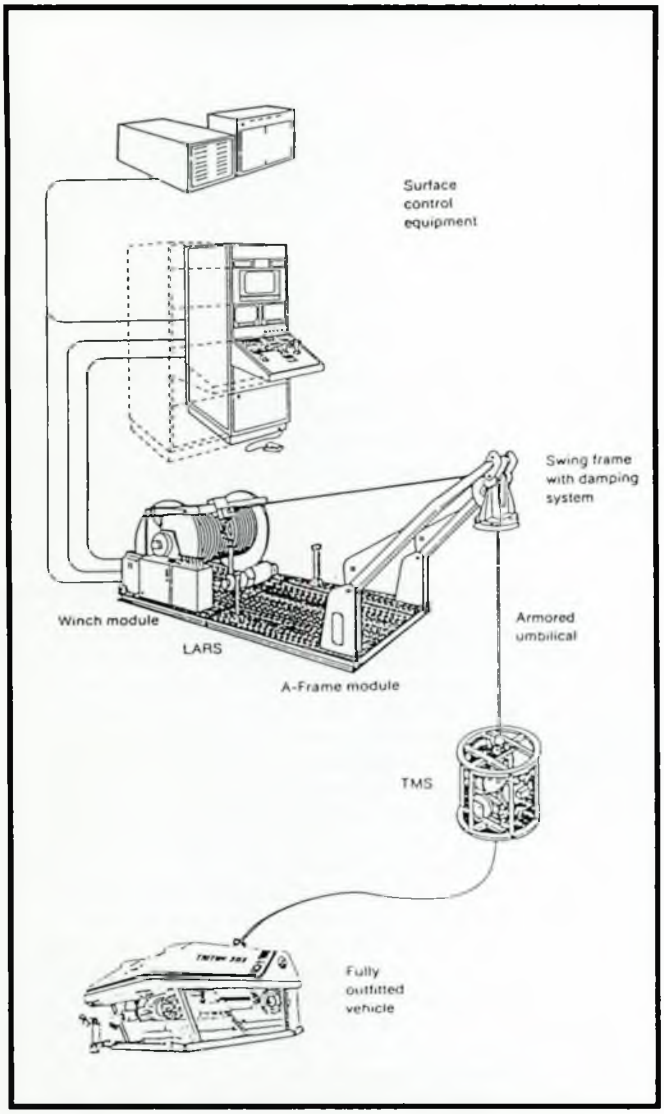

**Fig 1: Typical present-day work ROV system**

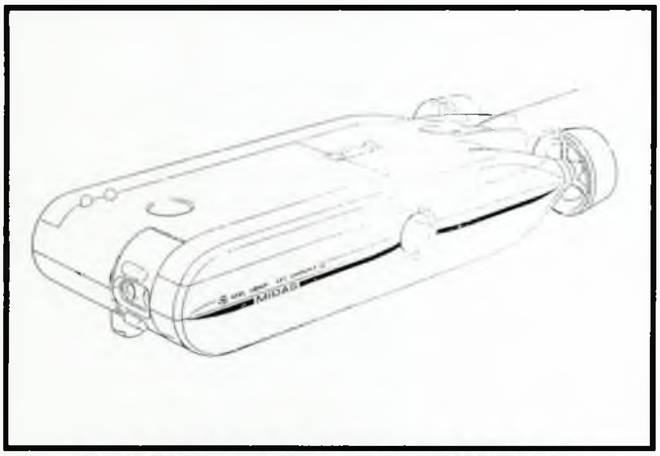

**Fig 2: Typical semi-autonomous ROV under development**

## The problem with an acoustic link

The basic problem is the narrow signal bandwidth available via an acoustic channel. Typically, a 10 kHz channel is achievable on a carrier of 600 kHz. Over a 100 m range, a signal attenuation of about 55 dB would be expected. Video requires a 6 MHz bandwidth, thus video compression techniques must be considered. An update picture of approx. 4 frames/s with low resolution (128 x 128 pixels) is achievable which would be suitable for coarse navigation purposes. Alternatively, 1 frame every 4 s could be achieved on a 512 x 512 pixel picture which would be suitable for some inspection purposes. Other problems for consideration are:

1. multipath effects
2. directivity of transducers
3. other sonar interference
4. mechanical cavitation noise
5. platform noise

The level of attenuation has been mentioned, and this low signal strength at the receiving transducer, coupled with these other problems, could lead to significant data errors. Directivity of the transducers appears to be particularly important in avoiding multipath effects.

Practical experimentation has dictated the need for a virtual direct line of sight. It is probable, therefore, that the surface connected hydrophone would need to be an underwater 'garage' for the ROV and directed towards the vehicle at all times to ensure reliable transmission.

Of course, an extensive amount of work is being undertaken by both commercial companies and universities.

Our particular feeling is that the amount of data required for inspection purposes is too high for transmission by this medium and it is recommended that a fibre optic link is maintained for all inspection purposes. The acoustic link will be the communication medium in the event of tether breakage or primary telemetry system failure. It is a means of controlling the vehicle for recovery into the garage system.

## FIBRE OPTIC CABLE LINK (FIG 3)

The proposal is that a fibre optic cable links the surface to the sub-surface vehicle with the option of a radio link between a central control area and the remote surface fibre optic interface. In the event of failure of the primary cable/radio link, a back-up acoustic control link would be required to re-direct the ROV.

The following developments in technology are thus important.

1. Fibre optic underwater cables and underwater connectors with simple deployment techniques.
2. Acoustic cable-free data and control links. Standardisation of underwater acoustic telemetry practice with development of reliable acoustic data transfer systems.
3. Short-range optical signal transmission. Distances of 20–100 m are possible depending on water quality. Rapidly pulsed blue–green lasers and application of image intensifiers and optically gated systems to minimise backscatter.
4. Display technology which maximises efficiency of information transfer between the signal processing device and the human operator in the marine environment. Non-optical displays should then be explored, such as auditory patterns or even two-dimensional arrays of tactile excitation applied to the skin.

## POWER SOURCE

The primary limitation of undersea systems is the use of electrical generating systems because of the non-availability of atmospheric oxygen. Conventional air breathing power systems are not available, nuclear power is very costly and

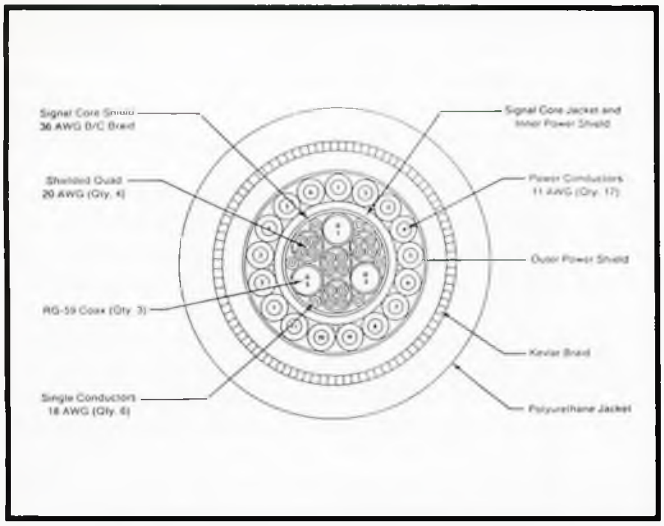

**Fig 3: Standard work ROV umbilical**

hazardous and non-air breathing submersible power systems have only an embryonic development. Another apparent limitation is that underwater systems that carry their own oxidant and fuel will have to carry approximately 8-times the amount of oxidiser than that of fuel.

New sophisticated solutions to this problem include the as yet unproven 'artificial gill', which extracts oxygen from the sea water. The extracted oxygen, combined with use of a methanol fuel cell, for example, has the potential of essentially eliminating the power system constraint on endurance performance of small autonomous underwater vehicles.

Within this context the need is evident for a number of development paths for energy storage and conversion.

1. Develop more effective and efficient power generation, distribution conditioning and energy storage.
2. Develop high-rate primary and secondary lithium batteries.
3. Increase power density of deep-ocean fuel cells by development of lightweight, pressure-compensated reactant storage and conversion sub-systems.
4. Develop power conditioning control, protection and regulation equipment for systems using high levels of electric power delivered by cable.
5. Develop stored chemical energy propulsion systems including conversion of shaft power to electrical power.
6. Develop buoyancy propulsion modules for sustained and burst power.
7. Develop techniques for efficient *in situ* low energy extraction of dissolved oxygen from sea water.

## MATERIALS

The implementation of the power and propulsion developments will require complementary developments in high strength materials and structures in order to take advantage of the energy potential for negative and positive buoyancy in waters of great depth. At present hull and structure advances have been dictated by a very conservative approach on the part of ROV manufacturers.

The potential with such materials as composites, glass and ceramics is enormous, as is the potential for unique and less costly pressure hull configurations. The construction of a low cost, 1 atmosphere hull with an 0.5 weight-to-displacement ratio would open up the entire ocean for utilisation at costs which are almost invariant or even inversely related to depth. Specific developments in this area are, or need to be:

1. the use of composite structures, both organic and metallic, or combinations thereof which offer significant advantages in the ocean of reduced weight, increased strength and reduced corrosion.
2. more efficient pressure-resistant structures with weight displacement ratios of 0.5 for all depths. Development of fibre composites, titanium (with emphasis on welding) and ceramics. As an adjunct, transparent materials such as acrylic and glass need to be examined for both pressure hull and optical transparency.
3. development of non-destructive testing techniques. The capability to perform non-destructive tests *in situ* and evaluation of underwater equipment, structures and facilities has increased.
4. advanced underwater materials development – concepts and practices for 'engineering' materials for deep water and for long exposures need to be developed, both for the commercial metals and the advanced technology composites.
5. corrosion and bio-fouling – deep water effects on corrosion have not been thoroughly studied and engineering practice in this design category is weak. Parametric studies and practices for handling the effects of deep water currents, oxygen and other dissolved gases, pH, and biological factors need to be conducted.

## INTELLIGENT REMOTE WORK SYSTEMS

This particular area of technology is directed more towards fully autonomous vehicles, but there are two particular items which would also benefit semi-autonomous operation even with the potential for an operator in the control loop. The two pieces are:

1. target identification by sonar and input to control of the vehicle, i.e. rather like a missile locking onto a target using radar or infra-red detection.
2. automatic homing of the vehicle in the event that the fibre optic link is severed.

These will need to take account of depth, distance, obstacle avoidance, stored energy, etc.

## NAVIGATION AND CONTROL

One extremely interesting feature of these vehicles is the digital circuitry and logic forming the artificial intelligence (AI) system providing guidance and control throughout the mission. These higher systems are being designed to perform functions previously carried out by pilots. Some of these functions range from interfacing the vehicle's sensors with its control and effector systems, to guaranteeing mission success in varying and often unknown environments and locations.

From this, we see that sensors suitable for AUVs (autonomous vehicles) and specialized piloted vehicles must often embrace both the traditional requirements of marine vehicle design and the newer needs of digital vehicle control systems. Features of sensors such as size, weight and power will always be of importance in vehicle design and, in particular, in those which travel large distances with limited amounts of energy.

Sensor interface to vehicle control, on the other hand, presents many new design requirements, some of which are not always obvious. Most existing sensors are tailored to the

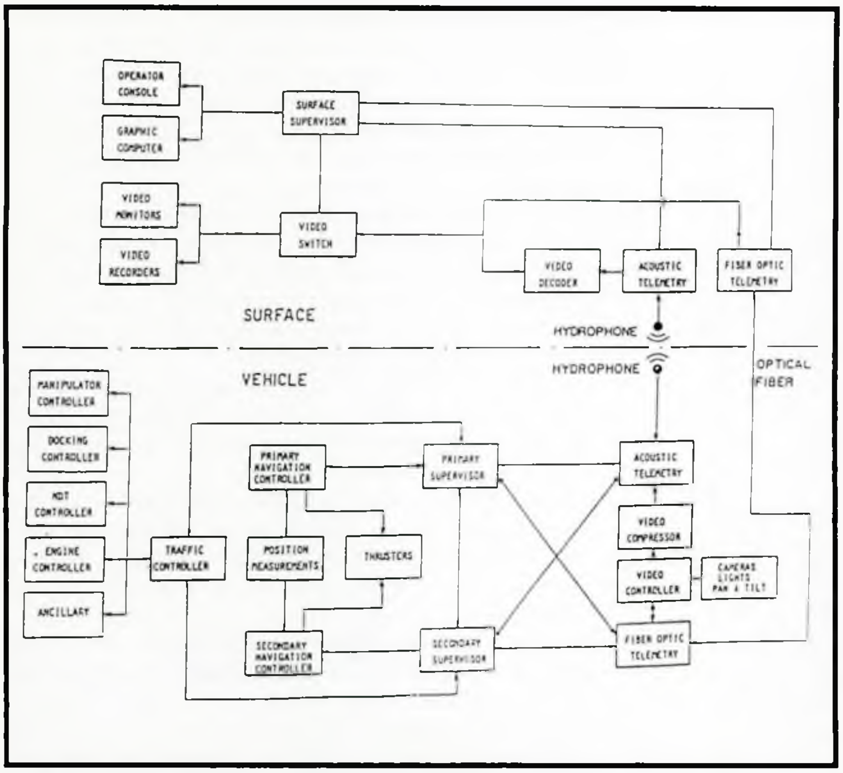

**Fig 4: Block diagram of the control system of a semi-autonomous work ROV being developed**

perceptions of the intuitive and adaptive nature of the near real-time response of the human operator and are not generally suited to the input/output of an AUV processor system.

As vehicle speed increases, for example, the information rate becomes more of a critical factor. This is true whether velocity is the result of vehicle propulsion or currents surrounding the AUV.

Not only must sensor data be fast and accurate to maximise processor response and vehicle control, but data quantity must be filtered so as not to swamp the processing system. Clearly, it is possible to obtain a massive amount of information on the vehicle's environment. To process or edit this information, however, inhibits the system functionally by drastically slowing its response time (Fig 4).

## CONCLUSIONS

### A predictive assessment of what will realistically happen to ROVs

It all started with replacing man underwater. We have seen aerospace companies use their technology to produce grand designs for underwater machines for inspection. We have seen large machines replaced by ROVs of equal or better performance weighing 60% less. We have come from a point where, if an ROV stayed in the water for more than 6 h without breakdown, the operator considered things were going well, to a point where, if the vehicle cannot stay down for several days, things are going badly. We have seen eyeball machines introduced and used on a large scale with the price of their performance reduced to a tenth in less than 10 years. We have heard of fantastic concepts to make autonomous ROVs conduct survey and IRM (inspection, repair and maintenance) tasks, but there are only whispers when market requirement is mentioned. We have all suffered because of the ruinous slide in day rates (manufacturers, service contractors, equipment suppliers, offshore operators), and we hear that there is no money to develop new machines. So what is really going to happen to ROVs?

The short answer is that they are still going to be used, but they are going to have to be very cost-effective. This does not necessarily mean the ROV will have to be cheap, but its performance in carrying out its task has to be good, with automation increased to a level which requires far fewer support personnel on the spread.

To this end the future would seem to lie with machines designed around reliability and maintainability. The situation is not that different from what happened to the British car industry. In the late 1960s not many people took much notice of the strange-shaped cars from Japan with less than sparkling performance and 'wishy-washy' handling. But very soon no-one could fail to notice that they were always top as far as reliability was concerned. Their popularity increased rapidly, especially as all the extras were included as standard for a price that was less than a comparable British car.

Successful ROV manufacturers are going to follow this analogy. Admittedly there is not the economics of scale, but the design will be based on reliability, low maintenance requirements and fast maintenance.

Present ROV designs have made some in-roads into improving reliability, mainly due to improvements in connectors and telemetry systems.

Operational techniques developed by contractors have also helped considerably to reduce downtime, but the future low maintenance machine will require a lot of lateral thinking as far as design and manufacture are concerned. The goal should be to have a machine which has a reliability of greater than 99% and in which no fault takes more than 1 hour to find and repair completely.

Present hydraulically controlled ROV designs would be hard pushed to meet these criteria. For example, if a hose bursts the system has to be drained, flushed and refilled. Often valve boxes have to be opened to clear insulation resistance faults and to change filters, then functions have to be bled, etc. Sometimes even other components have to be moved to gain access to a sump or junction box.

The solution to this problem could lie in the following strategies.

1. A system which is 100% reliable and guarantees no contamination.
2. A system which limits damage to a certain area which can be isolated.
3. A system which will operate reliably with a high degree of contamination.
4. A sea water-based hydraulic system.

Strategy 1 is probably impossible to achieve, strategy 2 would be very complex and hence give lower reliability, whereas strategies 3 and 4 offer opportunities for the future.

The removal of the tether, which supplies power and communications, creates major technical issues, but generates an opportunity to perform tasks quite impossible for the conventional ROV. The achievements of operational systems such as the Epaulard have demonstrated the versatility and reliability of the autonomous vehicle in simple, yet important, missions.

The research undertaken at several major universities and laboratories gives evidence of the difficulty, as well as the promise of the intelligent, untethered vehicle. It is quite evident that such machines will not take over ROV tasks in the near future, and indeed, probably never will. Progress in this parallel field, however, has been extremely rapid, and indeed a substantial transfer of technology back to the ROV could be a major consequence of the ongoing studies.

# Discussion

**A Burnett (Offshore and Marine International Services)** The development of the Duplus vehicle was fascinating following on from the Mantis.

The question remains of the relevance of the development costs involved. More information is required regarding the development costs versus the numbers off, or alternatively, was market research carried out prior to the development work leading to an idea of what the user demand was likely to be, and therefore to the level of development that was commensurate with likely market needs?

With reference to the paper on diving at 520 m, how long will it be before this development results in its every day, fully acceptable use? It was not clear from the paper whether the operational DSV would have to be fully inerted or not in order to guarantee full safety in operational use. What type of gas detection equipment was required in the DSV itself? Further, it was not evident, regarding full operational services of a DSV so equipped, who was responsible for the various aspects of safety, diving, marine DP, overall control, etc.

With reference to the paper on control of ROVs in the future, it is unlikely that divers in any format will be deployed deeper than 1000 m over the next 2–3 decades. Therefore, with the ever growing present requirement to develop reliable subsea separation/control/pumping systems, it would appear that the use of semi-autonomous ROVs will increase – but will sufficient reliability be available? Also the development and use of the fully autonomous ROV is probably unlikely to be cost-effective. It would appear that both alternatives will have to be developed slowly and surely along a suitable automation route – who will provide the necessary funding? What is the likely composite trend and development?

**D J Hampson (OSEL Group)** Development costs of Duplus. No real analysis of market requirements was performed. The design evolved as a result of customer demand and in particular five orders received before development was complete.

Estimates of development costs were made, but these were not followed up at an accounting level. As my paper describes, for small production runs of very specific equipment it is difficult to stabilise the design, and thus the costs, at any point in the product life – in this case more than 8 years.

In real terms development costs were quite modest, and were usually recovered on the particular vehicle on which they were incurred. It is undoubtedly true that for the last 5 years none of the builders of large vehicles have obtained the necessary return on capital employed.

Future ROVs. Although I did not give this paper, I have some comments which may be relevant.

1. Reliability, in the context of autonomous vehicles, is very different from that of conventional tele-operated types. It can only be measured in terms of the total mission success, since many of the failure modes are likely to be catastrophic to the system as well as the mission.
2. It is significant that there are philosophical problems in defining missions for autonomous vehicles, and in particular with incorporating the optimum level of machine intelligence to deal with the 'real' world. These difficulties are leading advanced robotics research away from full autonomy towards more sophisticated supervisory control and limited 'over-rideable' autonomous subsystems.

**J H Puckett and A P Bartholomew [Houlder Offshore Engineering (1987) Ltd]** Diving to such depths is unlikely ever to be an everyday occurrence – the conclusions to the paper state this. What was proven was the ability of the divers to work effectively at such depths and that the system, as used on the Orelia, could be mobilised and used as an intervention technique in deep water. The extent of modifications necessary would be judged by the scope of the work. There can never be absolute guarantees of safety. However, the inerting of the chamber area significantly reduces the risk level below that obtained by any other method.

In addition to the gas detection specified in the paper, detectors were located in the moonpool, bell handling space, gas control and LSU modules, gas transfer and mix station. Alarms were located in dive control, saturation control and the vessel operations command centre.

The responsibilities remained as defined in the Merchant Shipping Diving Operations Regulations SI 116 of 1975, extended as defined in the paper.

**K B London and R R Chapman (RUMIC Ltd)** Regarding reliability of semi-autonomous ROVs, it will be a very long and difficult process to achieve acceptable reliability. Going by past experience, this could take 5–7 years from the prototype stage.

Regarding necessary funding, EUREKA is already providing substantial funding for the development of autonomous ROVs. In particular, Ferranti (UK) and Tecnomare (Italy) have combined in a project costing over 30 M ECUs to develop a prototype.

**R L Allwood (Cranfield Institute of Technology)** In Mr Doug Hampson's paper, he rightly stresses the importance of vision in underwater operations. It seems to me that the conversion of a manned vehicle for remotely controlled operation presents an ideal opportunity to make a comparison between the viewing capabilities of the two modes. Can I ask the author, therefore, how the removal of the man from the actual work site affected the operation of the system when his vision was presumably impaired by the use of a television system?

**D J Hampson (OSEL Group)** No objective tests of comparability of work performance were carried out due to commercial pressures. The subjective impression is that initially work performance slowed dramatically and that the range of tasks which could be successfully completed was more limited in the ROV mode. In commercial terms ROVs have in general performed the tasks required of them, and their task range has continued to be increased.

**J E Stevens (Lloyd's Register)** I would like to congratulate Comex and Houlder Offshore on the magnificent achievement of the Hydra development.

The Orelia is an existing vessel adapted for the special requirements of Hydra VIII.

The inerting of the chamber area appears to be a satisfactory technique for containment of the hazard in enclosed spaces. I would ask the authors if the restrictions imposed by the inerting caused much inconvenience, and if, when designing a vessel from scratch, the technique of inerting enclosed spaces would be preferred to other methods of hazard containment?

**J H Puckett and A P Bartholomew [Houlder Offshore Engineering (1987) Ltd]** Before the trial the view would have been to avoid inerted spaces in the design of a new vessel. However, in the light of experience, and bearing in mind the reduction of upper deck space that would result from such a non-inerted design, it is probable that the inerting technique would be retained, and the design effort focused on removing so much other equipment from the chamber and reducing the inconvenience associated with operating chambers in an inerted space.

In the light of the Piper Alpha disaster it seems that the method of assigning hazardous areas on the basis of normal operation and likely events may need to be re-evaluated. There may be a case for inerting certain areas in the production process, particularly those that have an intrinsically high risk because of large rotating machinery. The constraints offered by such inerting would be less than those experienced in a diving chamber complex because once manned it is not possible to depressurise the chambers quickly due to the long decompression times, as indicated in Fig 7 of the paper.

**J Bevan (Submex Ltd)**

1. On safety – what Department of Energy Diving Inspectorate participation was there, and was an FMEA (failure mode effect analysis) carried out by a recognised authority?
2. What was the budget for the inerting exercise, and did this exceed the cost-saving in helium usage?

**J H Puckett and A P Bartholomew [Houlder Offshore Engineering (1987) Ltd]** The trials were outside the jurisdiction of the Department of Energy Diving Inspectorate, but as the Orelia is British registered, all activities carried out on board are controlled by the Department of Transport. I believe that the DTp did use the DEn Diving Inspectorate to advise them but the Inspectorate had no direct responsibility.

The vessel had extensive FMEAs when she was built and these have been revised as necessary throughout her life. The Hydra diving did not affect this analysis. The hazard analysis carried out on the diving system for these trials was a separate activity and did not affect the vessel's dynamic positioning capability.

The costs of inerting were relatively low but it had no impact on helium costs. The primary reason for using hydrogen in the gas mix was not to reduce gas costs, although this is an important benefit, but to reduce diver fatigue and susceptibility to HPNS at such great depths.

**J G Hawley (RNEC, Manadon)** The control and supervision of ROVs could be more effectively performed by launch and recovery from a moderately sized conventional diesel electric submarine offering the following advantages.

1. Operation is independent of surface conditions, therefore time spent at depth could be substantially increased, thereby increasing the cost-effectiveness of the operation.
2. Cable length and hence drag would be reduced by close-in supervision.
3. Autonomous ROVs could be fibre optically controlled.
4. Facility for on-site diver intervention.
5. Under ice capabilities.

**K B London and R R Chapman (RUMIC Ltd)** Conventional diesel electric submarines as a launch platform for ROVs. The only likelihood of this happening is if there is a demand from the military sector. The first commercial ROV (the RCV 125) was designed to be launched from a USN submarine torpedo tube.