WHO'S LEADING THE PACK NOW?
An Update on the Commercialization of AUVs

Robert L. Wernli
SPAWAR Systems Center San Diego
Code 27405
San Diego, CA 92152
bob.wernli@navy.mil

***Abstract* - The author presented the paper "AUV Commercialization - Who's Leading the Pack?" at the OCEANS 2000 conference and is continuously asked if it has been updated...so here it is. Four years later, AUVs have entered the commercial sector, and in some cases rather dramatically; so who's "leading the pack now?" Who's fallen behind? Were the assessments of operational efficiencies correct? Are those optimistic projections for the AUV market place of the future still being made? This paper will attempt to answer those and other questions regarding AUVs and related technologies.**

I. INTRODUCTION

When the paper "AUV Commercialization - Who's Leading the Pack?" was given at the OCEANS 2000 conference [1], it was stated that AUVs are at the "cusp of the acceptance curve, and that curve has begun to take an exponential change upward during this year." That statement is still true as AUVs are being used in greater numbers in the commercial, military and academic sectors; however, although their use is growing at an ever increasing rate, that exponential curve has tapered off somewhat. For brevity, the material of the previous paper will not be repeated, although key points and assumptions presented in that paper will be addressed for comparison purposes as follows:

- The leading commercial AUVs were *Hugin* (Norway), *Maridan 600* (Denmark), *AQUA EXPLORER 2* (Japan), *Sea Oracle* (U.S.), *Explorer* (Canada) and *CETUS II* (U.S.).
- The leading non-commercial AUVs were *Autosub* (UK), REMUS (U.S.), ABE (U.S.), *Urashima* (Japan) and R-1 (Japan).
- The military were placing their bets on LMRS (U.S.) and *Marlin* (U.K.)
- The number of deep subsea installations was projected to double between 1998 and 2003.
- AUVs were projected to significantly cut the costs of offshore surveys.
- The value of the subsea market was projected to increase from $4.9 billion in 1998 to $11.8 billion in 2003.
- Two main groups of offshore AUVs were envisioned—a Survey AUV for data gathering and a Hybrid AUV/ROV for subsea intervention.
- If AUVs met industry expectations, sales were projected to reach 30 units by 2004; possibly 20% of unmanned undersea vehicle (UUV) operations revenue: a cumulative total of $200 million.

Since the OCEANS 2000 paper was written, many events have occurred that have affected the AUV market. These events include company acquisitions, the U.S. stock market collapse, the war in Iraq and the acceptance and efficiency of the AUVs themselves. This paper will discuss the effect of such events in the following sections.

II. WHAT'S TODAY'S MARKET?

A. Military

On the military side of the equation, several countries are either vigorously pursuing AUV applications or at least using them to investigate their potential. In the U.S. Navy, the biggest thrust (at least in dollars) is still the submarine launched Long Term Mine Reconnaissance System (LMRS), which was scheduled for initial operation in 2003. Unfortunately, delays have moved the schedule to the right (first deployment is not expected until the fall of 2005) and politics have moved the project to an engineering development role. The technology and lessons learned from LMRS will then feed into the MRUUV (Mission Reconfigurable Unmanned Underwater Vehicle), also a tube launched vehicle. Another system under development is the ADUUV (Advanced Development UUV), by Lockheed Martin, which will also feed into the MRUUV. Are tube-launched vehicles the right path? Time will tell.

In contrast is the successful use by the U.S. Navy of small vehicles such as the REMUS. The REMUS was effectively used by the U.S. Navy's Naval Special Clearance Team One in Operation Iraqi Freedom performing mine countermeasure missions (MCM) [2]. The U.S. Navy's SPAWAR Systems Center in San Diego (SSC San Diego) is supporting the Special Clearance Team One's evaluation of small UUVs for their assigned missions.

The U.S. Navy's Office of Naval Research (ONR) is also investing heavily in UUV technology, including a contract with Bluefin Robotics for the BPAUV (Battlespace Preparation AUV, a 21 inch diameter vehicle).

Bluefin and Hydroid have both been awarded contracts by the U.S. Navy for vehicles to solve the very shallow water (VSW) search, classify, map (SCM) mission. Sponsored by the Explosive Ordnance Disposal – Program Management Office (PEO-EOD), the goal is to provide the Naval Special Clearance Team ONE (NCST-1) with an initial operating capability for the SCM mission by FY 06. The contracts have options for additional vehicles for the company with the system that performs best.

The U.S. Navy also completed in 2004 an update to the UUV Master Plan, which continues to support the importance of UUVs in the future. The plan should be officially released by December, 2004.

On the international front, there is a lot going on [3]:

- UK's BAE Systems continues developing the submarine tube-launched AUV *Marlin.*
- Sweden is developing a submarine launched AUV: Autonomous Underwater Vehicle (AUV) 62F.
- Norway's Kongsberg Maritime is moving the HUGIN vehicles into the military arena with their smaller HUGIN 1000 vehicle.
- France's Thales Underwater Systems (TUS) and its U.S. partner Bluefin Robotics are delivering two "Mine Countermeasures UUVs (MCM-UUV);" one for NATO and one for TUS.

Although the military market does not necessarily represent the commercial sector, the fact is that the technology pushed by the military will eventually spill over into the commercial market, hopefully enhancing their capabilities and reducing production cost.

B. Scientific

If you want to measure progress in the commercial market, look toward the international academic and research organizations. Their money strapped projects push them to smaller, more efficient vehicles that are designed to do one job and do it well. And they are becoming market savvy with academic spin-offs such as Hydroid and Bluefin Robotics, which are marketing vehicle lines based upon their academic base. If not for such vision and risk taking, i.e. transitioning a research tool to the commercial market, the successful use of small vehicles by the military would not have happened for some time. Leaders in the scientific area include:

- In the UK, the Southampton Oceanographic Center's Autosub, which is outfitted with equipment applicable to the scientific mission at hand, has now completed 377 missions covering about 5,000 km of underwater operation. The vehicle recently completed a 24 hour, 100 km under ice survey off Greenland [4].
- In Japan, JAMSTEC is operating their 9.7-meter long, 1.5-meter high, 3,500-meter depth AUV the *Urashima*. This vehicle will join JAMSTEC's *UROV 7K* AUV/ROV and their Marine Robot *MR-X1* that is under development. The University of Tokyo continues to conduct research with their *R-1 Robot*.
- The ABE developed by the Woods Hole Oceanographic Institution continues to log underwater miles, obtaining excellent data. WHOI is in the process of developing the next generation ABE.

C. Commercial

Today's offshore market is far from being short of cash with the global spend rate for offshore oil and gas growing from $91bn in 2004 to $119bn in 2008 [5]. But with the oil price crash of 1998/9, the oil industry demand had collapsed and the main driver of underwater vehicle activity was the booming submarine cable installation market. Contractors (both ROV and AUV) jumped on the cable industry band wagon and made significant investments, especially in the cable burial ROVs. The hot internet sector drove telecom cable traffic volumes to increase at 80-100% per annum. In 1998, 40,000 km of cable was laid and 2001 was projected for over 190,000 km [6]. After the dotcom bubble burst in March 2000, only committed orders were completed and no new orders were placed. As shown in Figure 1, the submarine telecom market is far from recovery.

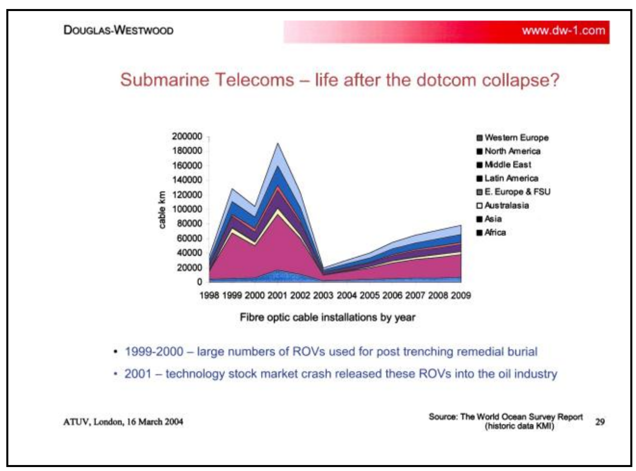

Figure 1.

So what happened to the projection for 30 AUVs working by the year 2004? Well, the offshore market problems were one of the causes to reduce that number to a slim few. These will be discussed in the next section. But one of the major factors, as John Westwood so succinctly put it, was that C & C Technologies, using their Hugin AUV, "hoovered up large amounts of the available work." The Hugin vehicle became so efficient, easily cutting survey costs in half, that it was spending considerable time at the docks waiting for the next job [7].

What does the future hold for AUVs in the offshore market? Projections range from a low of 12 to a high of 66 large AUVs operating by 2008, with a likely number of 28 units [5]. However, the deepwater survey, as C & C Technologies has shown, can be handled by a relatively small number of efficient AUVs; the real potential will be in surveys conducted in continental shelf waters [6]. For example, ocean survey is presently a $2.5 bn activity and growing with more than 300 government survey ships operating worldwide [5].

III. WHO'S LEADING THE PACK?

Two classes of commercial AUVs seem to be taking shape: those for hire and those for sale (although some firms are doing both). We'll talk about those for hire first. In the paper given in 2000, the *Maridan* and HUGIN vehicles were the first out of the gates and at that time, both were leading the pack, although each was doing rather different surveys. Japan's AQUA EXPLORER 2, operated by Kokusai Marine Engineering Corp. (K-MARINE), was available for hire after successful cable surveys in Japan. Thales Underwater Systems (at that time Racal Survey Group Ltd) had teamed with Bluefin Robotics to develop the *Sea Oracle*, an AUV based on the *Odyssey* vehicle. And Lockheed Martin was marketing the Cetus vehicle, which fits better in the smaller vehicle category.

Where are they today?

- The Cetus II vehicle is being evaluated by the U.S. Navy at SSC San Diego's UUV Research Laboratory. At this time it isn't a major commercial player but is being evaluated for missions needing its 3-D hovering capability.
- Japan's Aqua Explorer 2000 is being used by the University of Tokyo's Ura UUV Laboratory, in cooperation with KCS and KDD Laboratories, to follow and investigate sperm whales in real time. Essentially, the AE 2000, a cable survey vehicle, is not active in the present commercial market due to the conditions previously discussed.
- The Danish firm MARIDAN was acquired by Germany's ATLAS ELEKTRONIK, which will incorporate MARIDAN's AUV technology into both their commercial and military vehicle lines. The subsidiary company will be known as ATLAS MARIDAN ApS. At this time, the MARIDAN vehicles seem to be rather idle, while ATLAS is rolling out their new DeepC AUV (Figure 2).
- Boeing (teamed with Fugro and Oceaneering) has entered the fray with their Echo Ranger, a very large AUV, which began working in the Gulf of Mexico in 2002. They have worked for several oil companies and have logged over 200 hours of underwater operation [8].
- The HUGIN line of vehicles, especially C & C Technologies' HUGIN 3000, have exceeded over 36K km with a 95% uptime.
- Bluefin Robotics has adjusted their vehicle line to meet any need that might appear.

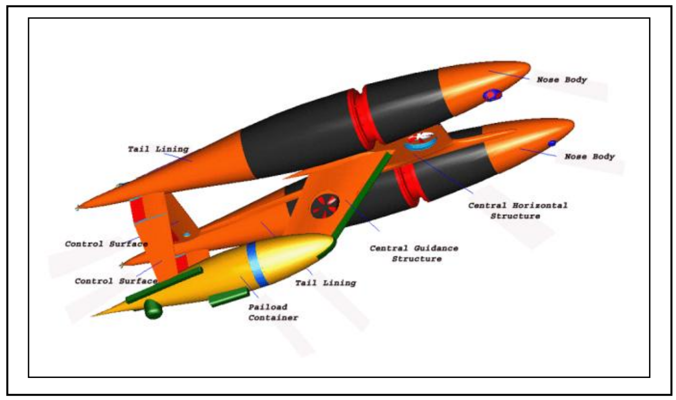

Figure 2. DeepC

Figure 3. Echo Ranger

The second group of AUVs appearing in the commercial arena are those that have been recently developed and appear to be available for purchase. These include both the larger and smaller systems. The larger vehicles include the following:

- ECA of France has completed the development of their ALISTAR 3000 AUV, a nice looking hydrodynamic vehicle, 5 meters long that is streamlined similar to the HUGIN. The ALISTAR 3000 (9,000 foot capability) follows on the heels of the ALISTAR 300, ECA's shallow water (1000 foot) demonstrator. A significant attribute of the ALISTAR 3000 is its hovering capability through the use of 4 horizontal, 2 vertical and 2 lateral thrusters.
- Subsea 7, a global provider of subsea services entered a 10 year agreement with the Southampton Oceanographic Center (SOC) to adapt SOC's Autosub technology to the offshore industry. This resulted in the Autonomous Search Vehicle (ASV) Geosub, which has completed sea trials and is now operational. Subsea 7 plans to continue development in the AUV arena, including a hovering AUV [9].
- International Submarine Engineering (ISE) has expanded their diversified line of AUVs with the delivery of the AUV Explorer to IFREMER of France (the contract has options for up to 5 vehicles). The 4.5 meter long vehicle has a depth capability of 10,000 feet, uses rechargeable Lithium Ion batteries and has a telescoping mast for GPS fixes and radio communications. ISE has also sold a vehicle to NOAA for use by a team of southern U.S. universities, has a commitment from Memorial University of Newfoundland and has two other orders in the works [10].

The largest number of sales is taking place in the smaller vehicle market. These systems include the REMUS, Fetch, Gavia and Bluefin Robotics' vehicles.

- The small REMUS AUV, which is about 1.60 m long and 0.19 m in diameter with a 100 m depth capability, is presently the leader in small AUV sales. REMUS was originally developed by the Woods Hole Oceanographic Institution (WHOI), with the design eventually being licensed to Hydroid Inc. of the U.S. Overall, 65 systems have been sold with about 70% to military establishments, about 20% to academic institutions and the remainder to commercial firms. Hydroid has indicated that they are presently conducting sea trials of numerous system enhancements, including video, GPS, acoustic communications, modular front end cap design to enable custom payloads, various optical sensors, and INS. REMUS is projected to evolve as Hydroid fields systems with greater sensor capabilities [11].
- Fetch2, developed by Sias Patterson Inc., of the U.S., is a little larger than REMUS, measuring in at 1.96 m long and 0.29 m in diameter with an operating depth of 150 m. There have been 5 Fetch2 vehicles sold with 2 to the government, 2 commercial and one academic. Recent successful missions with the AUV have included hydrodynamic research and wave height spectra data gathering. Fetch2 is projected to cost effectively support defense, marine research, oceanographic surveys and international fisheries research [12].
- Gavia, developed by Hafmynd Ltd. of Iceland, is similar in size to the REMUS at 1.55 m long and 0.20 m in diameter. However, it does have a few unique options such as a wireless LAN, Iridium satellite link, and an option of operating depths from 200 m down to 2,000 m. The U.S. Navy has purchased a Gavia (with an option for 10 more), and will be evaluating the AUV at SSC San Diego. A total of 3 of the first generation units are operational in Iceland, and, in addition to the current fully modular Gavia (Figure 4) sold to the U.S. Navy, another has been sold to the University of British Columbia [13].

Figure 4. Modular Gavia

- Bluefin Robotics Corp. of the U.S. has transitioned their best selling Odyssey line of vehicles into three different AUV sizes: 21 inch, 12 inch and 9 inch diameter versions (Figure 5). Their vehicles are modular and range in depth capability from 300 m to 4,500 m. Bluefin's diversity seems nicely staged to support the future goals expressed in the U.S. Navy's recently updated UUV Master Plan [14].

Figure 5. Bluefin Robotics' Vehicles

IV. AND THE LEADER IS?

Can a "leader of the pack" actually be chosen from the spectrum of vehicles working the world's oceans? Well, let's take a shot, at least based upon today's statistics. There are many great candidates and the next several years will be exciting, but there are two vehicles that stand out.

On the smaller front, Hydroid's REMUS has to be recognized. With 65 systems in the field and counting, they are making a real impact on the future of UUVs entering the market.

But the grand prize has to go to C & C Technologies with their HUGIN 3000 vehicle (Figure 6), which is now called the C-Surveyor I™. Here are a few of their stats [7]:

- 68 projects completed in 4 continents for 33 clients.
- 36,000 km surveyed worldwide (By the time this paper is published, C & C's AUV will have gone far enough to circumnavigate the globe.)
- Performed 92% of commercial AUV work to date.
- Uptime has gone from 16% to 95% today.
- 50 hours per dive using fuel cell technology.

Because of their success, C & C is constructing a second AUV, the C-Surveyor II™, that will be available for worldwide use in 2005, eventually to depths of 4,500 meters. They're even planning a meeting with all their clients in April, 2005 to solicit customer feedback. You have to admit, C&C has dropped the gauntlet for the competition. Congratulations.

Figure 6. C-Surveyor I

V. THE FUTURE

The paper four years ago stated that "AUVs are now at an early stage of acceptance." Today, their acceptance is complete; what is still required is the ability to finance their use. The larger vehicles will continue to have large price tags (both developmental and operational), especially military versions; but the smaller vehicles will see their costs drop as their numbers increase. With that will come the acceptance of AUVs, at least the smaller ones, as statistically "expendable." That is not to say that you only use them once, but when enough are being used, and the price comes down, then if one doesn't return it will not be the end of the program. Unmanned air vehicles (UAVs) are expensive, but their return on investment is so great in the battlefield, that an occasional loss is acceptable.

But what about the technology? There hasn't been a study performed on vehicle technology yet that hasn't had the same results. Autonomy, energy, communications, and sensors all need to be improved. But not all of this will have to be done by the AUV community.

Energy sources, which are mission and vehicle size dependent, are moving along nicely. Lithium-based batteries show extreme promise, especially for the smaller vehicles, and advanced pressure tolerant batteries such as lithium polymer are on the horizon. Several vehicles, including the URASHIMA and HUGIN 3000, are successfully using fuel cells, which are nicely adaptable by the larger vehicles.

Sensors continue to move forward with increased capability, smaller size and less energy usage. Recent pushes in sensor developments driven by terrorism and homeland security issues will add to the future capabilities of AUVs, including defining new missions.

Communications will always be driven by the laws of physics, however, engineers are developing new techniques to work around the problem, such as bottom or surface relays, to provide the necessary data to the user. As the number of vehicles used on any given mission increases, so will their need to communicate, which requires both communication and on-board "smarts."

Autonomy will evolve: advances in computer processing speed, memory and reduction in size and power requirements will help move this along. Moore's Law does apply, however, software programmers will need to ensure that they don't take advantage of the new capabilities by gagging the hard drives with inefficient code.

The increase in the acceptance of AUVs, just as in the acceptance of ROVs, will result in new missions such as: fisheries and environmental monitoring; port security; and tunnel and pipeline inspections. The advances in the critical technologies above will expand the spectrum of missions that can be performed by the smaller AUVs. This fact is supported by the range of AUV sizes being developed by such companies as Bluefin Robotics.

Hugin representatives also see this vision: "Since all the key components (heart and brain), to a large extent will be common for the larger AUVs and the smaller AUV, the step from the larger established AUVs (Example HUGIN) to a smaller AUV, should only be a limited engineering task. One should therefore expect to see more small AUVs in the market in the future."[14]. This does not necessarily say that small AUVs will rule in the future, but you can be assured that if possible, small will be chosen over large and the smart companies will have those options available for the customer.

AUVs and ROVs will meet half way through the development of the Hybrid AUV, i.e. a system that can autonomously fly into an area, dock with previously installed equipment, and turn the operation of an integral ROV over to a remote operator. Vehicles such as the SWIMMER (Figure 7) developed by Cybernetix of France will test the acceptability of such an approach; the feasibility has already been demonstrated.

Figure 7. SWIMMER AUV

Cybernetix is also taking the next step with their ALIVE AUV (Figure 8), a system that can dock with a remote station and autonomously perform operations such as turning valves.

Figure 8. ALIVE AUV

And finally, one should not ignore the small Slocum gliders such as those developed by Webb Research Corporation. One such glider, the Spray, recently crossed the Gulf Stream from Cape Cod to Bermuda. The Spray was developed by a team from WHOI and Scripps Institution of Oceanography, supported by government funding [16].

What can be gleaned from the above? Well, looking into my crystal ball, I think it is safe to say that the small to medium sized vehicles that do not require large, expensive launch and recovery equipment, and the boats to carry them, will become "very popular" in the future. Expendability will be achieved. And, just as in the ROV market, a few operators will corner the market with the few premium AUVs that win the reliability contest in a cost effective manner.

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