Trans IMarE, Vol 101, pp 171–180

Duplus – a case study in dual control submersibles

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SYNOPSIS

The paper describes the development of the Duplus system, from a technical, safety, and historical perspective; the benefits of the use of a dual control submersible vehicle are discussed.

Duplus is a small, one-man, tethered microsub which is operated in three modes – manual only, unmanned or ROV, and manual with ROV Duplus evolved from Mantis, a manual only microsub, which was designed in 1977/78. It was widely used as a system to support drilling, diving, salvage and survey operations offshore (Fig 1).

INTRODUCTION

Duplus is one of a small family of vehicle systems which incorporate dual methods of control as a primary design feature. It evolved from the one-man Mantis submersible, initially as a customer requirement. This evolution demonstrated the superior capabilities of a local human operator in terms of the precision required for navigation, control and manipulation.

It has been found that a local human operator is able to control a vehicle with much less powerful thrusters, poorer stability, and less dextrous manipulations.

The remote control requirement for Duplus exposed the weaknesses of the original Mantis in the areas mentioned above, and led to a complete mechanical re-design of the vehicle. This, in the nature of submersible design, implies a re-design of the electrical and electronic systems, in short, a new vehicle.

The Mantis was designed to use an eight-element unidirectional, two-state (on/off) dc thruster array, disposed at a compound angle of 45 deg to the orthogonal axes. This gave a wide variety of thrust vectors to the pilot, which he could change very rapidly by means of a keypad.

These dc thrusters were chosen to fulfil the safety requirement for standby battery powered thrusters in the event of a surface power failure or umbilical fault.

Control systems for all successful ROVs incorporate various auto-routines to control depth, height above sea bed, heading and, in some cases, speed. The use of the Mantis thruster array in an ROV control system led to some insoluble problems; eg to maintain depth and heading simultaneously required some of the thrusters to rotate in two directions at once. Clearly a separation of vertical and horizontal thrust vectors was needed for a responsive controller to be implemented.

The thruster configuration was changed to use dedicated vertical thrusters, which solved this problem, but since space was limited, reverse thrust was included to reduce the total number of thrusters. Even so, some variants of Duplus have been equipped with 14 thrusters – it has been a characteristic of OSEL vehicles to use many thrusters.

Surprisingly the lack of proportional control on the electric thrusters did not lead to any problems in the auto-control functions, which use step control of thrust. Most 'proportional' systems use discrete levels of thrust in their control laws in any event.

Doug Hampson has been involved in the design and manufacture of submersibles and remotely operated vehicles for more than 12 years. He founded the OSEL Group, which became the world's leading builder of manned submersibles, and he is now involved in the development of other robotic systems as an independent. He has written numerous technical papers, was Chairman of the Underwater Engineering Group from 1984 to 1986, and is now serving as Chairman of the Society for Underwater Technology. He is also a member of the Technology Committee of the Department of Trade and Industry's Advanced Robotics Initiative.

In terms of the control hierarchy the Duplus is most interesting – any theoretical concepts of dual control modes were rapidly discarded as a result of field trials and customer feedback. In general terms, if the vehicle is operating in the manned mode the pilot in the vehicle has ultimate control. He is equipped with a 'panic' button, which removes all control from the surface. It has been found from field experience that in such situations, the pilot wishes to retain dual control as a measure of confidence for a speedy resolution of his problem.

The ergonomic aspects of the control system were carefully considered; identical controls were used in the vehicle and on the surface. This reduced the training time for pilots and improved their ability in the ROV mode.

The major advantage of dual control is the reduction of the pilot's workload, leading to improved task achievement times under ideal conditions. In real operations this may not be of commercial benefit, other factors usually assuming greater importance.

From the user viewpoint, Duplus has proved to be a reliable and cost-effective tool, despite being outside the main trend of submersible design. It is hoped that the benefits of dual control systems will be more widely appreciated and analysed in the future.

MICROSUBS

The so-called 'microsub' (a term coined by the author in 1978) is essentially a very small, one-man submersible which typically weighs 0.5 to 2 tonnes, and is connected to the surface mother vessel by a tether or umbilical cable. The tether carries power to the submersible, and forms a lifting wire to support the submersible during excursions from the mother vessel into

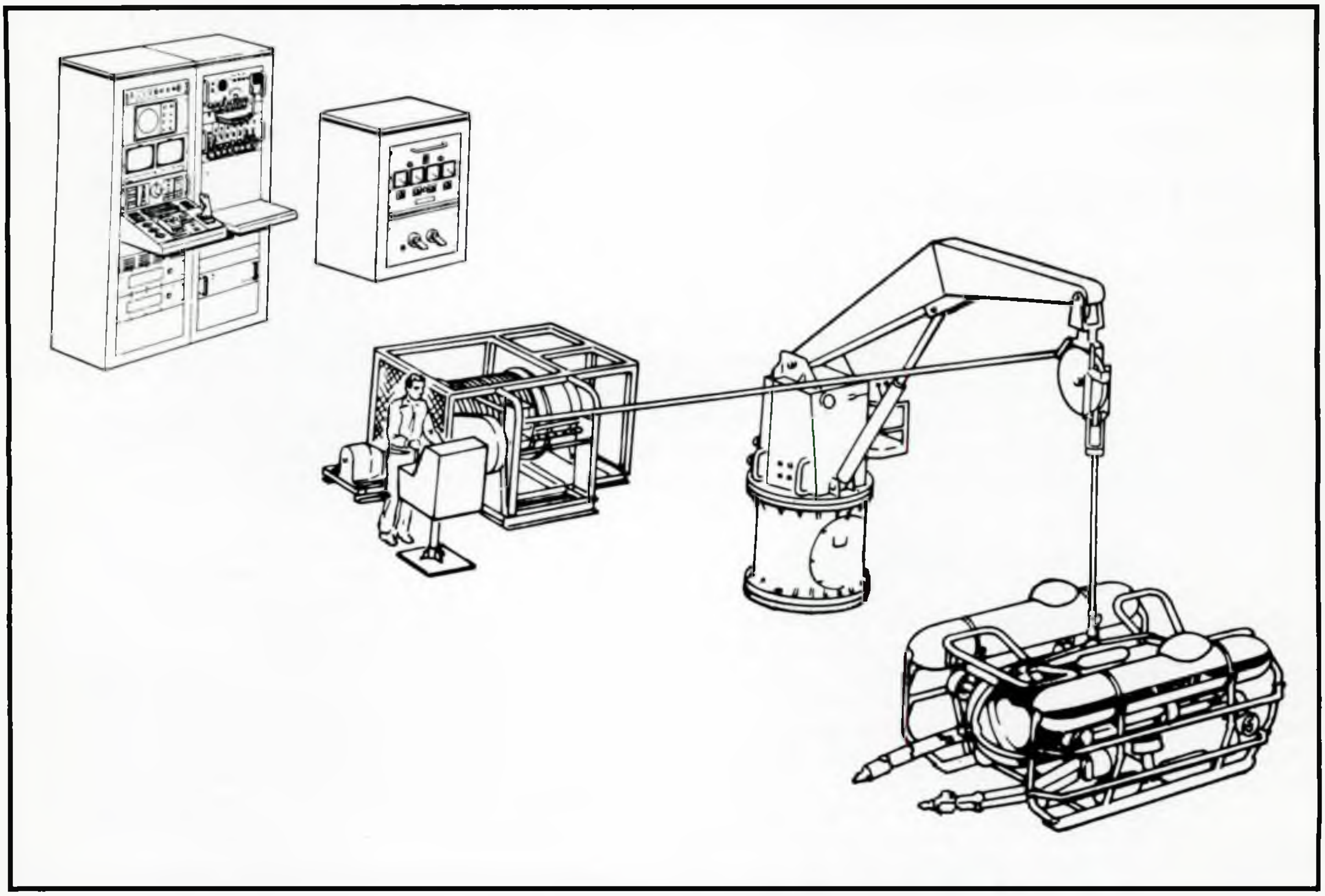

Fig 1: Complete Duplus system

and out of the sea. This tether is one of the system's great strengths and weaknesses, and will be discussed in some detail in later sections.

A typical microsub operates at a maximum depth of 700 m, has a maximum speed of 2 knots, and has an operating envelope of sea state 6–7, wind force 8–9, depending on mother vessel orientation and type, insurance requirements and geographical location. It is equipped with articulating manipulators, a video camera, a hemispherical viewport, thrusters for multi-axis control, an obstacle avoidance sonar, a variety of application-specific sensors and a range of tooling. The atmosphere inside the cabin is maintained at 1 atm by an automatic oxygen bleed system actuated by changes in cabin pressure and an electrically powered carbon dioxide removal system, or 'scrubber'. Humidity and temperature are also controlled.

SAFETY CONCEPTS

Essential safety features include redundancy in a number of areas, excluding the main life support capsule, of course! Thus, there are two completely independent oxygen systems, two electric scrubbers and one emergency oral–nasal mask scrubber (Fig 2), two emergency batteries to power thrusters, lights and scrubbers, an independent set of batteries to power the emergency acoustic, through-water communications, high and low cabin pressure alarms, oxygen percentage sensors and alarms, and carbon dioxide sensors. There are, additionally, methods of isolating the life support capsule from the remainder of the vehicle, and of removing the microsub from the tether cable if the vehicle is trapped.

Microsubs have operated for many thousands of man days without injury to the occupants, despite a number of operational mishaps. No microsubs have been lost underwater in the manned mode, although one or two have been destroyed in fires aboard the surface vessel and in subsea accidents in the ROV mode.

This contrasts with the experience of operating pure ROV; in the early 1980s annual losses were approaching 20% of the total number deployed.

Electrical safety

Electrical safety in submersibles and submarines is a complete subject in itself; apart from the dangers of using batteries in confined spaces (overcome in Duplus by housing the main emergency batteries in a separate container), the use of high voltages subsea is incompatible with traditional concepts of safety. Duplus uses thermally actuated overload devices for the main cable, tripping contact breakers. Secondary circuits in the submersible are protected by fuses, a cause of some debate since fuses cannot be reset remotely, but have been accepted as a necessary protection.

In addition, early versions use an earth leakage detector which is actuated by the magnetic fields in each leg of the three-phase cable. Any out-of-balance residual currents are deemed to be caused by leakage to earth, and the breakers are tripped. The higher powered Duplus (30 kVA) uses a line insulation monitor, which operates within 20 ms of the development of an insulation fault (the time required to meet the recommendations of the Association of Offshore Diving Contractors) which is the maximum time before physiological damage may be caused.

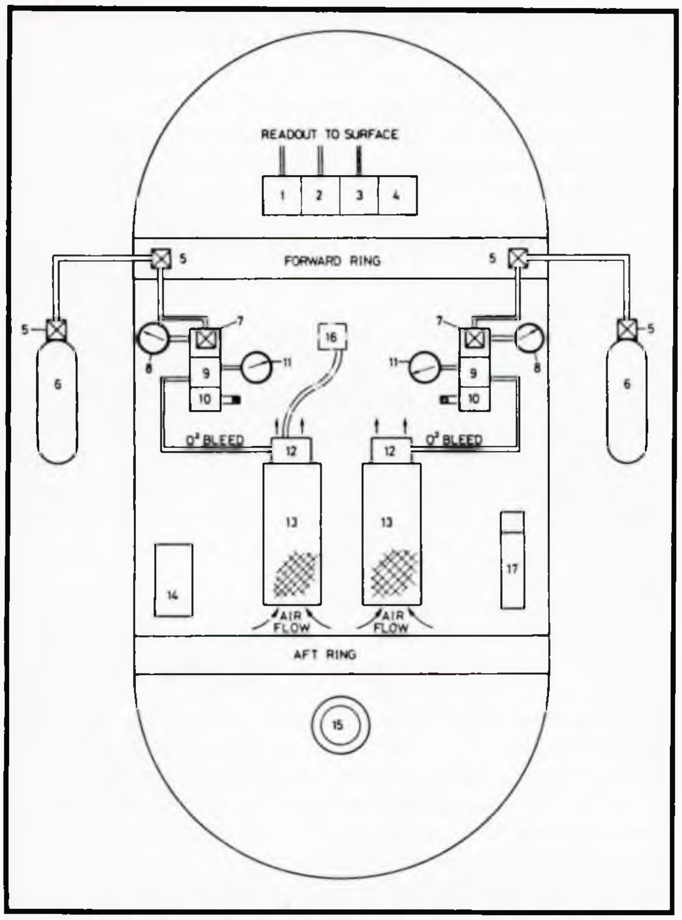

Fig 2: Schematic of Duplus life support system

1. CO_2 meter with alarm – 0.3%
2. O_2 meter with alarm – low, 19%, high, 23%
3. Cabin temperature and pressure readout
4. Humidity gauge
5. Shut-off valve
6. Air bottle 200 bar/7.7 litre
7. First stage HP regulator with shut-off valve
8. HP gauge
9. Second stage regulator
10. Flow control bellows with manual device
11. Flow gauge
12. Scrubber fan
13. Scrubbers
14. Draeger rebreather for emergency use only
15. Spare scrubber with oral/nasal mask for emergency use only
16. Oral/nasal mask
17. Cabin heater

THE DEVELOPMENT OF DUPLUS

The idea of producing a vehicle with remote control and manned facilities was first conceived in the late 1970s, and at that time both manned and unmanned tethered ROV technology was in its infancy. As early as 1977, the design team performed experiments with a microsub 'Wasp', using a simple remote control system. By the early 1980s the manned submersible concept had gained acceptance among operators, primarily for support of drilling operations. During the same period the use of work ROVs as opposed to 'eyeball' or 'observation only' ROVs also made great strides, at the expense of saturation diving and ultimately microsubs.

There was very little requirement at that time for dual purpose vehicles, incorporating remote control and manned technology. Most vehicle operators perceived the market as being exclusively split between the two technologies. It was only the Canadian armed forces with their particular requirements who specified a dual mode vehicle. However, as remotely operated vehicles became more reliable and effective, their market share increased, and the appeal of dual control submersibles diminished.

Early in 1981 a major user of Mantis requested the author to investigate the displacement of all vehicle controls to the surface so that simple observations could be undertaken remotely. This technology was incorporated in Mantis by late 1981 and the control of the Mantis was demonstrated in the remote mode. During the same period the author had also been involved in developing and manufacturing a small observation ROV system. That experience, coupled with trials results using the Mantis ROV concept demonstrator, showed that certain improvements would be required in order to make effective use of remote control on the Mantis.

It transpired that Mantis was very difficult to control in the ROV mode without such refinements as automatic depth keeping, automatic heading controls and two video channels. It was also discovered that the original thruster orientation, whilst useful for manned operations with its eight vectored thrusters plus two dedicated forward thrusters, resulted in conflicting demands being placed on various subsets of thrusters. As an example, in some modes a single thruster would be required to rotate in both directions at once (Fig 3).

By a simple thruster re-alignment these problems were overcome, so that there was no undesirable coupling between vectors. In addition to these changes in thruster layout, there was a requirement to enhance thrust available, not so much to perform tasks around a blowout preventer (BOP) stack, but for additional tasks such as picking up lost items and debris at some distance from the rig. By designing new thrusters, maximum installed thrust was boosted by 400%. In addition to these changes the configuration of the fixed buoyancy was altered in order to improve the static and dynamic stability of the vehicle. These developments were completed by late 1982 and the first Mantis ROV was deployed operationally in December 1982.

Design philosophy

The philosophy which had always been adopted in building manned vehicles was to maintain a very simple design concept incorporating the minimum of electronics which were vital to

Fig 3: Duplus prototype with vectored thrusters

the operation of the system. This approach was maintained in the safety concepts mentioned above.

There were several reasons for this. One was the lack of suitably qualified personnel willing and capable of working offshore for long periods in a relatively unpleasant environment. Most of the ROV operating companies would testify to the personnel problems incurred with high grade electronic technicians working on ROVs offshore. In addition to the use of simple subsystems, the design team followed a policy of building in redundancy in vital units by using two power supply units instead of one, a digital echo sounder, a digital depth gauge, plus a simple analogue depth gauge to back up the other two and a magnetic compass plus a gyro compass. Very few ROVs incorporate this redundant system philosophy. For instance no single or even triple thruster failure on a Mantis would result in the vehicle being disabled.

This philosophy of redundancy contributed to an operational track record in which very few dives were aborted. In the Duplus programme it was vital that the level of operator confidence which had been gained over a number of years should not be compromised.

Design constraints

The major design constraints were as follows.

1. The ROV system should be compatible with microsubs already in the field.
2. The redundancy policy should be maintained.
3. No microprocessors should be used in the vehicle to control communications (owing to mixed experience amongst other ROV manufacturers).
4. The existing safety features should not be prejudiced.
5. The timescale for design and delivery of the first system although short was approx. 14 weeks from order to delivery.
6. The choice of umbilical cable, which was extremely difficult and affected the whole system design, should be compatible with Mantis.
7. No suitable dynamic model of vehicle behaviour was available during the design of Duplus or Mantis ROV.

The implications of these constraints are discussed below.

Compatibility

Despite the intention, compatibility was not fully achieved in Duplus, although Mantis ROVs retained a great deal of compatibility with Mantis. A fundamental problem was the retention of the original umbilical cable.

In microsub operations, video recording is ancillary to the performance of the task. In ROV operation, remote sensors, particularly video, are central to the success of the work. The video cable conductor on Mantis was smaller than ideal, but adequate for manned use. Very careful video system design was necessary to maintain recording quality standards, including the use of dedicated, isolated power supplies and optical isolation of signals before feeding into the cable.

The increased weight of the Mantis ROV created problems – the cable's breaking strain must be 8-times greater than the all-up, in-air weight of the submersible, in order to meet regulatory and classification authority requirements for manned vehicles. The problem, as always with composite umbilicals, was to minimise cable drag, which can dominate system dynamics, whilst maximising services through the cable.

The Mantis cable was also, in the interests of minimising cable diameter, equipped with only two power conductors. In the case of Mantis ROV, this was adequate, but with Duplus, the increase in required thrust dictated the use of some ac electric thrusters instead of all dc; a change to a three power-conductor cable which could be used as a compatible replacement for a Mantis cable was then authorised. This change also relaxed the vehicle weight constraint by 200 kg.

Mechanical compatibility was maintained for a number of subsystems. Hull design was changed to reduce weight, however, and the power supplies for the ac Duplus were completely different, being three-phase instead of single phase. The slip rings on the winch were equipped with redundant rings, and the increased diameter of the three-phase cable could just be accommodated.

Redundancy

Full systems redundancy in Duplus was not possible. The use of eight ac and two dc thrusters meant that in an emergency, a fall back to battery power gave control of horizontal mobility by dc thrusters, and vertical mobility by variable buoyancy. The change was discussed at length with both the DTI and Lloyd's in the light of experience and trials with Mantis, and was fully accepted.

In all other respects, full redundancy was maintained. In the event of a cable power supply failure, control of Duplus in ROV mode could still be maintained – a unique feature! Thankfully it is rarely used. The use of battery power meant that electrical relays and electronic subsystems were constrained to use a 24 V dc power supply. This did not cause problems as a great proportion of proprietary subsystems use 12 or 24 V dc. The remote control of vehicle functions such as buoyancy tank vent and blow proved to be simple to implement and successful in operations. The manual controls were retained in the vehicle for emergency use, but the greater ease of using electrical actuation compared with manual proved to be an operational bonus in the manned mode.

Microprocessors

At the time of designing Duplus, several ROVs had used linked microprocessors in the vehicle and the surface control unit. None had been very successful at that time, and the use of dedicated conductors in the umbilical cable to control each vehicle function was still popular.

A fundamental decision was taken to use a microprocessor control system on the surface only, in order to enhance safety and maintain reliability. The necessity for the pilot to be able to control the vehicle easily in normal mode without dependence on microprocessors was probably the most important consideration.

In view of the short timescale, a proven reliable 8-bit microprocessor, the Nascom II, was chosen. The design engineers were experienced in using this processor, and the wisdom of the choice is evident because later, compatible variants of Nascom II are still in production today. Although the data handling capacity of an 8-bit microprocessor is theoretically limiting, a great deal of the work it does is sorting a relatively small number of input commands and sending them to the vehicle in a 30 ms cycle time. The main chip used is a Z80, which is reliable, is still used in vast numbers in current personal computers, and is consequently very economically priced.[1]

Although 16-bit processors were available, the engineers had limited experience in their use; the use of the Z80 has not proved to be a major constraint in expanding the Duplus capabilities.

The use of a surface-based micro which performs all the automatic routines means that all computations are performed on the surface. A very simple, empirical approach to control

laws was taken. This was forced on the design team by:
1. the lack of any facilities to generate a model of the dynamic behaviour of the vehicle,
2. the lack of suitable mathematical models available at the time,
3. in particular, a great theoretical ignorance about the effects of umbilical cables on system performance. This limitation will be discussed later.

Suffice it to say, that in a high inertia vehicle such as Duplus, field trials quickly showed the way to improve controllability. During operations, critical damping of vehicle motions is far more important than absolute accuracy of heading and depth autocontrol functions.

Existing safety features

Some of the safety aspects of using ROV microsubs has been discussed in the Redundancy section. The most fundamental aspect of operation in the manned, dual control mode, is the hierarchy of pilot over-ride in the vehicle. It was initially felt that any pilot command should over-ride all surface commands, but this proved to be impractical in normal operations.

There are now two levels of over-rides; in the first level the pilot over-rides the surface with only the commands he inputs, all other functions remaining under surface control. In the second level the pilot disables all surface control and assumes full command. The changeover is simple and intuitive to achieve.

The change to the use of dedicated horizontal dc thrusters in emergencies, combined with depth control by variable buoyancy, involved no major compromise. The original 24 V dc thrusters on Mantis were oil-filled and pressure balanced, ie they operated at the ambient pressure of the sea water. The second generation dc thrusters on Duplus are 5-times more efficient and the two thrusters deliver, using batteries, approx. 60% of the thrust delivered by eight of the original ones using mains power. The new thrusters use low-friction shaft seals, samarium–cobalt, high efficiency magnets in the motors, and run dry, with highly efficient ducted propellers.

The ascent or descent with the original thrusters was also rather slow, and the change to variable buoyancy alone in emergencies did not degrade vertical speed. In any event, Duplus stores twice the volume of compressed air for use in similar size buoyancy tanks to Mantis, thus extending operational time by a factor of 2.

The remaining features, such as the jettison of the main cable, and the separation of the life support capsule from the main exoskeleton of the vehicle were retained and improved mechanically (Fig 4).

Timescale

The short timescale meant that opportunities for non-essential change were denied to the design team, resulting in a conservative approach. Thus, the telemetry signals were multiplexed onto the pilot communication conductors in the cable, in a non-intrusive fail-safe manner. Signals are coupled into the cable via small isolating transformers which cannot interfere with the audio frequency communications. The telemetry operates at a 50 kHz carrier frequency for one direction, and 80 kHz for the other.

A new internal design for the vehicle was not possible in the timescale, so a new pilot's couch was designed, mechanically compatible with the original, to contain all the electronics for ROV interfacing. In ROV mode, two video cameras in different locations are often required. Previous experiments with frequency multiplexing of two video signals onto a single conductor had proved abortive, owing to poor signal-to-noise ratios at the higher frequencies, so a switching arrangement was incorporated to allow two cameras to be displayed sequentially on two dedicated monitors. Sonar for obstacle avoidance is also needed, so this also was sequentially switched onto the single video line. These 'quick fixes' prove to be surprisingly useful and durable.

Cables

The umbilical cable choice for any tethered vehicle has ramifications throughout the whole system. Ideally, the smallest conceivable diameter is required, and for a battery operated ROV using a fibre optic video link, diameters below 3 mm are credible. In the case of surface powered, remotely operated work/survey vehicles, power distribution and extra instrumentation payload interfacing dominate. The concept of a 'virtual twisted pair' or 'virtual co-axial conductor', superimposed by multiplexing onto a fibre optic conductor is very attractive. However, it cannot be realised without both a software and hardware interface to give power and impedance matching to any new subsystem, such as a sub-bottom profiler, cable or pipe detector, or sonar.

For the limited market size, it was easier to provide spare signal and power conductors in the umbilical cable than to invest, or expect clients to invest, in a range of user-definable interfaces.

This raised the problem of increasing cable drag, by increasing diameter. Power conductor size could be controlled within certain limits by increasing the voltage to reduce losses due to conductor resistance. But IEC regulations on insulation thickness limit the benefits of this approach.

The operating voltage of the Wasp prototype was 230, single phase, 50/60 Hz. Mantis 1 used a 415 V, 50/60 Hz, single phase supply, but Duplus uses a 660 V, 50/60 Hz three-phase supply. Duplus 30, the highest powered variant, uses a separate 700 V, three-phase thruster power supply and a 660 V, single-phase supply to minimise the effects of varying voltage drop in the cable.

Room temperature superconducting polymers may be the answer, but even then, the problem of cable strength arises.

If a vehicle is to be lifted out of the water by its own cable, a breaking strength of at least 6-times its in-air weight is necessary to meet the requirements of Lloyd's, the American Shipping Bureau, or the DTI (in several countries 8- or even 10-times is required).

In the interests of compatibility it was desirable to keep the weight of Duplus the same as that of Mantis, and to retain the same cable diameter. But at the same time, it was necessary to increase thrust by a factor of 4 and provide more user instrumentation conductors.

Clearly, these conflicting requirements will always result in a compromise design – in the case of Duplus the cable diameter increased from 17 to 21 mm. Fortunately, this increase permitted the use of the original winch design, but later variants of Duplus with more power and more conductors, dictated the use of a larger winch to lift the vehicle out of the sea.

The latest variant (Fig 5) uses a 30 mm diameter cable, with a doubled breaking strain to cope with a vehicle weighing 2 t instead of 1. Despite this increased thrust, the extra diameter and new payloads resulted in exactly the same forward speed as the prototype Duplus converted from a Mantis! The vehicle is far more capable, with much better video than the original, and is capable of operating at nearly 1000 m depths.

The problem of umbilical cables is common to almost all ROVs, and will only be solved by the development of new

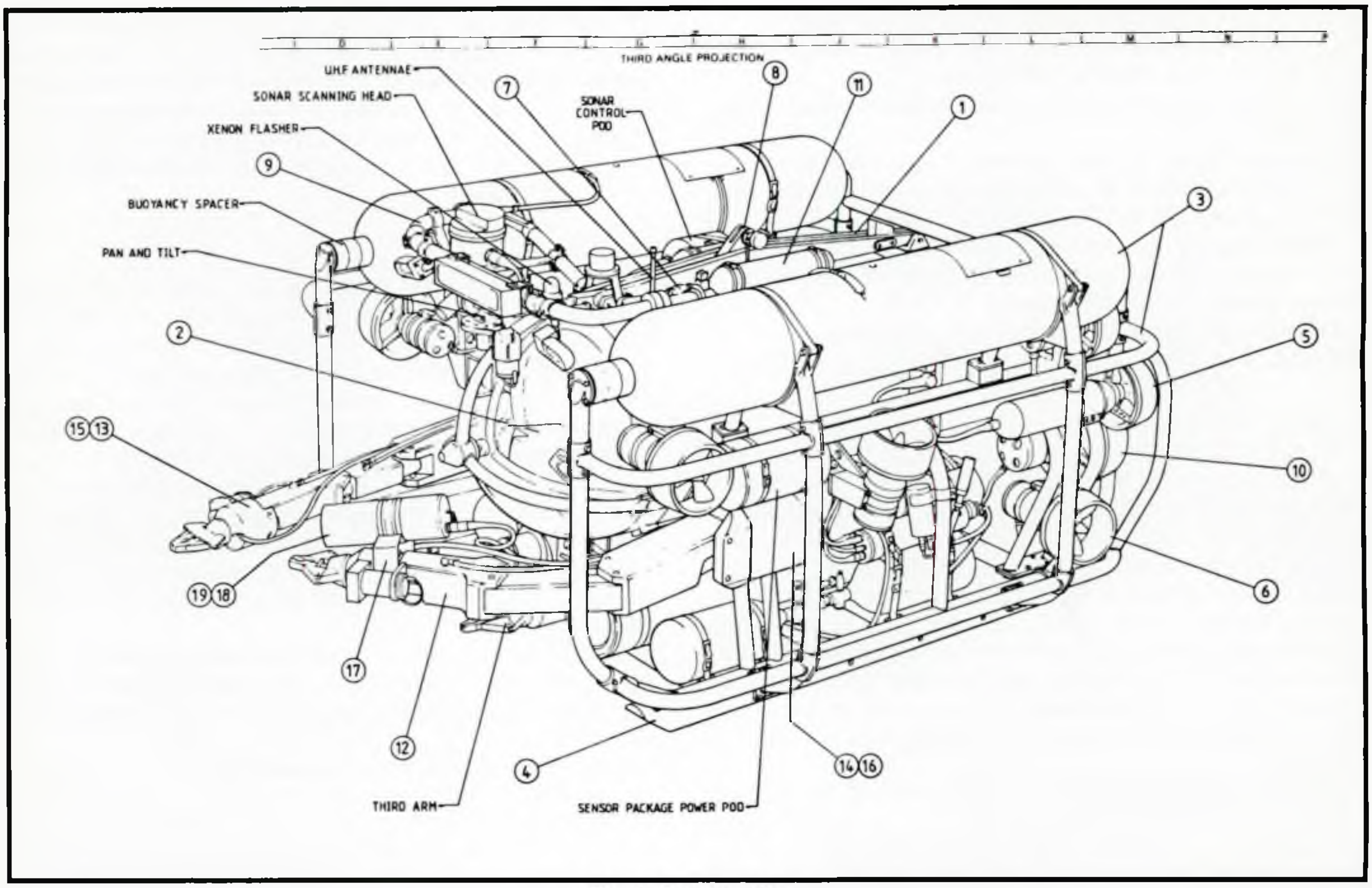

Fig 4: Duplus 030

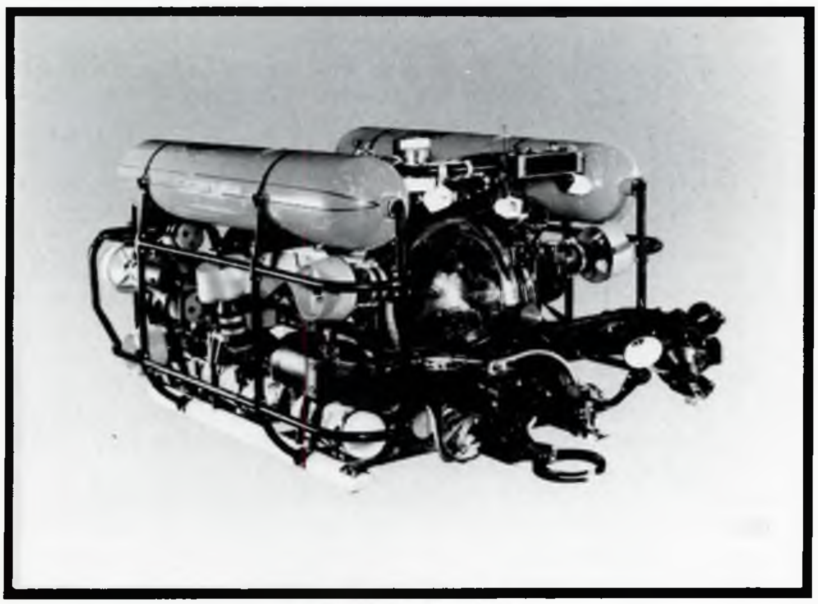

Fig 5: Duplus 30

subsea real-time, high bandwidth, low noise, long range communications, perhaps by lasers, which will eliminate cables entirely. Long endurance subsea power sources will also be required; several types are currently under development.

Dynamic vehicle models

The lack of any suitable mathematical model for predicting vehicle performance without first building a vehicle and measuring various parameters, was a major constraint on the design of Duplus. In the absence of a model, an actual submersible was built using the same thruster layout as the Mantis, but with a thrust increase exceeding 400% on each thruster, from 10 kg to 40 kg or more. This exercise showed the difficulties of incorporating vectored thrust in a vehicle which includes auto-routines for heading and depth control. The cross-coupling resulting from combined vertical, horizontal, and lateral thrust vectors meant that in some circumstances, when auto-depth and auto-heading were simultaneously selected, the individual thrusters would be required to rotate in two directions at once. The solution of using sequential operation of thrusters resulted in poor control loop closure. The only simple solution, without any modelling available, was to alter the thruster layout to give dedicated vertical thrust, effectively de-coupling vertical movement. The remaining six ac thrusters were deployed in a vectored horizontal mode, although in later variants, two extra side slip thrusters were added, yielding dedicated vertical, sideslip. and axial thrust vectors.

The control algorithms were very simple, relying on fixed levels of thrust applied for varying time periods. The product of thrust and time represents the applied forces. Necessity dictated this approach since variable speed, low noise, efficient ac motor controls could not be packaged to operate inside the Duplus. Simple, reversing contactors were used to change direction by reversing the motors.

The forward thrust is increased in four steps, the first three by increasing the applied voltage to the two dc thrusters, using

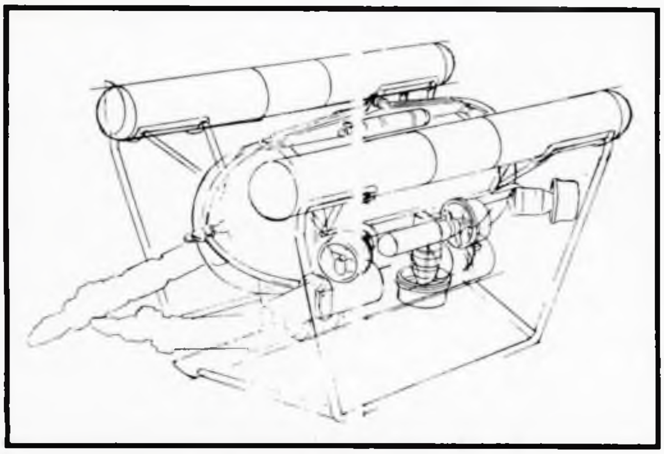

Fig 6: Design sketch for Duplus

Fig 7: Dragonfly

secondary taps on the single-phase, 660 V input 40/60/80 V output transformer, and the fourth step by adding all the ac axial thrusters.

The levels of thrust associated with these steps increased roughly exponentially, giving linear speed increases. The auto-control functions simply relied on using sensor feedback in a 'window' arrangement. For example, in the control of heading, a desired vehicle heading is inputted to the auto-control circuit which is then activated. The difference between the actual and desired headings defines the direction and level of thrust applied to turn the vehicle. If the difference is outside the large window of, say, ±20 deg, then full differential thrust is applied using the dc thrusters, one full ahead, one full reverse.

As the difference reduced to less than 20 deg the thrust reduced and the window size reduced in steps. The amount of thrust used is determined by experiment. The smallest window is ±2 deg in heading, and ±100 mm in depth.

This simple approach is only successful because of the high dynamic inertia of the submersible and the absence of cross-coupling between horizontal and vertical movements. For very small, lightweight, powerful ROVs a traditional servo-loop mechanism is required with infinitely variable thrust. In the absence of a dynamic model of the vehicle, the fixed levels of thrust and 'window' size simplify the control problem tremendously, and, in practice, adequate vehicle control is maintained to achieve the tasks at hand. The cross-coupling was reduced to an acceptable level by obvious but effective design changes. The negatively buoyant parts of the system were placed as low as possible and close to the geometric axial centre line. The fixed buoyancy was placed as high and as wide as possible. This resulted in a much improved static pendulum stability. The dynamic stability was enhanced by forming the buoyancy into two cigar-shaped cylinders, which are effectively decoupled from flow over the hull. The Duplus design is, in practice, extremely stable in all six degrees of freedom.

A number of configurations were drawn (Fig 6) before arriving at this particular layout, but the whole process took less than 2 weeks in total. The same basic layout has been retained for all variants of the Duplus. Although this conservative approach reduces control problems, it also reduces system accessibility to certain platform areas. The use of inherently unstable designs is very attractive in certain cases, such as vertical and inverted access to platform tubulars, for which present generation ROVs are unsuitable.

Dynamic vehicle models, and field experience with the OSEL Dragonfly (Fig 7), show that this control can be achieved, but only at the expense of using complex control algorithms, infinitely variable thrust, and a multiplicity of vehicle position and attitude sensors. A 'stability overhead' of roughly 25% of vehicle thrust is also required to maintain a particular 'flight' attitude.

Review of design constraints

It is apparent from earlier discussion that of all the design constraints, the restriction on the choice of the umbilical cable was the most onerous. Even the lack of a dynamic vehicle

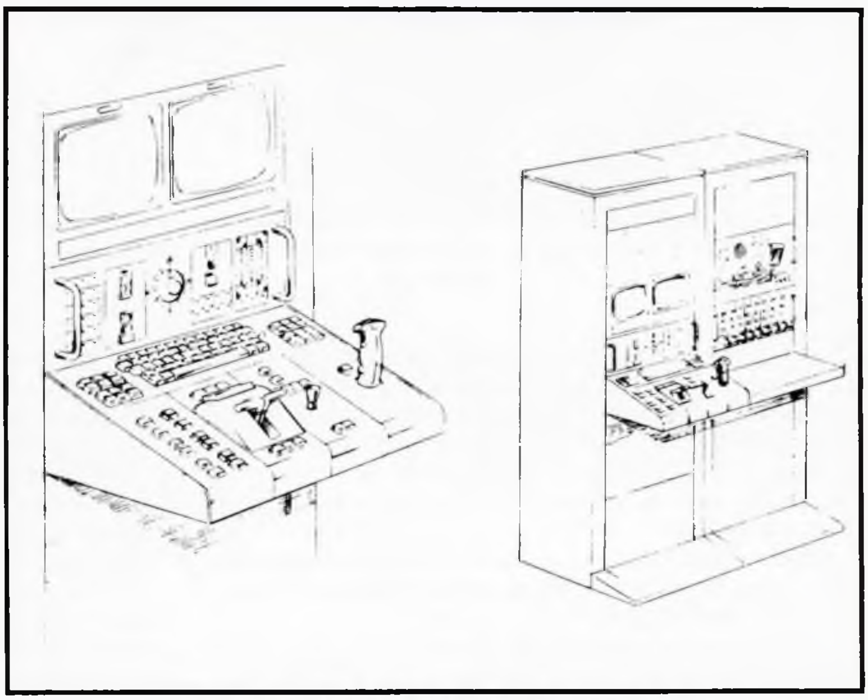

Fig 8: Design sketch for Duplus controls

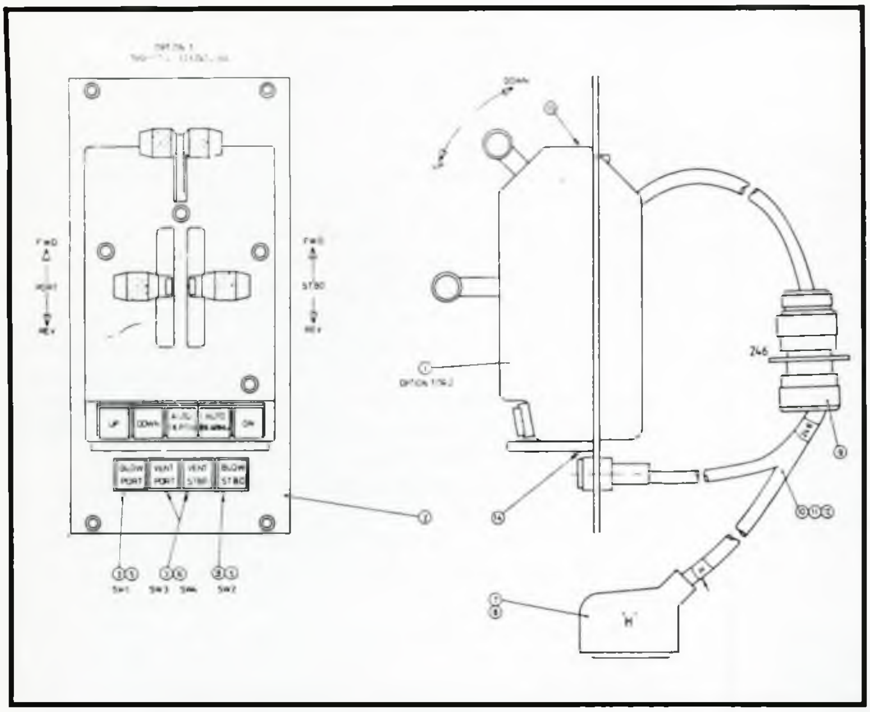

Fig 9: Duplus thruster controller

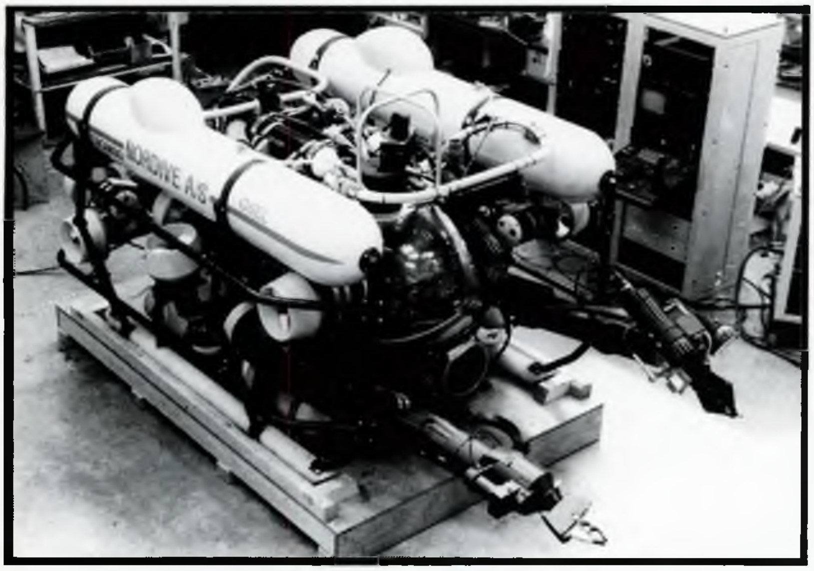

Fig 10: Duplus with control console showing sonar and manipulator controller

model was less important, because none of the models available, even today, take a rigorous approach to factors such as cable form, drag, vibration and attachment to the vehicle. For a great deal of operational work, cable effects can be reduced by de-coupling the cable from the vehicle by some means: by using a cable guide or anchor, or by laying cable on the sea bed in a short bight.

The use of fixed rather than infinitely variable thrust increments, proved to be of little consequence in terms of the autocontrol function accuracy.

The ergonomics of the control actuators was, however, a most important matter, and is discussed below.

ERGONOMICS OF THE SYSTEM

The ergonomics of the Duplus was carefully evaluated by employing an experienced ROV pilot to conduct field trials with it. As an ergonomic aid to the pilots, identical controls were used in the vehicle and on the surface as far as possible.

Most conventional ROV horizontal movements are controlled by use of a three-axis joystick. Forward motion of the stick initiates forward thrust, sideways and reverse movements initiate sideways and backward thrust respectively. Rotation in the horizontal plane is initiated by rotation of the joystick. Other functions are often controlled by extra switches on the joystick.

An encoder was linked to the joystick in which various threshold voltages increased or decreased the fixed thrust levels.

Field trials with this controller soon revealed its limitations. It was almost impossible to detect which thrust level was in use for a given stick deflection. Additionally, the composite vectors at various off-axis deflections of the stick did not correspond intuitively to vehicle movement. The pilot working in the vehicle was generally in better control, but the system was virtually incapable of reasonable work when controlled from the surface.

A controller was designed that is similar to the throttle controls of a twin-engined aircraft, but with multiple fixed positions corresponding to the thrust level selected (Figs 8 and 9).

Rotation was achieved by putting one 'throttle' forward and pulling one throttle aft. The positions could be retained, although both had a spring to centre bias. Sideways movement was achieved by pushing the twin assembly to right or left, against a light spring. No latching of the sideslip switch was permitted. Vertical movement was achieved by using a similar throttle at the front of the main assembly, moving up or down, close to the vertical plane. This switch could be latched.

The improvement in controllability achieved by this change was tremendous. The experienced ROV pilot was able to perform the complete range of tasks assigned to him. All throttle movements became intuitive, possibly more so than in the joystick mode with a conventional ROV, and any initial complaints about the discrete thrust levels were forgotten.

In the Mantis, the rate manipulators had been controlled by push switches in an array, each switch corresponding to a given direction. In Duplus, the controller was changed to a pistol grip equipped with non-latching switches; three arranged in an X–Y configuration, rotating in a similar way to a joystick, and three controlling jaw opening and closing, extension and retraction, and shoulder movement (Figs 8 and 10).

This arrangement, in which the direction of controlled

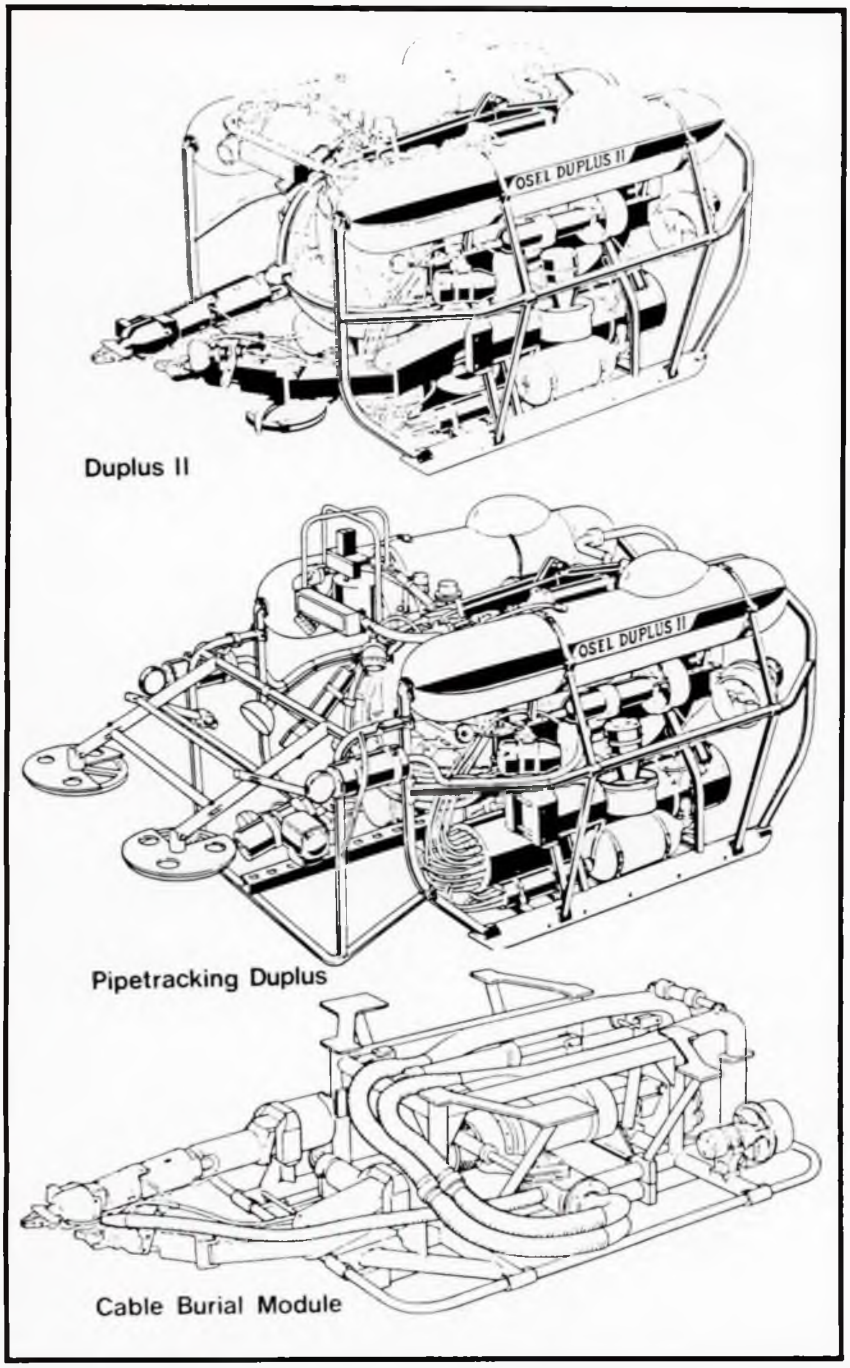

Fig 11: Duplus II, the pipetracking Duplus and the cable burying module

movement corresponded to joint movement, was much more intuitive than the previous switch arrays, and became very popular with pilots. It is interesting to note that one client replaced the master arm of a master–slave manipulator with one of these switched pistol grips. His operators found it to be far less tiring and just as effective as the complex master arm, both in time to complete tasks, and in complexity of tasks achieved.

A further ergonomic feature of the Duplus was the communication system. In conventional ROVs, there is no acoustic feedback from the vehicle, but in Duplus the pilot's communication system was used in both manned and unmanned modes.

The sound of the thrusters on start up could be clearly heard, providing a better feedback than visual speed indicators. When used in the automatic depth mode, a control method was evolved using this feedback, as follows.

The required operating depth was selected and auto-control was initiated. The intermittent operation of the vertical thrusters could clearly be heard almost continuously during the approach to the required depth. When the correct depth was reached, air was bled into or released from the buoyancy tanks until the vertical thrusters were only actuated once or twice per min.

This method achieved very accurate control of depth without resulting in juddering movement of the vehicle on video, a cause of great annoyance to ROV pilots engaged in delicate tasks.

The use of identical controls in the vehicle and the surface control cabin brought a number of benefits. Pilots could be familiarised with the control of Duplus by starting to use it in the ROV mode, to gain familiarity with the dynamic characteristics of the vehicle on the surface, whilst an experienced pilot inside the Duplus protected it from damage.

Similarly, a novice pilot inside the vehicle would be immensely reassured because he could leave control to an experienced instructor on the surface. He could become merely a passenger in the vehicle. This method of training lead to the development of close co-operation between the surface controller and the pilot – the reduction in pilot workload and instrumentation monitoring permitting higher levels of concentration on task achievement.

In conditions where the sea state is very high, and a dangerous task is undertaken, Duplus can be operated unmanned although it is often the unplanned intervention which requires the manned mode.

DISCUSSION

The development of Duplus has been described and the importance of cables discussed. There is no doubt in the opinion of the author, that there are many benefits in operating dual control submersibles and very few drawbacks.

In ROV mode, Duplus is as capable as Rigworker or similar ROV. It is easily maintained and suffers no significant cost penalty. The lack of hydraulic power is a drawback, although there has been very little client pressure to change this. Duplus is certainly a much better manned microsub, in every way, than Mantis, and in its ultimate form it is one of the most powerful ROVs built (Fig 10). Duplus, however, never became as popular as Rigworker or Scorpio, yet never suffered operational losses. Most of the original units, and variants (Fig 11), are still in use offshore.

Many of the original Mantis's were converted to ROV, and are also still operational.

Today, most oil companies specify ROV in preference to microsubs, anthropomorphic diving suits such as 'Jim', or dual control vehicles. The author can only attribute this to the greater numbers of ROVs, and the lack of rigorous analysis of the benefits of a dual control vehicle. A comparison published in 1983 by the author[2] suggests significant benefits in dual control.

As regards the safety argument against the use of any manned vehicle, firstly divers, who are at much greater risk of physiological damage, are still extensively used, and secondly the safety records of microsubs is extremely good.[3]

The author draws no conclusions from the decline of the use of manned vehicles, and bows to the inevitable by developing a range of pure ROVs for offshore use.

REFERENCES

1. J Luxford & J Dowle, A general discussion on factors affecting electronic design in ROV electronics in subsea design conference, London (1985).
2. D J Hampson, The manual ROV – A comprehensive approach to subsea work, ROV '83 Conference, San Diego (1983).
3. D J Hampson, A Review of the inter-relationship between diving and subsea vehicle technology, Tecno-Ocean '86 Conference, Kobe, Japan (1986).