

# **NEWTSUB 'DeepWorker 2000'**

## **An Overview of a Work-Class DOV**

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### **ABSTRACT**

As routine water-depths for offshore drilling approach 2000 feet in a number of geographic areas - conventional saturation diving has been excluded by both legislation and tacit inter-company agreement leaving the work field as the exclusive province of deep, work-class ROV's.

It is well known that the 'vehicle' in remotely operated vehicle is actually just the far-end package of a complex system that starts with the operator in a control van many thousands of feet away from the actual work-site. This very remoteness is a problem in itself - with a proportionate diminishing of work - sense resolution - but a more obvious and immediate problem is the data and power transmission link.

Simplistically, increased depth equals bigger umbilical, bigger umbilical equals more power required to pull, more power equals bigger umbilical, - and so on. ROV operators and current manufacturers are very aware of this problem, hence the active interest in AUV's (autonomous Underwater Vehicle) by virtually every major country. The desirability and inevitability of tether elimination is unquestioned - it is a matter of How? When? and at what cost?

The DOV (Directly Operated Vehicle) takes the operator out of the control shack and puts him into the ROV. He is actually at the work-site and sees, hears, and feels what is happening - not what he thinks could be happening based on remote sensors.

The NEWTSUB DOV 'DeepWorker' is a 'Now' AUV, completely tetherless in normal operation it can be fitted with an optic fibre cable of lead-pencil size for video or data transmission where required. Because of its autonomous design, the DOV has high power availability at the vehicle, coupled with directly operated, high performance manipulator capability.

This paper provides a general overview of this new class of underwater work vehicle.

## **INTRODUCTION**

Andre Galerne is a past president of this association of Diving Contractors, and a pioneer visionary of the commercial underwater industry. When he was asked, more than a decade ago, how he saw the future of the underwater business in the deep water; his response was that he believed the future of that work lay with "autonomous, deep-diving, submersibles..." Unequivocal. Mr. Galerne was talking about manned submersibles, but he might well have been talking about tetherless ROV - AUV's - or manned, deep-diving, autonomous mother subs delivering manned systems Wasp or Newtsuit to the work-site - or autonomous, manned submersibles with ROV's flying off them - in all cases, the key word is autonomous - 'free' - no tether.

But what about 'manned' - isn't it better and safer to get man out of the water? Safer, sure, in the same way that it is safer to ground all aircraft pilots, pull all climbers off the mountains and all the sailors out of the sea. Better? nope; not if you are looking for optimum efficiency and work performance.

Howie Doyle, the publisher of "Underwater Magazine" (the official publication of the Association of Diving Contractors) made a point in a recent article dealing with underwater work in the 21st century - the trend that will shape the future of our industry - "The future days of 'no-man-in-the-water' are mythical, much like the 'paperless office' that the computer age supposedly would bring."

Galerie says 'autonomous' and so do a large number of the designers and planners for 21st century diving Why all the emphasis on 'no tether?'

You would have to be an ROV tech or the user of some other tethered system before you could honestly understand just what a problem that damn tether is... The problem gets worse as you go deeper - but not in a nice, gently up-curving way. The tether length/size/drag/power horror story is really an exponential situation. To get your ROV deeper, you need a longer umbilical. The vehicle needs more power to pull the longer cable because of increased drag, so you have to increase the diameter of the umbilical (since you've already maxed out the possible voltage in the last move to deeper water!) You need more power to pull the larger umbilical so you need to make it bigger, and so on. Sailors will recognize the problem as something similar to 'hull speed' - The combination of wetted area, drag, turbulence, and a host of other factors that combine to say that past a certain, optimum point a 100% increase in power will only produce 10% increase in speed and a further doubling only a 5% increase, and so on. A three inch diameter umbilical, 3000 feet long has an area of nearly 3,000 square feet - about the same as the floor area of a good-sized house!! It takes an enormous amount of power to pull this through a medium several hundred times

denser than air...So, what's the answer? wait...we aren't finished with the problem yet! If the umbilical is used to lift the vehicle free of the water - then with today's work class ROV's it must be armoured because of the vehicles weight - but if we armour it, we have to increase the diameter and there is, of course, the matter of weight. The vehicle will not 'marche' with a negative umbilical laying on the sea-floor and dragging through the muck...so we add buoyancy - which increases the diameter and the drag...so we must add power...see what I mean about it being an incredible nightmare? Combine this with having to feed that expensive, easily damaged, umbilical through a heave-compensated, custom winch - handling system, so expensive that it would bring tears to a glass eye - through a series of slip-rings that you'd swear had platinum components, and then the Skipper zigs when he should have zagged and the whole mess winds up wrapped around the well head like so much high-cost linguine!

So what's the answer? Get rid of the umbilical. That simple.

Perhaps the best known free-swimming submersible is Cousteau's "Soucoupe sous Marine" 'The Diving Saucer' - (affectionately known to the crew of 'Calypso' as 'Denise') it is interesting to note that, in its earliest configuration, it was a tethered vehicle. But the operators observe that it did not become "fully functional" until the tether was removed.

Drew Michel is well-known to this association as an expert ROV technologist. He was a featured speaker at the 1994 AUV conference at Cambridge, Massachusetts - Drew said "The next quantum step is to eliminate the tether - something that terrifies conservative offshore operators" - AUV? Autonomous Underwater Vehicles - vehicles with no tether. The extent of the problem with a tethered system may not be common knowledge to the average client, but it is most certainly well-known to the ROV manufacturers and to the ROV operators. Everybody understands and agrees that, inevitably, we must get rid of the umbilical - and still control the vehicle. Easier said than done! Virtually every country with any sort of a sub-sea industry is working on an AUV project. The problem? control. Transmission of control data and video signal in realtime. Radio frequency, 'RF' signals attenuate almost immediately in water - so, at this time at least, we are left with acoustic signals. Compared to the electrons zipping up a hard-wire umbilical or the photons in an optic-fibre cable, the sound waves are slow as molasses! How can you work - operate a manipulator when the information you're receiving may be 3-5 seconds old. As they say, that's history. Your shiny new manipulator dropped the shackle pin 5 seconds ago but you are still blithely trying to insert it in the shackle! - And that supposes that the problem of transmitting high resolution video images will be solved shortly. With digital video it shouldn't be a problem, in theory, but it's such an incredible amount of information to crunch it hasn't yet been done in a practical fashion. (But...it will be)

Admittedly, the foregoing is simplistic. There are a host of partial solutions, hybrid systems, purpose-built systems that work fine in some specific applications but have poor general applicability, and so on. Tether-management cages, for example, fall broadly into this partial-solution arena, in that they solve one problem, but introduce other problems particular to the nature of the solution. A universal panacea? There isn't one...at least not one that I, nor anyone that I know, knows of...

There are only the best tools currently available - which will, inevitably, be replaced by better ones. Sometimes there is a real break-through in technology, but my experience in this business is that genuinely "new" technology is rare. There is, in the end, very little "new" under the sun - nor under the waves, for that matter. What is often touted as 'brand-new' is often just a fresh look at an old solution. Even more often, it is either a chance or contrived effort at applying current technology, current mind set, and current requirements to a concept that almost worked before.

So how do you eliminate the umbilical tether from an ROV today - now. Well, an obvious way is to eliminate the need for it. As most everybody at this conference is aware, "ROV" stands for Remotely Operated Vehicle. It means exactly what it says: the operator is remote from the vehicle. The ROV is not really a vehicle at all, it is a system. The system has the human operator at one end and a vehicle at the other. (I will spare you a repeat of my litany on what is in between!) The 'vehicle' is a TV camera, a sonar, a couple of little propellers and a pair of manipulators - on the end of a very long wire. The field of view and visual acuity is extremely poor, by our human standards. The thruster control is low-grade and sparse in vector and proportion - (a good lesson, in this regard, was seeing the Newtsuit ADS 'flying' circles around even the most sophisticated, responsive, ROV's - because the ADS was controlled directly and every nuance of feedback was instantly utilized by the operator and provided the input basis for the next instants application of control) And the manips - well, they run the gamut from totally ridiculous to good (the Western Space and Marine "G.E." force-feedback manips, for example, are old technology but rank among the very best in function). Combine all of this with a total loss of peripheral sense - the loss of the ability to upgrade horizontal and vertical position with a glance, to 'feel' the precise attitude of the vehicle, the loss of audio feed-back, and most important, the loss of that time-base clock that orients you in relation to the things around you and constantly, unconsciously, crunches time, speed, distance, 'head-winds', pauses, deviations, etc. to give you the overall sense that you know where you are and where you've come from - sonar is a partial substitute but nothing like the real thing.

Now suppose we could take that human ROV operator out of his control shack - walk him past all that expensive deck hardware, winches, 'A' frame, handling system, etc.. until we come to the work vehicle. We stick him inside the vehicle in a comfy little human occupancy pod patterned after a monoplace 'flyer' from

popular science fiction and chop the umbilical off the 'ROV'. You would then have a 'DOV' - a Directly Operated Vehicle.

## **SYSTEMS DESCRIPTION "DEEPWORKER 2000" DOV**

DeepWorker is far from the first DOV. The thought of marrying a pressure-proof hull and manipulator technology with an operator right there at the worksite, is not new. There have been a number of DOV type devices built, with varying degrees of success. Some of the ones that got a lot of P.R. didn't work well, at all - while others, such as the Oceaneering and Comex thruster-powered, manipulator bells - worked extremely well but were not well-known in the industry, and were large, expensive, tethered, systems.

A major problem with all ROV's and virtually all powered manned, one-atmosphere systems from the OSEL 'Mantis' to the OII 'Ocean Arms' series - to most currently, the ADS 'Newtsuit' is the fact that they are all tethered systems. DeepWorker is not.

DeepWorker also has the singular advantage of being able to draw from all the successful or partially-successful designs that preceded it, as well as to learn from some of the mistakes of the less than successful designs.

The designers of the DeepWorker 2000 had the specific advantage of being involved in the early development of the first work-class ROV (Saab-Sub), the design of the ADS Jim, Jet-Jim, Wasp, and Newtsuit, the deep-diving autonomous submersibles Deep Rover, Sea Urchin, Sea Otter, and Remora and a large number of bell-bounce systems, saturation systems, observation bells, and observation ROV's.

DeepWorker 2000 is a one-atmosphere, single person, under-sea work vehicle. It is propelled by thrusters powered by self-contained batteries and is fitted with a pair of manipulator arms and end-effectors. The vehicle is untethered and operates directly from a surface vessel or indirectly through a docking hangar suspended from a surface vessel.

DeepWorker is designed to meet the requirements of the American Bureau of Shipping (ABS) under the classification of manned submersible.

## **PRESSURE HULL & FRAME**

The pressure hull comprises a sphere joined to a short cylinder (with a hemispherical end-cap) and a pair of cylindrical, hemispherical end-capped battery pods. Material alternates are all aluminum or aluminum plus mild steel. (The purchaser must make a weight-in-air / submerged payload versus cost trade-off decision). On the drawing board is a titanium hull for greater depth at little or no increase in weight.

Entry into the pilot's cabin is via a large diameter flange / coaming ring which is sealed by a thick-walled acrylic vision dome which encloses the pilot's head and shoulders. The main sphere is 36" inches in diameter - a little less than a metre - and is quite 'roomy' and comfortable. The pilot has about the same space and comfort as a first-class air craft seat.

The hull design is unremarkable, but clean and competent. Where mild steel is used as the hull material, the flange rings for the entry dome, the leg tube, and the battery pod caps are made of stainless steel.

The hull is joined to the battery pods by means of a tubular frame. The frame mounts the vertical and horizontal thrusters, electrical distribution can, and lights, and is completely jettisonable as a last-ditch, self-rescue device when all other means have been exhausted. The main hull, along with the life support systems, can rise to the surface and the pilot may contact the support vessel via VHF and give his pick-up position via GPS.

The hull design is thought to be smallest, practical, comfortable volume and configuration. Experience with ADS - Jim and Newtsuit showed them to be too small to be comfortable over a long dive - WASP is better, but still too confining - whereas, Deep Rover or Aquarius are far bigger than needed for single operator comfort.

The short leg-tube was a novel way to reduce the hull diameter dramatically without sacrificing any personal comfort space.

## **MANIPULATORS**

The DeepWorker 2000 uses a manipulator design that is not standard to the ROV industry - (where most underwater manipulators are used). ROV manipulators are generally of a fairly dated geometry design (30+ years) and operated by conventional high pressure hydraulic motors pumping to hydraulic linear actuators (or 'hydraulic cylinders'). There are a few exceptions to this statement: The 'Hawkes arm' and the Kirby brothers 'Python' come to mind, but generally the manipulator suite in a standard work-class ROV is of the hydraulic 'back-hoe' variety. It has been pointed out that, like Edison - the pioneer of direct current power, the pioneers of hydraulic manipulators have become emotionally wedded to their concepts, and are their most dogmatic defenders, even against systems specifically designed for underwater use or systems that seem to offer better performance and require less maintenance.

This situation is ironic, considering that these same pioneers were once considered to be radical, progressive innovators!!

The basic considerations in the 'Newtarm' design used on DeepWorker were:

**A) Flexibility** - a different description of kinetics than the more commonly used 'number of functions' (5 function arm, 7 function arm, etc.) For example a wrist that can pitch/yaw/roll has much greater 'flexibility' than a wrist that has only roll-pitch -roll.

**B) Reach** - Long reach is as essential to offshore work as it is to boxers. Field experience has shown that one limitation to manned ADS systems (such as the Wasp, Newtsuit, or the new Chinese "Newtsuit") that use conduit-style arms, is the shortness of reach.

**C) Cross Section:** A manipulator designed to reach into or across a well-head, hydraulic actuator assemblies, change sealing rings, operate valves, remove and replace quick disconnects and the general host of offshore requirements should be as slim as possible, consistent with 'reach' and 'strength'

**D) Strength:** If human arms and legs were strong enough we wouldn't need fork-lifts. The manipulator must be much stronger than its' human equivalent - a likely strength requirement would be the ability to lift 150 lbs (45 kg) at full extension.

**E) Dexterity:** A combination of manipulator jaws/wrist and, the ability to make quick, easy, small motions of each spacer or limb segment. Overall dexterity is hard to define, yet immediately obvious to the user and critical to good performance.

The Newtsub DeepWorker 2000' uses an arm or limb geometry similar to that found on a number of atmospheric diving suits going back to the turn of the century. The proper name for this geometry is a rotating pseudoconic joint - although it is most commonly called a "stovepipe" joint. This same rotating conical segment geometry has most recently been used in a number of space suits (most notable the Ames AX1-5 and the Litton AES). The 'Newtarm' design has been optimized, based on previous experience with the conical segment Newtsuit limbs and the rotary connector/driver used in the Newtarm is of a proprietary design that is currently being written up for patent application.

The 'Newtarm' systems uses water hydraulics. The surrounding water is input by a simple, rugged, pump powered from the DeepWorker battery pack. Sea water for underwater tool use was described some years ago by the U.S. Civil Electronics Lab (1980) but those designs used high-pressure, zero leakage systems virtually identical to surface hydraulic-oil systems. The 'Newtarms' use a large volume, low pressure, open hydraulic system with some designed leakage providing compliance. The degrees of motion possible with the 'Newtarm' design are roughly the same as those of its human counterpart and even provides for adduction and a pseudo pronation in the wrist area. The arm design allows a significant degree of 'hinge mirror' - that is, the position that you could assume if your elbow, for example, could continue past straight and achieve 90 degrees perpendicular to the underside of your arm.

The mechanics of the 'Newtarm' are simple, but like the space shuttle's remote manipulator system (RMS) - this apparent simplicity conceals some subtle engineering and unexpected capabilities.

Since all the functions of the Newtarm are achieved by rotation only - precise, accurate control is much simplified compared to 'back-hoe' systems.

The large external manipulators (slaves) respond precisely to a set of smaller arms (masters) located inside the DeepWorker. The master is a framework conduit made of light weight rings that duplicate the geometry of the slave but on a much reduced scale. A series of position transducers provide for position reference of the joint elements. The slave's position indicators 'chase' the master's indicators with a fraction of a second delay.

The Newtarm has a very small or 'slim' cross-section related to its length. The section is roughly oval and not exceeding 6.5 inches in the reaching sectors.

The reach of the Newtarm is unusual since each of the functional conical segments are driven independently - they can easily be 'stacked' or extended by using spare spacer pieces or by dismantling one arm in order to greatly increase the length of the other. If the specific task is to reach fifteen feet into an assembly and carry out dexterous manipulation while viewing via the wrist camera - it is not only possible with this system, it is relatively quick and easy to set up.

The system described is powerful - lifting more than 150 lbs. at full extension. The provision of variable air chambers within the arm segment enables the weight of grasped objects to be offset. So maintaining, the crafts stability. It is dexterous for the reasons given and its rotary drive system puts all of the drive components on the inside of the arm - giving a smooth, snag-free exterior. Finally, the manipulator design is well suited for the installation of sensory feedback to achieve precise positioning and a sense of touch. The Newtarm is easily fitted to a standard work-class ROV and it will be interesting to supply some of these systems to ROV operators and get their operational feedback.

## **PROPULSION/STEERING**

The propulsors/thrusters are of the permanent magnet design and samarium cobalt as the magnet material. The use of these 'rare-earth' materials result in a driver with a power/weight/size ratio that would have been unimaginable even a few years ago. The thrusters are rated for full ocean depth and produce an exceptional thrust per watt ratio. The thrusters are available in various horsepower ratings and even at the most modest levels will propel the vehicle at three knots.

The thrusters are powered from a bank of lead - acid batteries contained in two pressure pods that do double duty as skids and thruster/manipulator mounting

platforms. The batteries are readily available, deep-cycle recreation vehicle batteries. They are high power, high capacity and are cheap enough to replace every season. Control of the thrusters is effected by a digital electronic controller circuit and the throttle is located within the foot pedal section.

DeepWorker 2000 is steered and directed in exactly the same way as a surface vehicle such as a golf cart or ATV. At the lower end of an adjustable rack in the leg tube are two pedals - the pedals pivot just like the brake and throttle in your automobile. They have a raised lip around the outside of each of the foot-shaped pedals. So, push the right pedal with toe and ball of your right foot and you go forward - push harder and you go faster. Push with your heel and you go in reverse, swing your right foot to the right and you turn right - or left, to turn left. Push on the toe of your left foot and you do down. Push on the heel and you come up. Swing your left foot left and you move laterally left.

The controls operate simultaneously. If you swing your right foot right, while pushing hard on the right toe, you will make a fast, angling, dive to port-side. Absolutely brute simple.

The movements are so intuitive that the learning curve is very short; almost immediate. Plus - unlike a fast car or a helicopter - you can push anything, see what it does, then try again. When you get comfortable with the system, however, you will use only two levels; stop and full-speed!!

## **LAUNCH & RECOVERY**

The DOV weighs less than a tonne, all up and ready to dive. This modest weight, by submersible standards, makes launch and recovery more a matter of available options rather than a dedicated launch and recovery system. The L/R system may be a small, extendable boom, mobile crane - a work vessel stiff-leg crane - a deck mounted pedestal crane - an 'A' frame or 'U' boom system of a size generally used for deployment of oceanographic instruments - a stern launch/recovery ramp and so on.

Typically, a rigid-hulled inflatable craft - a chase boat - is lowered with a two man launch/monitor/recovery crew aboard. They stand by as the DOV is launched, release it from the launch hook and then station-keep above while the DOV works on the bottom. The L/R crew is in constant radio communication with both the DOV and the support vessel. The L/R vessel is often equipped with a tracking system and/or a GPS so that it may go immediately to the DOV's surface co-ordinates, should the DOV surface in limited visibility weather. The DOV IS usually towed back to the support vessel, hooked up and recovered, then the L/R vessel is recovered.

The system has worked well for many years and has been used from work-over barges - salvage vessels - survey vessels with decks nearly awash - to exploration rigs with a fifteen-story air-gap!

Because of the tetherless nature of the DOV it changes the concept of the 'handling' system. There is no 'handling' - you launch and recover, period.

This DOV may be launched in a hangar - a 'smart cage' that can secure and release the DOV either with surface control or DOV control. Using a deployment hangar is quite different than an ROV tether management cage - since there is no tether to manage! Where conditions dictate the DOV may be fitted with an optic-fibre link for the real-time transmission of video image. The real-time aspect is not usually critical in DOV operations since the eyes and the brain are at the work site. With an ROV, real-time video is, obviously, critical since the vehicle is 'blind' without it. - In ROV operations, video is a basic requirement in order to perform any task. In DOV operations a digital video camera is used to record work as it is being done. There will be the same delay in transmitting video to the surface in a wireless mode (when that becomes possible in adequate resolution) with the DOV as with a tetherless ROV. The difference, of course, is that the DOV is simply relaying back records of what the pilot on site has already accomplished - whereas the delay in an AUV makes manipulative tasks virtually impossible. As one of the Nuytco technicians put it: "The delay's OK, if the man's in the can!"

The ability of the DOV pilot to obtain high quality digital images on site, view them for complete coverage, and then store to tape or disk is unmatched by any other inspection or recovery system.

Because the DOV has room in the cabin, the pilot can use 'night vision' light intensification devices for his own eyes and for the video camera - and get a wide angle, long distance view better than the usual low-light SIT camera and at a fraction of the cost. The same holds true for the digital video and video still cameras. No housings or control devices are required.

## **LIFE SUPPORT**

Again, nothing particularly remarkable. The life support system comprises a dual, redundant O<sub>2</sub> system of a sealed bellows design that we have previously used on the Jim, Wasp, Newtsuit, Deep Rover, Sea Urchin, etc.

An important departure from the usual practise is the combination of mechanical control and full electronic monitoring. Physiological monitoring is carried out by the production of a system that Nuytco Research Ltd. originally developed for the National Energy Board of Canada. It is called the 'Bio-Sensor' system and reads out both physiological data - human respiratory rate, temperature, cabin pressure, life support duration at current usage rate etc., as well as systems

status data - Port and starboard O2 supply pressure, ballast gas supply pressure, depth, outside temperature, cabin O2 percentage, cabin CO2 percentage, and a previous 5 minute graph of O2 and CO2, cabin pressure and depth, to look at 'trending' information. A future development program for the 'bio-sensor' system will research obtaining of actual blood gas measurement by laser spectrometer mounted on an ear-lobe clip.

Data from the Bio-sensor system is read out in the DeepWorker on a flat screen note-book computer and faxed to the surface by wireless communicator system. The term 'faxed' is used advisedly since the protocol will require a 'read-back' to ensure that data has been accurately received on the surface. The 'Bio-sensor' system also makes surface intervention quite possible in the unlikely event of pilot incapacitation. Digital control may be used to operate the life support functions, blow ballast tanks, etc.

## **SAFETY**

The DeepWorker 2000 has the usual drop weights, buoyant hull, as required by the certifying agency. Life support is long duration - exceeding four days. Rescue of a trapped DOV by an ROV, a second DOV, a submersible flown in on a 'Subsmash' program, or any combination of the above is the usual means of providing working back-up. All international functional work-class submersibles currently provide back-up for each other on a proximity priority. For example, Deep Rover located in Vancouver, B.C. often provides back up for the Hawaiian Underwater Research Laboratory (HURL) submersibles "Ma'hi'li'ki' and 'Pisces 5' - located in Honolulu, Hawaii. When the USN submersible 'Turtle' or 'Sea Cliff' are working on the test range at Barking Sands, Kauai, Deep Rover drops back to second or third priority, and so on.

As mentioned earlier, the pressure hull is able to separate from the frame and battery pod and rise to the surface. This option would not normally be selected unless a recovery by 'back-up' was, for some reason, not possible.

Working submersibles of all classes - military, research, and commercial have an unparalleled safety record. The author is a member of the Deep Submersible Pilot Association (DSPA) and a review of the literature provided by the DSPA over the past thirty years indicate that such activities - carried out by the qualified personnel - are extremely safe. Thousands upon thousands of logged dives with incident rates so low that you may be far safer in a DOV then driving home from the dock side after your shift offshore!

## **ECONOMICS**

The Newtsub DeepWorker 2000 is a low-cost system relative to a typical work-class ROV or a new-build saturation system or a 1000'ADS.

Taking a leaf from the computer manufacturers, Newtsub systems are designed in a modular fashion to be easily upgradable.

The lowest cost, basic work system is a DeepWorker fitted with simple 'back-hoe' style manipulators. An upgrade to Newtarms boosts the cost, but the 'back-hoe' arms will be taken back for credit-less a cost for refurbishment . When the client moves into deeper water, the 2000 foot hull can be swapped for a 3000 foot hull. The thrusters, frame, battery pods, lights, instrumentation etc., are all rated for the greatest depth.

A lower cost is reflected in a lower day rate and in these budget-conscious days, that's very much the name of the game. Cost of acquisition and economy of operation are at least as important as clever technology - Vic Hall, one of the founders of the large ROV company Sonsub - addressed this reality at a recent autonomous vehicle conference where he was the keynote speaker: "The strong message that the contractors are receiving (from offshore operators) is that cost, not technology, is the driving consideration in future development projects: The quest is for a 'cheaper' mouse trap, not a 'better' mousetrap." And he was absolutely right. These are the facts.

## **CONCLUSION**

You will note that the foregoing discussion and hardware description is very general. This paper is meant to be an overview of the introduction of a new designation to a specific class of underwater work vehicles. Major emphasis is on the autonomous, tether-free aspect.

The system described is a light, small, middle cost underwater vehicle. The power thrusters and manipulator capability are purposely over-sized to enhance capability.

The purpose of this machine is to carry a strong set of arms and that most sophisticated of computers, the human brain, to the work site and bring them back again. Safely and easily.