Project Silent ANZAC

Preliminary Analysis of Imagery Data

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The Silent ANZAC
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HMAS AE2 at Port Melbourne – © John Thomson

Preliminary Analysis of Imagery Data arising from the 2014 Internal Investigation of HMAS *AE2*

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Extended Abstract/Executive Summary

In May/June 2014 an internal investigation was undertaken of the sunken submarine HMAS *AE2,* which lies in 73 metres of water in the Sea of Marmara, Turkey. This investigation was undertaken as part of "Project Silent Anzac" under the coverage of the *AE2* Commemorative Foundation Limited (AE2CF), with full approval of both Turkish and Australian governments, and it was undertaken in accordance with currently-accepted maritime archaeological practices. The scientific methodology adopted for the survey was based upon a "progression intrusion" principle whereby baseline measurements were made with the submarine in as near as possible its undisturbed state, and then the upper hatch was opened to enable remotely-deployed sensing technology to progressively and systematically investigate the interior of the submarine.

In large measure this report is focussed upon analyses of video imagery data recorded from inside the submarine. Two different video sensor systems were used; one was a camera system deployed by divers through the partially-open upper hatch. Images recorded from this system, with its associated lighting modules, were obviously confined to the vicinity of the conning tower and the control room in the immediate vicinity of the entry. Remotely Operated Vehicles, which carry propulsion systems, were able to be used to image a much larger proportion of the boat. Imagery was recorded from the conning tower, the control room, wardroom, forward torpedo room, midships torpedo space and part of the petty officers mess.

In addition to the video imagery, a limited dataset was recorded, from a location below the lower hatch, using an ARIS 3000 imaging sonar. This system generates a two-dimensional segment of sonar imagery, much like a plan view representation.

In total 12 terabytes of imagery was recorded from inside *AE2*. It is beyond the scope of this report to present the results of a full, scientific analysis of the imagery. Indeed, it is beyond the resources available to the AE2CF team to have undertaken a full analysis. The purposes of the work described in this report were to:

- Propose a mechanism whereby analysis and interpretation of the imagery can be systematically undertaken;
- Analyse a subset of the dataset, thus demonstrating how the proposed mechanism would be applied;
- Give consideration to the potential application of sonars such as the ARIS 3000 system for future investigations of this type;
- Use this preliminary analysis to support interpretation of specific elements or subsystems of the boat;
- Use the preliminary analysis to support creation of an interpretive toolkit which may be useful in "telling the story" of *AE2* and the expedition.

All of which were achieved in full and in some cases exceeded expectations. In particular:

- The analysis and interpretation of the imagery was a further development of a technique devised earlier for work on HMVS *Cerberus*. The result in the attached "Work Book" is better able to be appreciated on a computer screen (Excel Spread Sheet format with hyperlinked footage/images). It provides the basis for further research and it can be an interactive tool for educational and research purposes.
- An interpretative application and toolkit, "AE2 Explorer", has been developed and is described in detail. This has potential to be used by both analysts and by public institutions such as museums. This application is designed to be very flexible, so that different users or institutions can tailor its outputs to suit their needs.

The Australian National Maritime Museum is set to become the custodian of the data and intellectual property which arose from Project Silent Anzac. The AE2CF team felt a strong sense of obligation that they should hand the data over to the new custodians in a form and manner that will facilitate its use to support ongoing research. In preparing this report it is hoped this obligation will be substantially met.

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1. Introduction

1.1 Project Silent Anzac

In May/June 2014 an internal investigation was undertaken of the sunken submarine HMAS *AE2,* which lies in 73 metres of water in the Sea of Marmara, Turkey. The 2014 Maritime Archaeological Assessment (MAA14) was undertaken as part of "Project Silent Anzac" (1):

(1) Under the coverage of the *AE2* Commemorative Foundation Limited (AE2CF), with full approval of both Turkish and Australian governments, and it was undertaken in accordance with currently-accepted maritime archaeological practices. The scientific program was developed to support this project – one of several programs undertaken as part of this project.
(2) This program aimed to significantly enhance the knowledge of the *AE2* submarine, while minimizing the impact upon the vessel. Where it was impossible to avoid disturbing the vessel in the course of scientific investigations, every effort was made to record or measure what was done, so that the likely long-term impact of the activity can be assessed.

1.2 The Scientific Program

The general objectives of the scientific program were to:

(a) Collect essential information to enable assessments to be made of the state of the vessel from a corrosion protection perspective;
(b) Make an assessment of the environment inside the submarine, to see whether it is reflective of the outside environment or of a "micro-environment";
(c) Gather data which can be used to make assessments of the change in the physical state of the submarine since it was last studied in detail in 2007;
(d) Collect detailed archaeological information from inside the boat, enhancing the knowledge of the state of preservation of the vessel plus building upon the knowledge of how submarines were operated in the early twentieth century; and
(e) To develop methodologies and representative technologies that may be applicable for use in other relevant research programs.

The initial assessment report for the project (2) summarised the manner in which the scientific program was structured to address each of these objectives. This report, and those included in the other annexes of this final report, will expand upon the description.

In large measure, however, this report is focussed upon objective (d) above. The objective cannot however be considered in total isolation, hence the following paragraphs provide a brief summary of the overall, planned scientific methodology for the project so that the reader can consider the results in the context of the scientific program as a whole. This report describes in some detail the hardware which was developed and assembled to support the internal investigation of *AE2*, it introduces some of the methods that have been developed to support analysis of the data generated, and it provides examples of the interpretation of subsets of the data. The volume of data generated in this mission was considerable – there was no possibility of the team undertaking a full set of analyses. The hoped-for outcomes of the work reported below were to develop and demonstrate analytical methodologies that may be applied to the data, and to use specific examples to illustrate their validity and value.

2. Planned Scientific Methodology

The scientific methodology adopted for the survey was based upon a "progressive intrusion" principle whereby baseline measurements would be made with the submarine in as near as possible its undisturbed state and then, following opening of the upper hatch, using remotely-deployed sensing technology to progressively and systematically investigate the interior of the submarine. In the first instance the sensing technology would be confined to the vicinity of the hatches. This meant it was not necessary to provide propulsion systems for the instrumentation packages. Hence, apart from the inevitable disturbance associated with the hatch-opening process, the inside of the submarine should remain relatively unchanged. Finally, it was planned that a Remotely Operated Vehicle (ROV), which carries a propulsion system, would be used to progressively extend the investigation into more remote parts of the submarine. It was recognised that the prop-wash from the ROV's thrusters would almost certainly increase the turbidity of the water inside the submarine. The proposed schedule for the science program allowed time for the ROV to be left idle from time to time, inside the submarine, to enable disturbed material to settle out of the water column.

As part of the 2007 Maritime Archaeological Assessment (MAA07) of *AE2* (3), a simple "drop camera" system had been inserted through the partially open upper hatch, enabling a limited amount of video imagery to be recorded from inside the submarine. It was apparent from the MAA07 imagery that, from an archaeological perspective, while study of the control room should be a significant focus for MAA14, the inside of the conning tower should not be ignored or bypassed[1]. It was agreed, virtually from the first planning meeting for the return visit (initially called the "Implementation Phase" of the project) that the scientific program should include a survey of the inside of the conning tower. This had fairly significant implications from an engineering perspective, because instrumentation would need to be capable of operating across a vertical span of approximately 5 metres, while the whole time being supported in a manner that would not negatively impact the submarine.

The proposal to use ROVs to conduct the final phase of the progressive intrusion into the submarine was a fairly obvious one, but once again an imperative was to develop insertion/extraction procedures and vehicle management systems that would minimise the negative impact upon *AE2*. In particular, it was critical to develop tether management systems that would enable the ROV to move relatively freely inside the boat, which would have the important secondary benefit of minimising the probability of fouling the umbilical. The approach which was ultimately adopted was deceptively simple – an obvious approach in hindsight but actually the result of a great deal of debate amongst the science team – and it proved to be very effective.

2.1 Planned Scientific Serials

2.1.1 Baseline Measurements

The plan was that, in the first instance baseline measurements would be made of the environment before the site was disturbed in any measurable way. These measurements comprised:

2.1.1.1 Visual Surveys of the Outside of the Wreck using a ROV

Data gathered would allow an assessment to be made of the general physical condition of the vessel's exterior. The survey would also allow assessments to be made of the relative state of burial of the boat, compared to its status in 2007. In addition, some differences had been noted between the flora and fauna of the site as observed in 1998, 2007 and a preliminary ROV survey undertaken in October 2013. This more detailed survey would support further analysis of these differences.

2.1.1.2 Assessment of the Physical Properties of the Environment

A YSI EXO1 water quality Sonde was used to assess the water quality of the environment immediately adjoining the submarine. This instrument measured: conductivity, temperature and depth (yielding salinity as an incidental measure); dissolved oxygen; pH; and oxidation reduction potential. The device was strapped to a remotely operated vehicle and delivered from sea surface to a position in close proximity to the submarine, thus a full-height profile was recorded for the full water column.

1 To quote the final report by the scientific team from the 2007 expedition [3]: "It was a matter of great frustration to the team that the driving imperative of this serial was to get inside the main pressure hull, so only passing attention could be paid to the conning tower. Any return visit *must* include a detailed assessment of the internal state of the conning tower." (Page 121)

2.1.1.3 Low-Impact Insertion of Sensors inside the Submarine

A system was developed to enable the Sonde to be inserted into the submarine through the partially open upper hatch, along with a high definition camera and two lighting arrays. This was known as the "drop camera" system.

The design enabled divers to insert the system into the submarine, lower it to various depths inside the boat and rotate the camera. The design brief was for all of this to be achieved without the need to disturb the upper hatch. As this would minimize disturbance to the environment inside the boat, it represented another baseline measurement. Because the submarine was believed to be a relatively "closed" environment, there was some possibility the properties of the water inside the boat may be quite different from those of its surroundings.

2.1.2 Measurements Involving Minimal Disturbance to the Submarine

Having undertaken the baseline study of *AE2*, the planned-for next step was to take a set of measurements which required some disturbance to the boat, but for which the disturbance would be maintained at a realistic minimum.

A set of representative sites were selected to take corrosion potential measurements. Corrosion potential readings give a measure of how well protected the vessel is from degradation due to corrosion. This required cleaning concretion from the sites and application of a measurement probe to the cleaned surface. These readings comprised the final set of baseline measurements, to be used in the long term in monitoring of the effectiveness of the cathodic protection system (planned for installation as part of the mission). It is worth noting that corrosion potential readings had been taken during MAA07. At that time the mean E_{corr} value was -0.619 volts vs. $Ag/AgCl_{sea}$ ((3), page 77) – that measurement combined with the planned 2014 readings would provide an excellent starting point from which to monitor the performance of the cathodic protection system.

The upper hatch of the submarine was scheduled to be opened to enable insertion of a more complex sensor suite than could be incorporated into the drop camera. This system added an ARIS 3000 scanning sonar and a more sophisticated insertion and rotation system to enable the instrumentation to be more precisely controlled. This system was dubbed the "Pole Camera". The aim was to use the sonar data to support the development of a digital "wireframe" model of the conning tower and control room and to drape video imagery over that model. This would provide a precise model of these spaces *as built*. DSTO previously developed a virtual equivalent of this, based upon the General Arrangement (GA) drawings of the submarine. It is of great interest to compare the two models. Apart from the fact the hatch would have been opened, this was still designed to be a relatively minimal disturbance evolution. The system carried no propulsion system and its cross sectional area was relatively small in comparison with the area of the submarine's access hatches, hence it would be expected to cause minimal disturbance, both during the insertion/extraction process and while it was being deployed inside the boat.

2.1.3 Measurements Involving Insertion of an ROV

The proposed final step in the survey process was to use a ROV to survey the space beyond the vicinity of the lower hatch. Because ROV use a propulsion system, they will inevitably cause some disturbance of the environment. Specifically, it was expected that the prop-wash from the vehicle's thrusters would cause mixing of the water within the submarine. Careful ballasting of the vehicle was planned, however, to ensure it was as close as possible to neutrally buoyant, hence minimizing the need to use thrusters to maintain station in the vertical plane.

The ROV which was planned for use in this exercise was a specially-configured SeaBotix vLBV, configured to fit through the two hatches. This vehicle was fitted with a high definition camera system and an ARIS 3000 sonar. The plan was to undertake the survey by progressively advancing into the interior of the boat. The planned sequence of advance was to first survey the spaces in the boat which represented the least risk to the ROV, and then move to spaces which the science team believed would contain a higher concentration of fouling hazards. Thus the planned sequence of the survey was to cover the control room; then forward to the wardroom; next, presuming the doorway through the forward bulkhead is open; the forward torpedo room would be entered. The vehicle would then return to the conning tower hatch and move aft, surveying the midships torpedo space. This was expected to be a particularly challenging part of the boat to manoeuvre within, because plans show a complex hanger system that supported the torpedo reloads and a bridge that led to the back of the boat. Presuming the torpedo space could be safely traversed, the midships petty officer's mess and workshop would be investigated. This would bring the ROV to the aft bulkhead. A number of the crew's diaries state that the door leading to the engine room is dogged shut. Thus it was of particular interest to investigate whether the aft half of the boat could be accessed.

The main objectives for this part of the operation were to locate and identify as much of the "fabric" of the boat as possible. This included installed machinery and fixtures, any equipment (instruments, tools etc.) that may be scattered throughout the boat, plus personal effects of crew members. It was hoped that the survey, combined with the results from the pole camera survey, would enable the science team to:

1. Learn more about how a submarine was operated in the early twentieth century;
2. Provide an insight into what life was like for the crew of *AE2*, specifically during the final week of operations; and
3. Provide better understanding of the nature of the sinking of the boat.

Of particular interest to the team was to identify items or systems for which archival searches provided little or no information. Obvious items of interest were the wireless telegraphy set and the gyro compass.

2.1.4 Final Measurements

In order to gain a preliminary indication of the effectiveness of the cathodic protection system, post installation, it was proposed to take a further set of corrosion potential readings immediately prior to departure from the site. This would enable the corrosion team to check performance of the system against predictions.

Finally, if time permitted, it was proposed to record a final water property profile from inside the submarine. By making comparisons with the baseline data, this would give an indication of the impact of operations upon the internal environment.

2.2 Scientific Infrastructure

2.2.1 Development Strategy

A two-phase strategy was adopted for development of the scientific instrumentation to be used in MAA14. For each of the three primary systems – Drop Camera, Pole Camera and ROV – working prototypes were developed for evaluation in a trial undertaken at Corio Quay, Geelong in December 2013. This trial, supported by the RAN reserve dive team ANRDT6 and a full-size mock-up of the centre section of *AE2*, allowed the systems and proposed deployment procedures to be trialled in an environment that was as representative as could realistically be achieved. The lessons learnt from this trial (and there were many, both positive and negative) were used to guide final development of the systems. Thus, despite a very tight development schedule, the systems that were delivered to Turkey in May 2014 had achieved quite a reasonable state of maturity.

Where ever it was possible, the team made use of pre-existing technology. In most cases the development work that was undertaken was in the systems integration domain. Hence video cameras, sonar systems, LED light arrays, communications infrastructure, and underlying ROV technology were all commercial off the shelf (COTS). The actual packaging of these components into the various systems, however, was very much bespoke. Because of the unique nature of the physical environment and the known configuration of the submarine, there was no possibility of sourcing COTS systems that would meet the requirements of the mission. The following paragraphs describe the development work that the science team undertook. There was one important piece of infrastructure which was not so much "scientific" as "engineering", but it proved to be of critical importance to the success of the mission, so it is described.

2.2.2 Diver Support

There was a requirement for divers to provide support to most of the operational serials planned for MAA14. During the early stages of planning for the expedition it was the understanding of the science team that support divers would be surface-supplied and wearing weighted boots. Thus initial planning had been based around the assumed availability of divers who could spend quite long periods at depth. It was then found that the work duration for each dive would be limited to about 20 minutes, and that it would only be practical to undertake three dives on each day of operations. The consequence of this was that every effort had to be made to optimize the efficiency of the divers' work output.

As details became clear of the nature of the support that divers would be able to provide the expedition, several of the dive serials had to be re-thought. Thus considerable effort was devoted to refining equipment and operations so that all of the planned serials could still be accommodated. The decision was taken to design a Diver Support Platform (DSP), to be deployed onto the submarine, which would enhance the operational effectiveness of the divers by providing them with a general-purpose work platform.

2.2.3 Installation of a Diver Support Platform

Initial planning for the dive serials was based upon the understanding that divers would be weighted, hence a design concept needed to be developed to enable them to traverse the seabed from their service bell to the submarine, and then to ascend to the level of the conning tower. Again, because the divers would not be buoyant, it would also be necessary to provide them with a platform so that they could perform work at the level of the *AE2*'s bridge and periscope standards without impacting negatively upon her physical structure. While it was known from MAA07 that the hull was in relatively good condition, the structural condition of the conning tower itself was less well known. The decision was therefore taken to design a Diver Support Platform (DSP) which could be lowered to, and installed upon, the submarine via crane and would have the following features:

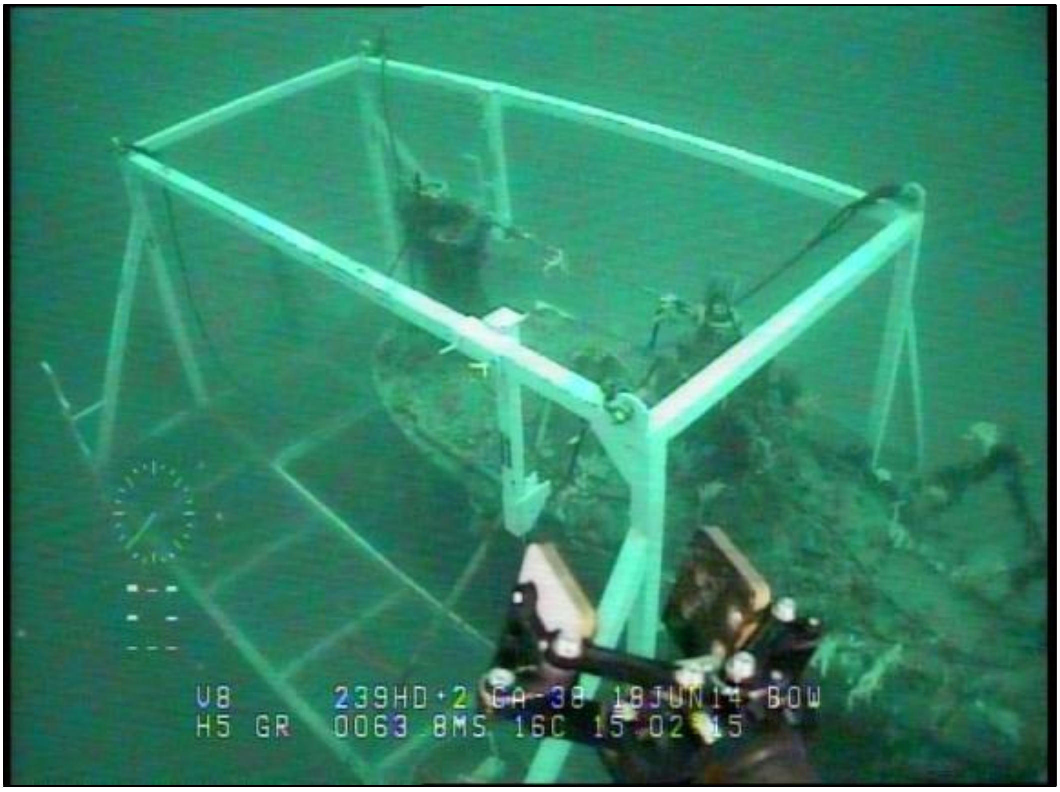
- The DSP would straddle the submarine, sitting upon the pressure hull on four pads, each of which would be sufficiently large to span at least two of the submarine's frames. The net pressure imparted upon the submarine via the pads would be less than 1000 kg per square metre;
- The DSP would have a horseshoe-shaped working platform, spanning the length of the conning tower on both sides and crossing its forward end. The platform would be designed so that divers standing upon it would have the top of the conning tower at approximately waist height;
- The DSP would facilitate attachment of support brackets, enabling instrumentation to be safely installed into the submarine and appropriately secured;
- Ladders would be incorporated into the DSP to facilitate divers transitioning from the seafloor to the working platform.

Quite late in the planning cycle it became apparent to the team that the divers, while surface-supplied, would in fact be buoyant. After discussions with the Turkish Company who were providing the diver support (Deep Offshore), it was decided to proceed with construction of the DSP as planned. While the need for a working deck and access ladders was somewhat reduced, in general the DSP design was judged to be quite serviceable - it would certainly facilitate installation and securing of scientific instrumentation – hence the platform was constructed as-designed. Figure 1 shows the DSP as it was being recovered from the water, complete with an old fishing net that had been fouled upon *AE2*. A pair of "hanging brackets" carried a cross-beam to which instrumentation could be secured. These brackets could be shifted fore-and-aft so that the crossbeam could be positioned as required relative to the submarine's hatch opening. The nominal height of the crossbeam was 400 mm above the upper deck of the conning tower (i.e. the submarine's "bridge"). Figure 2 is an ROV-derived image of the DSP in its deployed position upon the submarine.

Figure 1 - The DSP was recovered at the end of the Mission

(Note that the crossbeam which was used to support scientific equipment has been unshipped from its brackets and is strapped to the deck of the DSP.)

Figure 2 - Showing the DSP as deployed upon the Submarine



2.2.4 Drop Camera System

The primary driver for development of the Drop Camera system (when things were going well, fondly described as the "Drop Cam") was that it must be mounted inside a housing that would be capable of being inserted through the opening formed by the partially-ajar upper conning tower hatch. Despite the fact that Australian's had dived upon the wreck in two previous expeditions, it was found that only representative estimates had been made of the height of this opening. The best estimate that could be made was that this was in the order of 12 cm. Hence the conservative decision was made to design the Drop Camera system around a maximum housing diameter of 100 mm, with the housing tapering to 95 mm at the two ends (to facilitate insertion through the non-uniform opening formed by the hatch), and a length overall of 260 mm.

In the first instance the option of building a 4K High-Definition camera into the housing was considered, but at the time (2013) no suitable camera could be sourced. Hence the decision was taken to base the camera system upon a Sony FCB-EH6500 High Definition camera. This camera promised good low-light performance, plus could be remotely controlled via a VISCA digital interface.

The experience of MAA07 (3) had been that it was advisable to separate the source of illumination as far as possible from the camera, as co-locating camera and light source causes bad "flaring" due to specular reflection from suspended matter in the water, as can be seen in Figure 3. Hence it was decided to build luminance-controllable, LED lighting modules that would be mounted approximately 450 mm above and below the centreline of the camera. Providing two lighting modules had the twin benefits of:

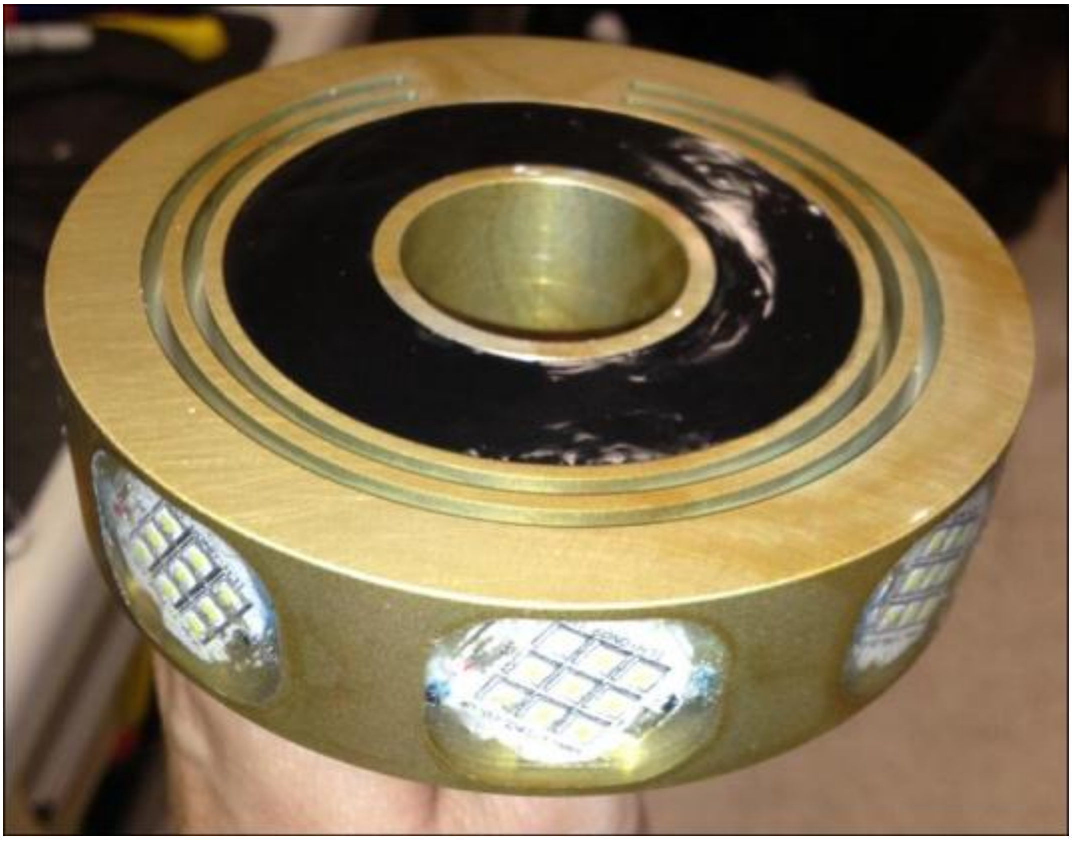
1. Promising uniform, whole-of-volume illumination; and
2. Providing separation and redundancy to reduce the probability of loss of all light in the case of equipment failure.

Each lighting module comprised five separate, ultra white (6,500 K colour temperature) LED arrays arranged at 45 degree intervals. Figure 4 shows the individual LED arrays mounted into one of the lighting modules. Power rating, per array, was 30 watts with light output of 3,200 lumens, yielding total power output across the two modules of 300 watts. The light output of each individual LED unit could be individually controlled from the surface to allow the operator to optimise the imagery produced by the camera system.

Figure 3 - An Image recorded from the MK 1 Drop Camera used during MAA07, showing the Conning Tower Telegraph at Right.

(Note the flare on the image is a result of having the light source virtually co-located with the camera.)

Figure 4 - One of the Lighting Modules showing three of its five LED Arrays



It was necessary to provide a means for the Sonde unit to be inserted into the submarine as part of the Drop Camera system. This unit was approximately 600 mm long, and due to the requirement to sample as much as possible of the water column inside the boat, it would be inserted first. Clearly it would not be possible to mount the Sonde, lower lighting module, camera housing and upper lighting module onto a rigid pole, as it would be impossible to pass them through the opening formed by the upper hatch cover. It was not an option to separate these various elements via a fully-flexible coupling such as a rope or chain, because it was a requirement that the system be capable of being trained in a controllable manner, both up and down, and through 360 degrees. The solution was to use a coupling system that was flexible along the length of the system (although relatively incompressible in length), but rotationally inflexible around the central axis. An additional complexity was that an arrangement had to be made to enable the system to be lowered vertically from a point directly above the centre of the lower hatch. Finally, an arrangement had to be made to enable a diver to both raise and lower the system inside the submarine and rotate the rig in a controlled manner.

Figure 5 - The Drop Camera System in Final Form

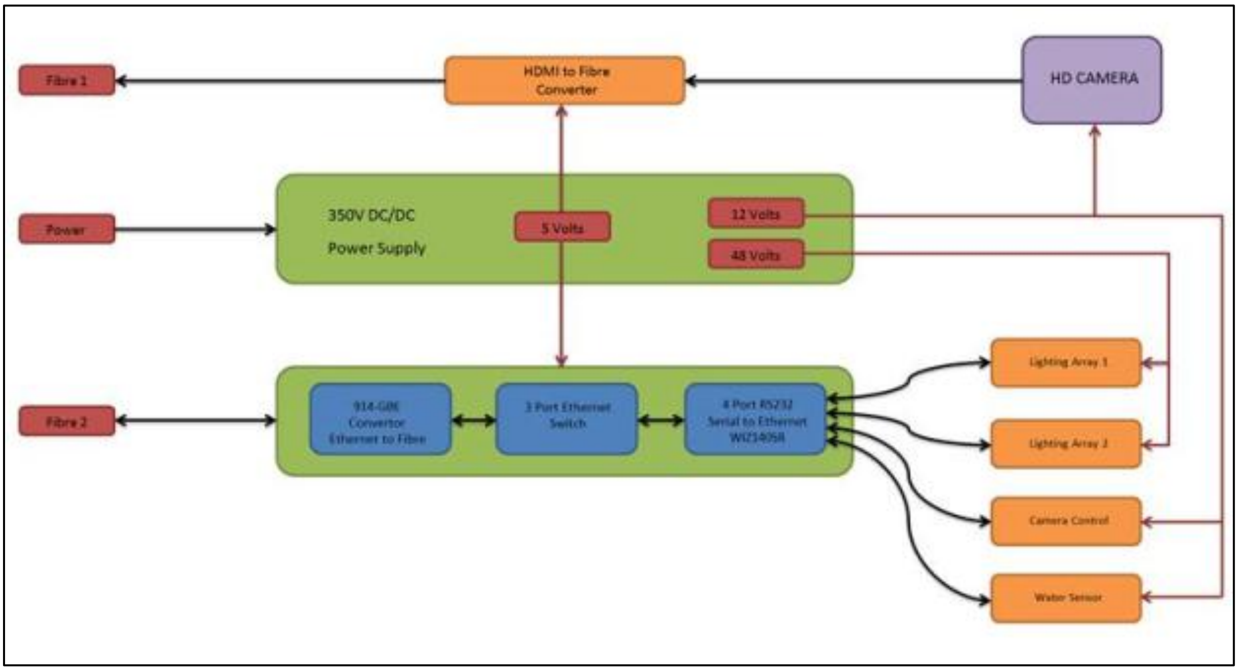
Figure 6 - Illustrating the manner in which the Data Umbilical was fed through to the Camera Module

Figure 5 shows a number of the important features of the camera system. The black and blue cylinder is the Sonde instrument, which was planned to be inserted into the submarine first. Immediately above the Sonde is the lower lighting array. Three of the five, high-intensity LED arrays are visible. The along-axis flexibility of the black, corrugated hose is apparent. This material was relatively resistant to twisting, so it enabled the lighting array to rotate in alignment with the camera module. It also protected the internal cabling that interconnected the camera and lighting modules, as shown in Figure 6. The camera module was next, followed by another flexible section and the upper lighting module. The upper module was hard-mounted to the stiff steel spring, which in turn passed through the grey elbow section evident at the right of Figure 5. Once the camera system was installed through the upper hatch, the concept was for the yellow wedge to secure the elbow section into the hatch opening, such that the camera system was centred over the top of the lower hatch. A simple clamping arrangement was developed to grip the spring immediately adjacent to outer end of the elbow – essentially a modified "vice grip" tool. This had the dual functions of setting the depth at which the camera was deployed and enabling the diver to rotate the rig around a vertical axis. It will be seen in Figure 6 that the spring was marked at 300 mm intervals using the simple expedient of "gaffer" tape. The concept of operations, which proved very effective, was for the diver to be instructed to lower or raise the camera by so many intervals and then secure the camera at depth using the clamp.

2.2.4.1 Electronics, Communications & Video Capture Configuration of the Drop Camera

Figure 7 is a block diagram of the functional configuration of the Drop Camera system. The data umbilical (the green cable visible in Figure 6) carried power via copper wires and data via two optical fibres. Power was supplied to the camera module via a 350 volt DC surface power supply. This was stepped down to 5, 12 and 48 volt internal supplies inside the camera module. The video output from the HD camera was transmitted up one optical fibre, Fibre 1, having been converted from LVDS format by a unit that resided inside the camera housing. System communications were provided via Fibre 2 for control of the various instrumentation units within the system. It should be noted that Figure 7 indicates the water sensor, the YSI Sonde device, as being remotely controlled. In the event, despite what was stated in product documentation, the YSI control software did not work "straight out of the box". Given the very tight timelines associated with this project, and the number of competing demands upon staff member's time, it was decided to simply operate the Sonde via an external "set and forget" interface, i.e. data sampling was initiated immediately prior to deployment of the system and sampling took place continuously until the data upload was initiated after the equipment was recovered from the water.

Figure 7 - Functional Diagram for the Drop Camera System



2.2.5 Pole Camera System

The Pole Camera system ("Pole Cam") was designed to be deployed into *AE2* once the upper hatch had been opened. The camera system and lighting modules formed the core of the pole camera system, but it was heavily reconfigured. Two obvious changes, visible in Figure 8, were that an ARIS 3000 sonar was inserted between the camera and the lower lighting module and that the whole system was reconfigured inside a faired housing and rigidly attached to a pole. The fairing was designed to: enhance rigidity; protect the instrumentation if the system touched part of the submarine while it was being lowered and/or rotated; and being constructed of buoyant Isofloat®[2] material, reduce the apparent weight of the system in water. Referring to Figure 8 it can be seen that the system still carried lighting arrays top and bottom, the black object is the ARIS sonar, the camera module is protected by the aluminum fairing section and at the very top of the image is a "camlock" fitting that allowed the rig to be attached securely to a length of aluminum scaffolding pipe.

Figure 8 - Two Views of the Instrumentation Pod for the Pole Camera System

The ARIS sonar is an imaging sonar, which operates at very high frequency, hence yielding high-resolution, two-dimensional images at typical ranges in the order of 1-5 metres. It is described in further detail in Section 2.2.7. The sonar was mounted 300 mm below the camera system and a rig was designed to enable the system to be lowered into the submarine, through the opened upper hatch, at 300 mm intervals and then rotated through 360 degrees at each depth step. The concept of operations was based upon the fact that the sonar sweep taken at step ***n*** would correspond in depth to the video sweep recorded at step ***n+1***. The plan was to extract range information from the sonar imagery, hence building an "as-built" wireframe model of *AE2*'s conning tower and control room. The video imagery could then be draped over the wire frame model, providing a visually-realistic representation of these parts of the boat which could be "flown through" at will by third-party observers.

One significant challenge in designing this rig was to make an arrangement that would enable a single diver to quickly work through a sequence of operations involving:

1. Orienting the rig in a particular direction relative to the longitudinal axis of the boat;
2. Rotating the rig through 360 degrees; and
3. Lowering the rig 300 mm to the next depth step.

Because it is always sensible to assume visibility will be poor (from the diver's standpoint), the aim was to develop a system that could essentially be operated by "feel".

In addition to the above requirement, it was desirable to have the ability to adapt the system so that, during the ROV Operations phase, the Pole Cam could be installed inside the submarine at a fixed depth, and then rotated around a vertical axis from the surface via remote control. A search for a suitable automatic or manual off-the-shelf system to meet either or both of these requirements was unsuccessful; therefore, a bespoke system was developed.

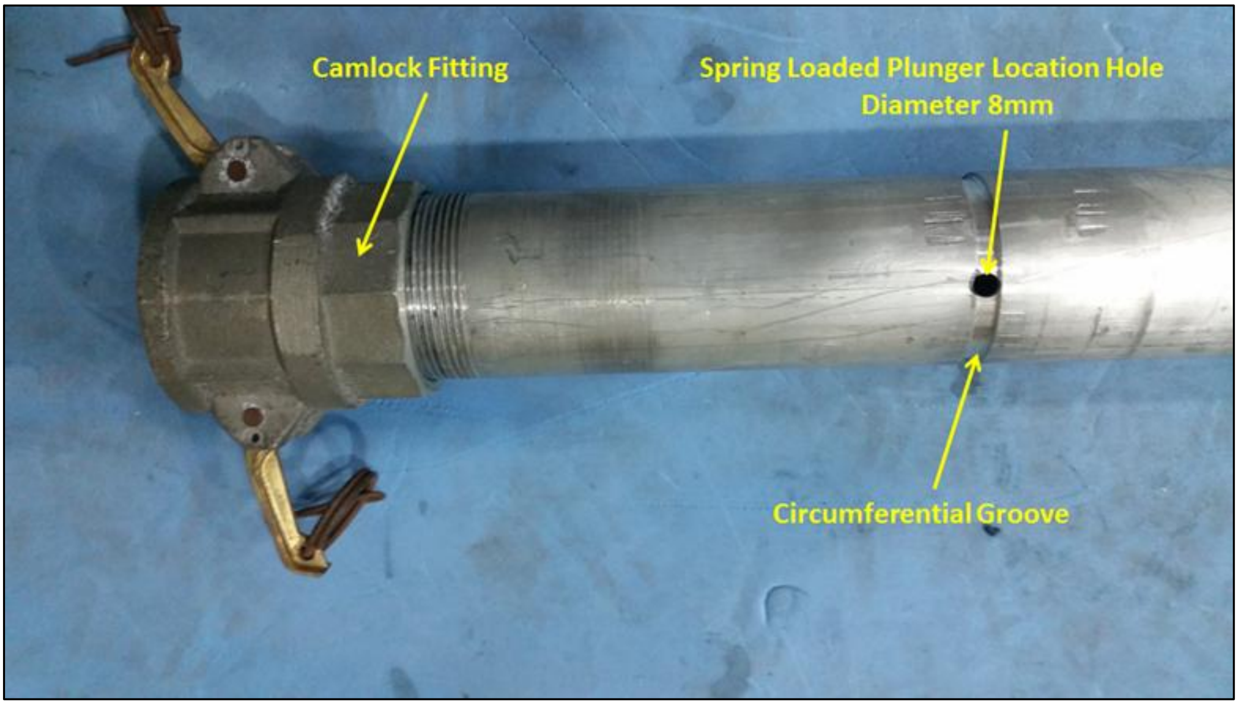
2 Isofloat® is a registered product of Ron Allum Deep Sea Systems.

2.2.5.1 The Pole Cam System Configured to be operated by Diver

In order to facilitate deployment and operation of the pole camera by "feel", the diver required a perceptible confirmation that each one of the three operational steps (orient; rotate; lower) had been successfully achieved. Fortuitously, the aluminum scaffolding pipe attached by camlock fitting to the pole camera system, described earlier, provided the ideal basis for the development of the diver operated rotation system.

Circumferential grooves to a depth of 2 mm and width of 6.5 mm were machined into the aluminum pipe at 300 mm centres over the length of the pole. A line was scribed along the length of the pole and where the scribed line intersected the centre of a groove an 8 mm hole was drilled through the full wall thickness, as shown in Figure 9.

Figure 9 - Aluminium Scaffolding Pipe machined groove and 8 mm locating hole



A thick sleeve section was machined from aluminum. The sleeve had sufficient clearance to slide easily along the aluminum pipe. The aluminum sleeve was also machined to accept 4 handles and a hand-retractable, spring loaded plunger. The spring loaded plunger provided a simple but robust mechanism to capture/release the pole camera system at predetermined intervals of 300 mm and, once the plunger was engaged in the locating hole, it acted as a reference for orientation. With the pole camera system now captured in the vertical direction the diver could align the pole camera system to the predetermined longitudinal axis of the submarine. To achieve alignment the diver rotated the pole until the plunger engaged with the 8 mm hole coupling the sleeve and pole camera system together.

Coupling the sleeve and pole camera system enabled the diver to perform a controlled simple rotation of the entire system through 360° using the handles. The preferred rotational speed would be relayed to the diver via verbal feedback from ship control room.

The sleeve was supported on a section of ultra-high-molecular-weight polyethylene (UHMWPE) material attached to the support bracket to provide a contact surface of very low surface friction between the sleeve and bracket enabling ease of rotation for the diver. Figure 10 below shows the Diver Operated Pole Cam Rotation System and UHMWPE support bracket.

Figure 10 - Diver Operated Pole Cam Rotation System

The rotation system also provided a safeguard against damage to the camera and sonar system should a diver inadvertently lose grip of the wet aluminum pole during a lowering sequence because the spring loaded plunger would catch in the next groove and quickly arrest the fall of the pole camera system.

2.2.5.2 The Pole Cam System Configured to be controlled from the Surface

While it had been anticipated as being a matter of importance, the need for careful management of the ROV tether when operating inside the pressure hull or conning tower was highlighted during ROV operations inside the *AE2* replica sections, undertaken as part of the MRTE13[3] exercise in Corio Quay, Victoria during December 2013.

During the period that DSTO's ROV was inserted and operated in the control room of the *AE2* replica the tether became fouled. Prior to the deployment of the ROV a diver, positioned in the control room, operated a hand held SplashCam®[4] camera to monitor the progress of the ROV insertion procedure into, and transits within, the control room. The SplashCam vision showed that the tether was fouled on the handle of the forward mock periscope. Even though water clarity in Corio Quay was acceptable for ROV operations, due to the constraints imposed by the environment (i.e. the cluttered and confined nature of the control room mock-up), the ROV pilot had great difficulty in freeing the tether from the obstruction. Although it was accepted that in this and most other foreseeable cases an experienced ROV pilot would have the skills to free the tether and continue the survey, given the time constraints of this exercise the ROV was released by a diver.

It was decided to investigate the possibility of deploying a separate camera into the control room to monitor the progress of the ROV and tether once inside the *AE2* pressure hull. The basic operational parameters for the ROV tether monitoring camera were:

3 MRTE13 – AE2 Mission Rehearsal and Training Exercise 2013.
4 SplashCam® Marine Video product of Ocean Systems Inc.

- Diver insertion from the DSP of an independent HD/SD camera system 0.9 m below the lower hatch and adjacent to the control room ladder.
- Minimal placement and setup time by a diver on the DSP was an imperative.
- 360º horizontal rotation.
- Separate surface to camera control tether undesirable.
- Variable rotation speed to provide stable imagery.
- Tether protection from the eel if left in the conning tower and pressure hull for an extended period of time.

A search for a suitable automatic or manual off-the-shelf camera system to meet the unique operational objectives listed above was unsuccessful; therefore a bespoke system would be required. It was determined that the Pole Cam system could be adapted to fulfil this role.

The Pole Cam system was designed so that it could be easily reconfigured on the deck of the support ship, enabling it to be attached via a camlock fitting to an alternative aluminum pole which was mated with an electrically-powered, surface controlled rotation unit. Figure 11 shows the final setup of the surface controlled camera rotation system. The system was comprised of 2 adjustable radial bearings, a DC drive motor and splined pulley system with tension adjustment. The DC motor was powered and operated via a short tether "piggy-backing" off the ROV tether management unit located on top of the ROV pole assembly. Each pole mounted system could be controlled from the surface by one person operating a single joystick, thereby eliminating the need for an additional tether from the surface. After testing the system was deemed to meet all critical design parameters.

Figure 11 - Surface Controlled Pole Camera Rotation System

2.2.5.3 Articulated Mounting System

The submarine is known to have a list of approximately 3° and it is also bow down. In an attempt to compensate for the list and any potential misalignment of the DSP relative to the submarine's two access hatches, it was determined that a method to adjust the insertion orientation of the Pole Cam system (in both diver-operated and surface controlled forms) would be advantageous. It was also agreed that, for the sake of simplicity and reliability, the best option would be for a diver to undertake any rotation and/or linear adjustments when either system was attached to the DSP crossbeam. Proper alignment of the pole systems would assist the diver as he manually "threaded" the poles though upper and lower submarine hatches. This served the primary purpose of enabling safe, uncomplicated and robust pole insertion and removal at depth , while delivering an important, though secondary benefit of minimising the time required to undertake these operations.

The geometry that would apply to the implemented alignment system was multi-dimensional. There may be requirement to make adjustments around at least two axes of rotation (along-ship, and across-ship) and also to make positional adjustments in these directions. A review of commercially available components that may facilitate rotational alignments indicated that the most precisely-controllable, COTS component was limited to rotational incremental steps of 10°. The distance from the DSP crossbeam to the lower control room hatch was planned to be 3.1 m. Therefore, rotation of the pole around either along-ship or across-ship axis by 10° would translate to a horizontal shift of the pole at the lower hatch of approximately 0.55 m (neglecting the vertical translation). The lower hatch diameter is only 0.584 m; hence coarse corrections of 10° would not provide sufficient control to ensure the pole camera/ROV systems would enter the lower hatch without significant difficulty.

In order to provide an articulation system that provided more precise rotation about each axis, a simple articulation system consisting of telescoping stainless steel tubing with lock/release threaded sections was developed. The articulation system provided unrestricted rotation about any axis, as well as limited linear movement in any direction. Two articulation systems were fabricated, one for the pole camera and a second system for ROV insertion tasks.

During dive rehearsals in Tuzla, Turkey the divers requested that each tubular rotational component of the articulation system be colour coded to distinguish which tubular section represented an axis of rotation. Figure 12 below shows an articulation system close up (not colour coded – the blue clamp was not part of the final rig) and Figure 13 depicts the colour coding of articulated components.

Figure 12 - Pole System Diver Operated Articulation System

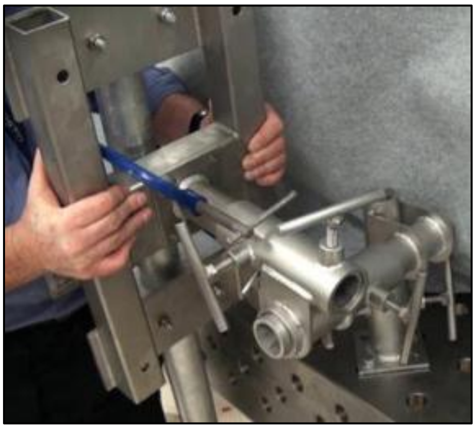
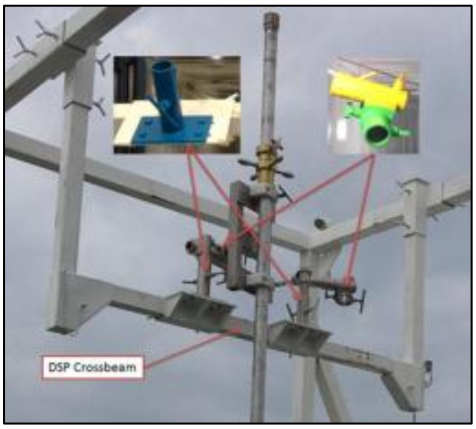


Figure 13 - Dual articulated pole articulation system installed on the DSP crossbeam. (Insets - Colour coded articulation components)



2.2.6 ROV Systems

There were two significant challenges to address in developing the concept of operations for the internal ROV investigation.

The first challenge was to source a remotely operated vehicle which would fit inside the submarine, and yet which could carry the desired suite of sensors. Specifically, it was highly desirable for the ROV to carry a good quality, high definition video camera system, lighting modules which were reasonably well separated from the camera and, if possible, an ARIS 3000 sonar. This determined that the ROV would not be particularly small. The ROV company SeaBotix had a vehicle, the vLBV, which had the required capabilities, but unfortunately was slightly too large to fit through the *AE2*'s hatch openings. The company offered to reconfigure a vehicle, to make its maximum diagonal less than the specified, 23 inch clear opening of the hatches. The vehicle was configured with its umbilical deployed from the top surface, which would facilitate the vehicle being inserted into the submarine in its normal, operational orientation. Because the reconfigured vLBV would effectively be operating with a short umbilical, as explained in the next paragraph, it could be fitted with low-power thrusters, calibrated for precise control by the pilot. This was expected to reduce the amount of turbulence generated by the vehicle, and hence the amount of debris which would be thrown up by the vehicle as it manoeuvred throughout the interior of the submarine.

Figure 14 - The Modified vLBV with High Definition Camera & ARIS Sonar Deployed

The second challenge was to develop a deployment concept that would enable the umbilical to be passed through the two hatches and down to a point well down in the control room, in a way that would reduce the probability of it becoming fouled. The concept that was ultimately adopted was to mount a small, surface-controllable, "tractor feed" system at the top of a six metre length of aluminum scaffolding pipe, and to place a trumpet-shaped outlet (hereafter called the Trumpet) at the bottom of the pipe. This outlet was machined out of UHMWPE, which has the desirable characteristic of becoming "slippery" when immersed in water. Figure 15 shows the tractor feed system mounted at the top of the insertion pole, and Figure 16 shows the vehicle mated with the Trumpet.

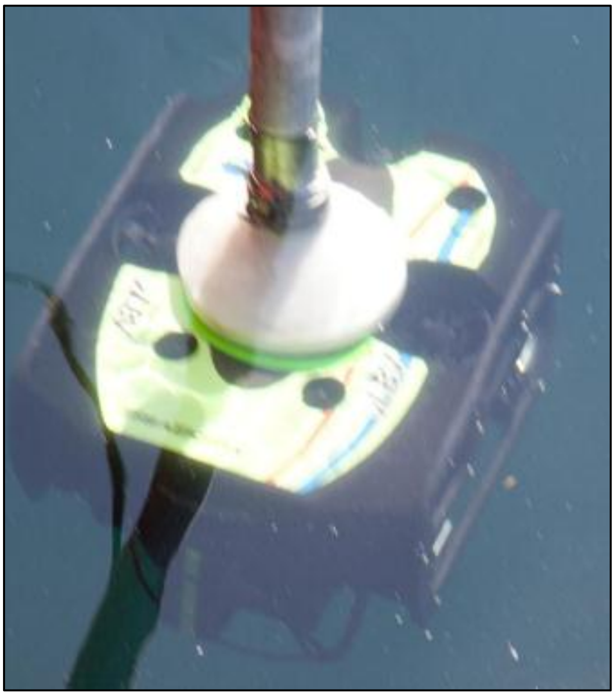
The tractor feed system was a very important part of the experimental set-up. The effect of environmental conditions in the Sea of Marmara (including its characteristic, cross current flow structure), ship motion due to prevailing weather conditions, along with the normal drag on a relatively long ROV tether, deployed from the surface to the submarine 73 m below, had the potential to adversely affect the performance of the ROV. This could impact negatively upon the quality of images recorded within the pressure hull and conning tower and it would certainly impact upon the ability of the ROV to manoeuvre safely inside the submarine. As tether drag force increases an ROV pilot must increase thruster power to compensate. Increased propulsion power equates to increased prop-wash, with the likelihood of significantly increasing sediment disturbance, particularly in a closed environment such as the *AE2* submarine hull.

In order to compensate for these environmental and operational conditions, the ROV was de-coupled from the exposed tether extending from the exterior of the submarine back to the surface by integrating a remotely operated tether tractor feed, supplied by SeaBotix. The tractor feed was attached to the ROV pole system using a simple camlock fitting. Working under instruction from the ROV pilot, a second person operated the tether management system using a joystick to slowly feed out or retract the trailing ROV tether as required. The de-coupled system proved very successful in coordinating ROV transits within the pressure hull.

Figure 15 - The Tractor Feed System Mounted at the Top of the ROV Insertion Pole

(Note there is a UHMWPE Trumpet at the top of the pole to control the bend radius of the umbilical as it leads up to the surface)

Figure 16 - The vLBV ROV Mated with the Lower Trumpet



The concept was for the ROV to be mated to this pole system while it was being inserted into the submarine, and thereafter for the pole to be clamped into position for the full duration of the mission. This approach had a number of benefits:

1. It limited the effective length of the deployed umbilical to the length of the pole plus the maximum range traversed within the submarine – anticipated to be about 30 metres maximum;
2. The Trumpet at the base of the pole provided 360 degree fly-off angle for the ROV, complying with the minimum bend radius requirement for the umbilical and without any need to use moving parts;
3. Because there was a rigid pole between the tractor feed and the Trumpet, the former could be used to supplement the ROV's thrusters during recovery manoeuvres;
4. The ROV could be recovered to the Trumpet and parked there; and
5. While the ROV was mated with the Trumpet, the umbilical was fully protected by the scaffolding pipe.

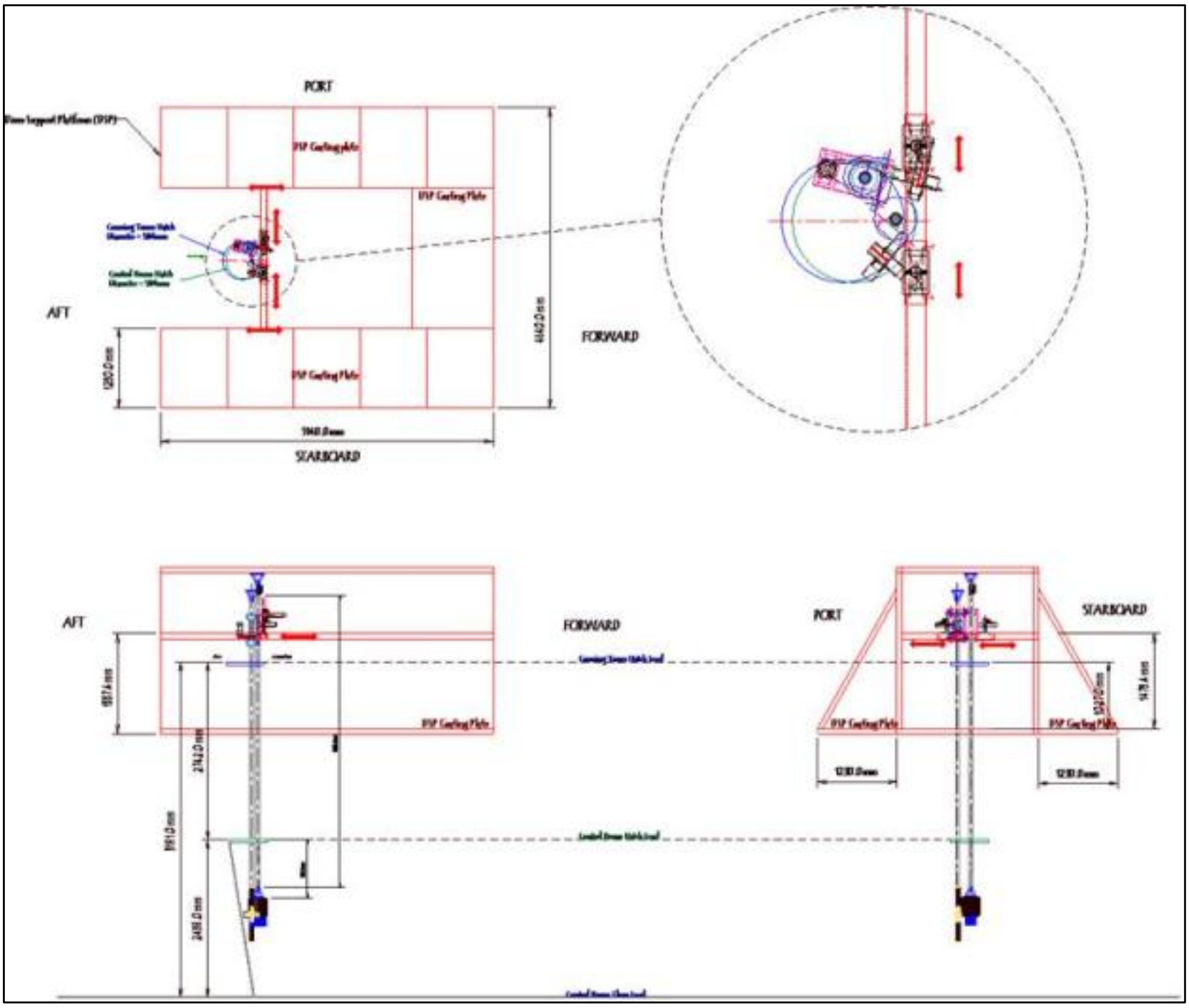
The desirability of being able to park the ROV stems from the fact the team could not sustain 24 hour operations, and hence it was planned to leave the vehicle inside the submarine overnight. During MAA07 it was found necessary to leave the MK 1 Drop Camera inside the submarine for several hours while dive teams changed over. During this time the resident eel spent some time investigating the camera's umbilical – with its teeth! For MAA14, while the vLBV was regarded as being relatively eel-resistant, an unprotected umbilical would have been very vulnerable.

Figure 17 - The vLBV Vehicle is being lowered ready for insertion into the Submarine

(A couple of other points of note in the photograph are the float at upper left, which was part of the four-point mooring system, and the pole at right which supported the hydrophone of the ultra-short baseline acoustic navigation system).

Figure 17 shows the ROV mated with the insertion pole system and Figure 18 is a sketch showing how it was planned to deploy the ROV inside the submarine. It will be seen that the sketch shows the Pole Cam and the ROV insertion pole both installed into the submarine. Because of the known, high density of machinery and instrumentation in the proposed ROV fly-off point, it was judged that the umbilical would be particularly vulnerable to fouling in this vicinity. The proposal was that the Pole Cam, complete with the remotely-controllable training mechanism (described in Section 2.2.5.2 of this report), be used to monitor the tether, thus hopefully assisting the ROV pilots in case a fouling incident occurred. In the event, time pressures prevented the Pole Cam from being deployed into the submarine for this purpose. While the ROV survived the mission, this would definitely have been a useful capability to have.

Figure 18 - Illustrating the proposed disposition of ROV Support Pole & the Pole Cam when simultaneously deployed into the Submarine



2.2.7 ARIS 3000 Sonar

The ARIS 3000 sonar is an "Identification" class sonar which operates at a relatively high frequency of 3 MHz. As a result of the high operating frequency, the resolution or ability of the sonar to "see" small objects is high. The resolution of the ARIS 3000 is 3 mm at a range of approximately 0.7 m and 22 mm at a range of 5 m. Given that the *AE2* is less than 8 m in diameter the majority of the submarine could be imaged to a resolution of better than 20 mm.

Figure 19 - The ARIS 3000 Sonar uses an Acoustic Lens to Facilitate Beam-Forming

The ARIS sonar was selected to fulfil two purposes. The first and main reason, described in Section 2.1.2, was to use its high resolution return in conjunction with other sensors and information, to develop a three dimensional point cloud of the interior of the submarine. Once this point cloud was captured, the high resolution video image would be able to be placed over it, giving a pseudo 3 dimensional mosaic of the interior of the submarine. The second purpose was to aid in navigation of the ROV inside the submarine if there was excessive silt or debris disturbance due to the use of the ROV thrusters. The sonar would enable the ROV pilot to navigate from a position inside the submarine back to the "docking station" in the control room.

2.2.8 Data Recording Systems

There were a considerable number of data feeds associated with this mission, most of which entailed generation in one form or another of video imagery. Even though the source of illumination is acoustic, even the output of the ARIS sonar is essentially a form of video imagery (although it was stored in a proprietary format). In essence, the Sonde was the only instrument whose data differed from this norm. For the Sonde, data was recorded directly on board the instrument. Upon recovery from the water, data was transferred to computer and proprietary data extraction software was used.

In addition to the ARIS, at various times during the mission, live video feeds were provided from the following sources:

- A vLBV ROV. There were actually two vLBVs available, one full-size unit (used for operations undertaken outside the submarine) and the modified unit. These vehicles carried up to three cameras, although only two could be used at any time. There were a pair of standard definition cameras – one mounted looking forward and one looking aft. The video feed from these cameras was internally switchable, so only one at a time could be used. The high definition camera had a dedicated feed, transmitted via a dedicated optical fibre.
- The Drop Camera. This was a high definition signal, transmitted via fibre optic tether.
- Diver's Helmet Camera. The divers' helmets carried an integrated camera. These were standard definition resolution cameras, transmitting a composite video signal via copper cable.
- The DSTO LBV remotely operated vehicle. This was a standard definition video signal, transmitted via a dedicated line in the LBV's umbilical.
- The MK 1 (2007) Drop Camera. This transmitted a standard definition, composite video signal.
- A downwards-looking camera was also intended to be mounted at the base of the Drop Camera system. The standard definition signal from this camera was intended to be multiplexed onto Fibre 2 of Figure 7. Unfortunately the camera interface proved to be unreliable in practice, and again due to the need to prioritise resource that could be devoted to fault-finding in the field, the camera was not used during the MAA.

The composite video signals were captured using DVD Maker USB 2.0 composite video to USB converter modules, interfaced with laptop computers. The ARIS sonar ran dedicated control and data capture software on a laptop computer. All other signals were captured by an Apple MACPRO computer, supported by a number of Blackmagic Design UltraStudio Multi-Configurable Video Capture units.

On board the ship, the primary data storage unit was a Drobo Data Storage System. To supplement this system, after each day of operations the day's data were duplicated and copied to a pair of external hard drives. One of these was returned to the shore headquarters and one was put in storage on the ship. Returning data to shore in this way had the twin benefits of securing the data and enabling the headquarters team to initiate processing of the data.

2.3 Detail of Planned Sequence of Operations

The plan of operations described below was based around 3 dives per day over a period of 15 days which included an allowance for inclement weather. The operational serials which were based around the ROV were not strictly dependent upon divers for support. In the case of ROV operations undertaken outside the submarine, no diver support was required. In the case of ROV operations undertaken inside the submarine, diver support was only required during insertion and extraction phases of the operation.

One of the first jobs undertaken after the support vessel was moored was to use a full-size vLBV ROV to undertake an exterior survey of *AE2*. This survey confirmed that the level of siltation around the submarine was similar to 2007, i.e. in the midships portions of *AE2* the conning tower, casing and some of the pressure hull was proud of the sediment. This meant that, with no need for diver intervention, it would be possible to use the ROV to guide the process of orienting the DSP preparatory to lowering it, the final couple of metres, into its working location. Once this task had been successfully undertaken, the DSP became part of the working infrastructure of the mission. While it will not be discussed further in this report, it fulfilled an important role - at various times items were clamped to it, strapped to it and stored upon it.

2.3.1 Drop Camera Operations and other Baseline Measurements

As was referred to above, one of the first tasks was to use a vLBV ROV to undertake a survey of the outside of the submarine and its surroundings. A series of sweeps were undertaken covering the full length of the submarine on both port and starboard sides, starting at seabed level and then progressively working upwards until the whole boat had been surveyed. These data were specifically recorded to enable direct comparisons to be made with the 2007 (and other available) survey data. The data were also reviewed in situ to enable candidate locations to be identified for installation of the clamps for the cables leading to the cathodic protection anodes. Once sites had been identified, divers cleaned them of concretion and used a hand-held device to measure corrosion potentials at each location.

The final baselining activity, and the one of greatest relevance to this report, was for the divers to deploy the Drop Camera system and Sonde into the submarine. The arrangement was for the Drop Cam to be slung on a bracket attached to the dive bell, and then carried across to the submarine by the diver. Upon arrival at the submarine the Sonde would be inserted through the upper hatch, progressively followed by each of the other Drop Cam modules. Finally the elbow section would be slid through the gap, the light modules turned on so that the diver could determine that the unit was approximately centred on the lower hatch and the wedge inserted to lock the unit in place. Thereafter the camera was to be lowered by 300 mm depth intervals and rotated through 360 degrees at each step until the unit reached the deck of the control room (which incidentally formed the cover of the battery tank). While it was not specifically an intention to lower the Drop Cam until the Sonde unit entered the silt lying on the deck, the coupling between the lower light module and the Sonde was sufficiently flexible that it was not considered to be a particular risk to the system if this occurred. The original MAA schedule allowed ample time for a comprehensive Drop Cam survey to be undertaken, including fine tuning of the illumination provided by the LED modules.

2.3.2 Pole Cam

Subject to the divers being able to successfully open the upper hatch, the next planned sequence of operations was to introduce the Pole Cam into *AE2*. In several respects this was to be a repeat of the Drop Cam operations, but there were two important differences. The first was that the introduction of a solid mounting system and more controllable turning arrangement (the Diver Operated Pole Cam Rotation System described above) was anticipated to provide much higher quality imagery. The second was that the addition of the ARIS 3000 sonar should provide a much richer dataset.

The plan was for the Pole Cam to be lowered by the ship's crane, and guided by a diver into a bracket mounted on the DSP. Given that the bracketing system was designed to enable the position and orientation of the Pole Cam to be adjusted with a high level of fidelity, as described in Section 2.2.5, the plan was to make reasonable time allowance for the diver to align the Pole Cam on with the centre of the lower hatch. Given that the upper hatch would be open, by locking the Pole Cam in a mid-pole position and turning on the light modules, the diver would be able to centre the system with quite high precision.

Once the Pole Cam was in place and the brackets secured, the system would be returned to the highest position, and the "align, rotate, lower" sequence, referred to in Section 2.2.5, would begin. Based upon the experience of the December 2013 Corio Quay trials, it was anticipated this sequence could be completed in the dive serials.

2.3.3 *Internal, ROV-based Operations*

The program schedule was that the ROV-based investigation be undertaken as the final stage of the internal survey so that the knowledge gained during the Drop Cam and Pole Cam operations could be used in refining the survey strategy.

The proposed sequence of operations was that the vLBV, mated with the tractor feed system described in 2.4.4, be lowered to the submarine by the ship's crane. A diver would then insert the vehicle through the top hatch and, using the output of the ROV's own camera to inform his dive-master, he would lower the vehicle/pole rig under instruction to insert the vehicle through the lower hatch. The intention was to then secure the insertion pole at a position which placed the top of the ROV 900 mm below the underside of the lower hatchway and as far aft as could be achieved while maintaining clearance from the ladder. The next planned step was for the "automated" version of the Pole Cam to be installed. The aim here was for the camera unit to be as far forward and as high up as could be realistically be achieved, within the confines of the lower hatch opening. As described above, this system would be used to monitor the ROV tether in the vicinity of its departure from the lower Trumpet.

Once all support infrastructure was set up, the plan was for the ROV operations to be undertaken with no further support from the divers (until the recovery operation). The ROV would then survey the starboard side of the control room, moving progressively forward. The aim was to do this in a series of stages, with the ROV moving forward a certain distance, undertaking the survey and then returning to the Trumpet. This sequence would be repeated as often as required to cover the control room, with the ROV moving slightly further forward each time. The logic that underlay this concept was that, as ROV's manoeuvre around objects and obstacles; it is very difficult to maintain full control of the trailing tether. By periodically returning to the starting point, fully recovering the tether each time, the risk of snagging the ROV would be significantly reduced. The planned, full sequence of compartment surveys was:

1. Control room, starboard;
2. Control room, port;
3. Wardroom, starboard;
4. Wardroom, port;
5. Forward torpedo room (both sides);
6. Control room aft of entry ladder, in a single sweep moving from starboard to port;
7. Midships torpedo space, starboard;
8. Midships torpedo space, port; and
9. Finally the petty officers' mess.

It was anticipated that it would be impossible to enter the engine room, but of course if the door was found to be open, then this space would also be surveyed.

2.4 Proposed Analysis Methodology: Internal Video Imagery

In December 2012 DSTO used an ROV to undertake an internal survey of the 19th century monitor HMVS *Cerberus* (4). In many ways the *Cerberus* survey paralleled MAA14, because the cluttered nature of the interior of the ship[5] prevented the ROV from following a simple, predefined course. A logging system was therefore developed to help researchers, returning to the ROV's video imagery, to know where the vehicle was at different times throughout the mission, along with what was being seen by the vehicle's sensors. In essence the method involves working through the video imagery, identifying and recording snapshot images of appropriate "landmarks" or objects of interest and relating the position of the ROV, relative to these landmarks, at a particular time. The reader must understand that, using this method, the position of the ROV cannot be defined with great precision. Several factors contribute to this lack of precision. One is that the fluxgate compass in these vehicles does not give a reliable heading estimate when operating in such environments, so the vehicle heading has to be estimated by the pilot or analyst – in cases where visible range is limited, it would not be unusual for the estimated heading of the vehicle to differ from reality by up to 30 degrees or more. A second factor is that the camera's vertical orientation is variable and at times unknown. At times the need to record an unencumbered camera image overrode the ROV pilot's natural desire to have the vehicle status data displayed on screen (which includes camera angle and depth readouts but partially obscures the imagery), means that the vehicle's vertical dispossession relative to the landmark object may not be

5 In the case of *Cerberus* the clutter was substantially a consequence of the collapse of the lower hull, not the presence of obstructions caused by intact ship's equipment, as occurred with *AE2*.

precisely known. Despite these caveats, the logging system described below has proven to be quite effective[6].

2.4.1 Details of Data Logging for Video Imagery

An Excel spreadsheet was established which effectively logs the ROV's course through the submarine and records objects of interest discovered along the way. Each row of the spreadsheet represents a time-and-position record for the vehicle. The information that was recorded for each row took the following form (columns delimited by semicolons):

Image Thumbnail; Image Filename; Video Filename; Day/Date; Time Code; ROV or Asset; Camera; Location (CT or Main Deck); Closest Frame; Side; Height; Camera Orientation About Vertical Axis; Camera Orientation About Horizontal Axis; Material of Interest (wood, brass, glass, etc.); General Description.

The following table provides a more detailed explanation of each data field:

Table 1 - Video Imagery Data Field Descriptions

Column Title	Description
Image Thumbnail	A thumbnail of a still image which was stored for each landmark or object of interest. These images were effectively a copy of a single video frame.
Image Filename	The filename of the still image extracted from the video stream.
Video Filename	The name of the video file recorded from a particular camera. The time of creation, recorded as part of the metadata for this file, effectively allows the video imagery to be related to absolute time.
Day/Date	Mission diaries generally referred to the day relative to the start of the mission (e.g. Day 8). This is a convenient shorthand reference to these diaries.
Time Code	Video imagery is generally referred to in the form: hours (0, 1, 2 etc.): minutes (0-59): seconds (0-59).Frame (either 0-24 or 0-29, depending on the framerate). This mission did not generally need to include frame numbers in the time codes.
ROV or Asset	The candidates for inclusion in this field were: vLBV, LBV (the DSTO vehicle), Drop Cam, or Pole Cam.
Camera	Various cameras were used on the various assets – candidates were HD (High Definition), SD (Standard Definition), GoPro (a strap-on, high definition camera), Drop Cam, or Pole Cam.
Location (CT or Main Deck)	The location of the ROV or camera was either conning tower (CT) or the main deck (which included control room, wardroom, forwards torpedo room, midships torpedo space, petty officers' mess and workshop.
Closest Frame	This is the frame number of *AE2*, which is estimated to be closest to the location of the camera. The frames were numbered from 1 at the stern to 99 at the bow. When the Drop Camera data are analysed this will be constant at frame 57.
Side	While the location of the ROV relative to the midline of the submarine could not be precisely defined, it could be estimated to be either midships (M), port (P) or starboard (S).
Height	As discussed above, the position of the ROV could not be precisely defined, so it was described in terms of position within the space currently being surveyed – High, Midway, Low. When the data for Drop Cam or Pole Cam are analysed it will be possible to define height in terms of absolute height above the deck level.
Camera Orientation About Vertical Axis	The estimated orientation of the camera relative to the ship's head. For example, if the camera is pointing directly to starboard the orientation will be G90 (meaning green, ninety degrees). A view looking in the direction of the port quarter would be P135.
Camera Orientation About Horizontal Axis	The estimated orientation of the camera relative to the horizontal. The angle is in degrees and the sign determines if the camera is pointing upwards (positive) or downwards (negative). Thus -30 means the camera is pointing thirty degrees down relative to the horizontal.

6 While it has not been done for this report, it would be possible to use the logging system described below to re-create the course followed by the ROV while inside the submarine. If a return visit is ever considered, this may help the survey team plan a route through the boat that will help avoid traps that cost the team considerable time and stress in the 2014 survey.

Column Title	Description
Material of Interest (wood, brass, glass etc.)	This field is fairly self-explanatory. Obviously some objects were made of many materials, but some could be quite simply categorized. This may be useful for future categorisation.
General Description	A "free text" field that enabled the analyst to provide as much detail as possible regarding the object of interest.

2.4.2 How Video Imagery was analysed

It was stated in Section 1.2 that, given the large volume of data that were gathered during MAA14 and the limitations on the human resource that could be devoted to analysis during the second half of 2014, it was not possible to undertake a full interpretation of all data. It was decided, therefore, to undertake a general review of the video imagery so that the team could develop a reasonable understanding of what had been achieved, and then follow up with more detailed analysis of subsamples of the data. A number of teams, typically comprising two people, were established to undertake scans of the data. One team focused its attention upon the conning tower. A second team concentrated upon the control room, and the two torpedo spaces. A third group reviewed the imagery recorded in the wardroom, and a final group analysed the ROV video imagery of *AE2*'s exterior.

Depending upon what support information was available, analyses took different forms. In some parts of the submarine there was very little prior knowledge of the layout or configuration of the space. In this case the analysis took the form of an "engineering interpretation". That is, an attempt was made to identify objects that were found and hence infer what their purpose may have been. Some parts of the conning tower fell into this category, as archival material regarding this part of the boat is very incomplete.

There were other cases where the video imagery confirmed that the "as built" configuration of the submarine was very similar or identical to what is shown on plans. In this case it was possible to base an interpretation upon quite a reasonable level of understanding of the system in question. An example, included below, is an interpretation of the training system for the periscopes.

Finally, there were cases where information available on plans gave some idea of the likely layout of a compartment, but clearly the "as built" layout differed somewhat from what was expected. The wardroom fell within this category. In this case the analysis took the form of sketching the actual layout, attempting to attribute dimensions to what was found and then building a 3D computer model of the space. There were a number of secondary resources which could be drawn upon in this case:

- Known features, frames and machinery could be used to estimate boundaries;
- The arrangement plans and images of later E-class boats assisted in gauging dimensions (heights);
- In some cases standard imperial dimensions were available for screws and hardware for the fittings as well as other antique furniture parts;
- Second hand timber supply merchants proved to be a useful resource with regard to wood sizing;
- Timber type and finishes were selected based on other, contemporary ships and E-class images.

3. Results

As explained in the Introduction, this report is in no way presented as a full and final description of the outcomes of Project Silent Anzac's scientific program. It is anticipated that the material gathered during MAA14 will form the basis for ongoing analyses, by individuals other than the authors of this report, for some time to come. The results that are presented below are included to demonstrate analytical methodologies that may be applied to the data. Specific examples are used to illustrate the validity and utility of these methodologies. In addition, the report presents a detailed description of the events which took place during MAA14, and the steps that were taken to overcome challenges that arose. Finally, and perhaps a little unscientifically, the report presents some of the "real time" interpretations the team made of the video imagery as it was being recorded. It will be of interest to compare these interpretations with the formal conclusions drawn after full analyses have been completed.

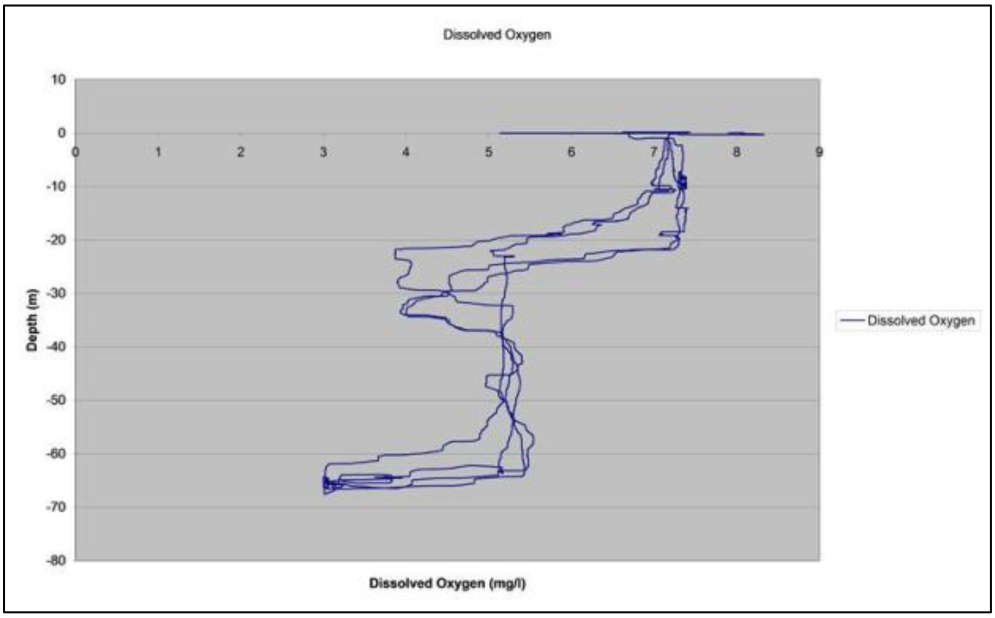
In the course of the expedition, a number of physical challenges and technical issues had to be addressed and overcome, as is described below. The Sea of Marmara is not a controlled laboratory and inevitably, in the process of meeting these challenges, modifications and compromises had to be made with regards to the scientific program. Indications from analyses undertaken to date, nevertheless, are that the majority of the scientific objectives of the expedition can be deemed to have been met.

3.1 Baseline Measurements

On-site analysis of the external visual survey undertaken by the ROV indicated that *AE2* was substantially unchanged relative to the 2007 survey, although in some places holes in the casing that were evident in the earlier survey had become considerably larger. In one or two places substantial areas of concretion appeared to have either been knocked off the boat or corrosion processes caused exfoliation of the corrosion layer. One example was a patch of bare metal at the stern. For the purposes of MAA14, the team concluded that the structural integrity of the pressure hull was unlikely to have altered significantly and hence that the DSP could be deployed onto the submarine.

The ROV carrying the YSI Sonde undertook two return excursions through the full height of the water column. As can be seen below, the dissolved oxygen profiles show good repeatability and the halocline, extending between approximately twenty and thirty metres depth, is very evident. The very significant reduction in measured dissolved oxygen levels as the instrument approached the seabed is of particular significance for the submarine in terms of its long-term wellbeing. Other measurements delivered by the instrument showed similar relative repeatability and were consistent with reasonable expectation for this environment. The AE2CF's corrosion expert, Dr Ian MacLeod, has prepared a detailed report interpreting these and other environmental and physical measurements recorded during MAA14 (5).

Figure 20 - Dissolved Oxygen Profiles recorded external to *AE2* by a Sonde Device



Insertion of the Drop Cam proved to be more difficult than was initially anticipated. The 2007 drop camera (3), which had a diameter of 8.5 centimetres, was inserted into the submarine with no difficulties whatsoever. Divers at the time stated that there was approximately 3 centimetres clearance for that camera, so the decision was made to build the 2014 drop camera system around a maximum diameter of 10 centimetres. What was not known or reported by the divers at the time was that, just inside the hatch is a bulge in the casting, which would significantly impinge upon the hatch opening. Hence when an attempt was made to insert the system, while the Sonde and the first lighting module could be inserted into the opening, the camera simply would not fit. The only alternative was to send a diver down with a lever and attempt to force the opening slightly. The plan, which proved to be achievable, was to force the opening by the smallest amount needed to permit insertion of the camera, thus causing relatively minimal disturbance to the environment.

On the second attempt the system was successfully installed into the boat, with the Sonde being lowered to the level of the battery tank. The lighting modules proved very effective in providing uniform, soft light for the interior; hence excellent video imagery was able to be recorded. Figure 22 shows the first view of the control room's starboard side as the camera cleared one of the suspended, overhead trunks. The "smoky" appearance of the image is not an artefact. This is a realistic representation of what the water is like near the top of the control room. On this occasion the diver exhausted his time on the bottom so the system was left inside the submarine overnight.

Figure 21 - The Drop Cam successfully installed inside the Submarine

(The illumination provided by the LED lighting modules is evident.)

Figure 22 - The first view of Speed and Depth Gauges as the Drop Cam is lowered into the Control Room

On the next morning the plan was to take advantage of improved visibility inside the submarine (because material disturbed during the insertion process had settled out of the water) and undertake a further set of video sweeps with the drop camera. Unfortunately, shortly after commencing the sweep, a leak in one of the lighting modules caused the system to protect itself by powering down, so the evolution was aborted and the system was recovered. Nevertheless, the system had shown that the interior of *AE2* was relatively unencumbered, and apparently in excellent condition. There was therefore excellent justification for proceeding with the other planned experimental serials.

The YSI instrument had been collecting data overnight, resulting in a very large data file being stored on board the instrument. These data have proven to be very valuable, as described by MacLeod (5).

3.2 Measurements Involving Minimal Disturbance to the Submarine

A series of corrosion potential measurements were taken in the vicinity of the conning tower. To make these measurements, concretion needed to be cleared from a small area of each test site. The results, interpreted in detail by MacLeod (5) showed good consistency with the measurements taken in 2007. For example, two readings taken from the conning tower in the vicinity of the upper hatch were -0.630 and -0.633 volts respectively. The 2007 average corrosion potential, recorded from different locations on the boat, was -0.619 volts. This was interpreted as being indicative that *AE2* has good electrical continuity, and hence that it was indeed a good candidate for protection using a cathodic corrosion inhibition system. The external survey was used to confirm that the initially-suggested sites for attaching the anode arrays were potentially viable. These sites were:

- The leading edge of the portside, Aft plane guard;
- The aft periscope standard; and
- A web on the capstan.

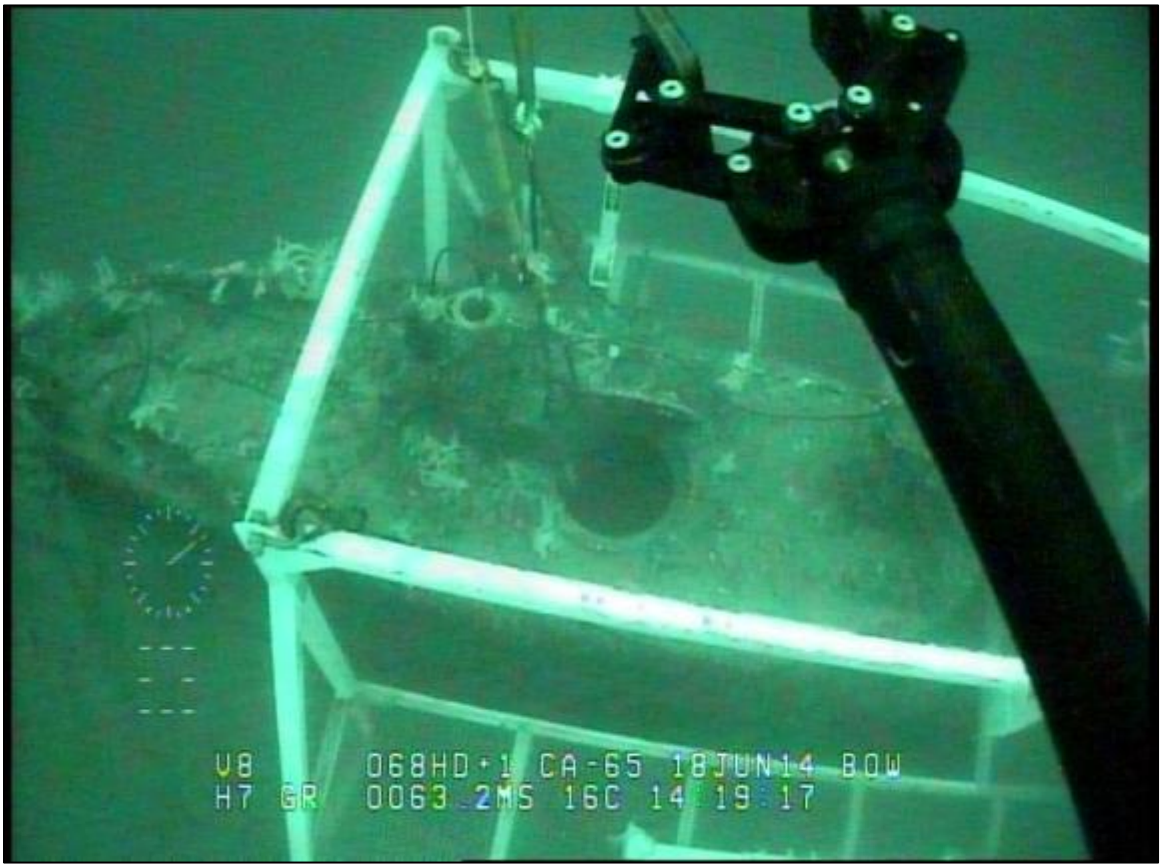
The next step was to clean concretion from these candidate sites and to visually confirm they could have the anode clamps secured to them. The cleaning and inspection was successful and the cables leading to the anode arrays were subsequently secured to these locations.

After successful opening of the upper hatch, the plan was to insert the Pole Camera system. During the course of the "set to work" of the system after it had been reconfigured from Drop Cam to Pole Cam configuration, it proved impossible to get the ARIS sonar to communicate with the rest of the system. Diagnostic procedures revealed that the interconnect cable between sonar and the Ethernet connector inside the camera module had been wired in a way which was incompatible with the sonar. This required rewiring and repotting the cable connector, which would delay the operation by at least 36 hours. Hence it was decided to hold this operation over until the end of the survey. In the event, time pressures prevented the Pole Cam operation from being undertaken in its planned form, but a considerably "cut down" form of experiment was undertaken on the last operational day of the survey. This is described in Section 3.4.

Regardless of whether the Pole Cam was to be deployed or not, the hatch had to be opened to allow insertion of the ROV. The divers configured a long-travel, mechanical screw jack so that its baseplate could rest on the hatch "coaming"[7] and a modified runner inserted under the hatch lid. This proved very successful in opening the hatch, but as the hatch opened the top of the jack had to shift over to port to follow the rotation of the hatch cover. The result was that, eventually the jack slipped under the copper jumping wire, which links the two periscope standards, and jammed. At this point the hatch was judged to be opened to an angle of approximately 75 degrees, as shown in Figure 23. Considerable time was lost in releasing the jack from the jumping wire and geometric modelling showed there should be sufficient clearance to allow the vLBV to be installed into the submarine, so the hatch was left at that orientation. From a material disturbance point of view, the impact of the hatch opening evolution was that a reasonable amount of concretion was removed from the top of the conning tower in the vicinity of the hatch (varying between about 50-100 mm), one hatch clip had to be cut and the hatch was rotated through approximately 65 degrees.

7 The hatch opening was not surrounded by a traditional, raised coaming. It was in fact effectively a recessed opening cast into the top of the conning tower.

Figure 23 - Showing the Final Orientation of the Opened Upper Hatch



3.3 Measurements involving Insertion of an ROV

The "miniaturised" version of the vLBV vehicle was set to work and proved to be in all respects seaworthy. The vehicle was then mated to the insertion pole, as shown in Figure 17, and the insertion operation initiated. The diver was able to pass the vehicle through the upper conning tower hatch, albeit with some difficulty. The vehicle was then lowered to the level of the lower hatch, whereupon it got thoroughly jammed. As the diver's evolution was complete there was no choice but to leave the vehicle in place until the next day.

On the following morning the vehicle remained jammed, and no amount of shunting with the vehicle's own propulsion system would move it, either in or out. An attempt was made to jerk the vehicle free by pulling on the tether from the surface, but once again the vehicle would not release from the hatch opening. It was decided that a diver operated system would be the most viable proposition to release the ROV and so a retrieval system was developed using items that were available on board the expedition vessel. A camera[8] was therefore attached to a long boat hook to provide critical, real time visual imagery of the boat hook's location and orientation relative to the ROV in order to provide guidance to the diver from the ship's dive control personnel. This operation was successful, but again the diver ran out of time and had to leave for the surface, with the vehicle still inside the conning tower. This proved to be rather fortuitous as the ROV undertook a detailed survey of the space, providing the team with a wealth of information. The high definition camera system on the vLBV worked very well and provided some of the best imagery of the mission. This is expanded upon in Section 3.6.

At this point it was decided there was no prospect of successfully installing the vLBV into the submarine's control room. The alternative was to reconfigure the smaller DSTO vehicle, arranging for it to be installed "nose-first" and then allowed to reorient to its normal horizontal attitude once it had been inserted into the boat. In the course of the next 24 hours the vehicle was physically reconfigured, had a high definition camera installed, re-trimmed to be neutrally buoyant at 70 metres depth, interfaced to the insertion pole and tested. The modified vehicle is shown below:

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8 Ironically, the camera used to undertake the first internal survey of the *AE2* during the 2007 Maritime Archaeological Assessment had an unplanned return visit into the *AE2* submarine conning tower, however this time as an integral part of the jammed ROV retrieval system.

Figure 24 - The Modified DSTO LBV Vehicle

The DSTO vehicle was successfully installed into the submarine and it was operated for three consecutive days inside the boat. The image below is one of the first views the vehicle revealed – the starboard side ballast pump and controller. During the time the vehicle was inside the boat the control room, wardroom, forward torpedo room and some of the midships space were surveyed. Unfortunately the threat of bad weather caused operations to be curtailed.

Figure 25 - The First Image Recorded by the DSTO ROV from inside the Control Room

(It shows the starboard ballast pump control slide, a Kingston wheel and a pressure gauge.)

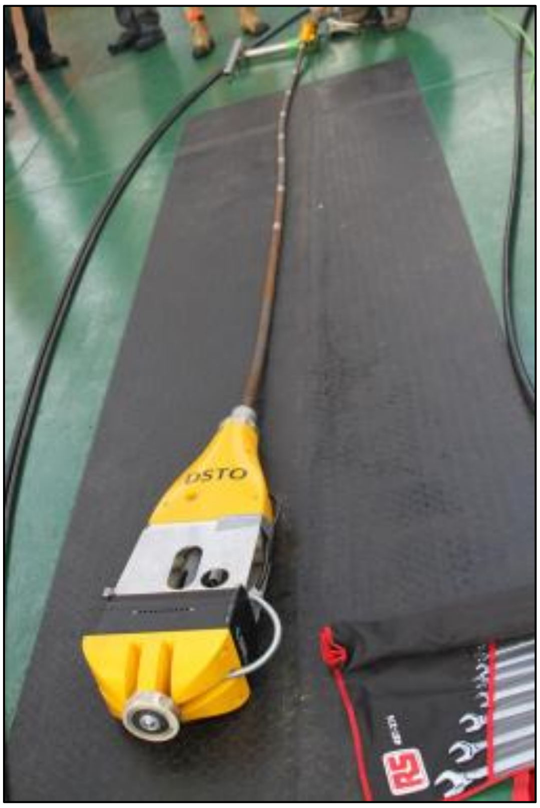
While the DSTO ROV was being reconfigured a vigorous debate weighed the pros and cons of leaving the mechanical scanning sonar on board the vehicle[9]. While it would have been of great value in assisting the pilots to navigate the vehicle, because of the exposed nature of its mounting system, it represented a very significant fouling hazard. In the end it was decided (by Neill) to remove the sonar. While the vehicle did not get irreversibly fouled, perhaps justifying the decision, the pilots found it very challenging to navigate without a sonar. A vehicle carrying a sonar, such as the ARIS unit would be much easier to navigate.

One of the greatest surprises of the first day's operations inside *AE2* was that the wheels of the two hydroplane controls and the main helm were found to have corroded away to stubs. This contrasted to virtually every other control wheel inside the boat. The team concluded that, perhaps these three wheels were aluminium. Was this to make them lighter for the crew members to turn? While this had not yet been debated or considered by the corrosion experts, what was apparent was that, while they lasted, these wheels had played the role of sacrificial anodes.

3.4 A Reconfigured "Pole Cam"

During the course of MAA14, considerable time was lost due to weather effects, equipment failures, and unexpected difficulties such as the jamming of the jack being used to open the conning tower (described in Section 3.2). While diver time was substantially exhausted, there was an opportunity, if it could be achieved without using divers, to insert a modified version of the Pole Cam. The full-size vLBV was available to provide support, so a concept was developed that may allow it to facilitate insertion of the camera into the submarine. The idea was that, rather than using the rigid pole arrangement, the steel spring that was a part of the drop camera system be used to support the camera/sonar/lighting rig, as shown below. Because of its inherent flexibility, this system was able to be inserted into the submarine using the ship's crane to support it and the ROV to guide it (see Figure 27). The ROV proved capable of rotating the system by using the vehicle's grabber to attach to the upper end of the spring, although obviously it was not possible to achieve a high level of rotational fidelity with this system. Three heights within the submarine control room were surveyed. While the dataset recorded from this modified system was limited, it proved possible to simultaneously record video imagery and acoustic scans from the ARIS 3000 sonar unit.

Figure 26 - The Modified "Pole Cam" which dispensed with the Pole



9 This sonar is much less capable than the ARIS 3000 unit installed upon the vLBV and hence could not be used to build a 3D representation of the boat as planned for the ARIS, but it is useful device to provide an obstacle avoidance capability.

Figure 27 - An ROV Image Recorded while the Modified "Pole Cam" was being inserted into *AE2*

Figure 28 shows imagery, recorded separately from HD video and the ARIS sonar. The images are looking to starboard, and they both show two of the Kingston valve actuation wheels, plus some of the other ballast control infrastructure. While it may appear to be the case, these images were not recorded simultaneously. The reader is reminded that the sonar is actually a two-dimensional ranging system, not a three-dimensional imaging system. What is actually shown in the sonar images are two-dimensional slices, taken along the direction of the sonar's field of view. In this case, by chance, at one point the system tilted somewhat, so that the sonar was looking slightly upwards, hence the wheels look like wheels. The sonar image which was, in fact, recorded simultaneously with the video image is included as Figure 29. That sonogram takes the form of a cross-sectional view through the Kingston wheels, including presenting a cross-section of the turning handle attached to one of the wheels. Also evident is some of the piping that led to pressure gauges and tapping points. The fidelity of the sonar imagery is sufficient to show that it can be used to facilitate dimensional scaling.

Figure 28 - Video & Sonar Images at the same Position

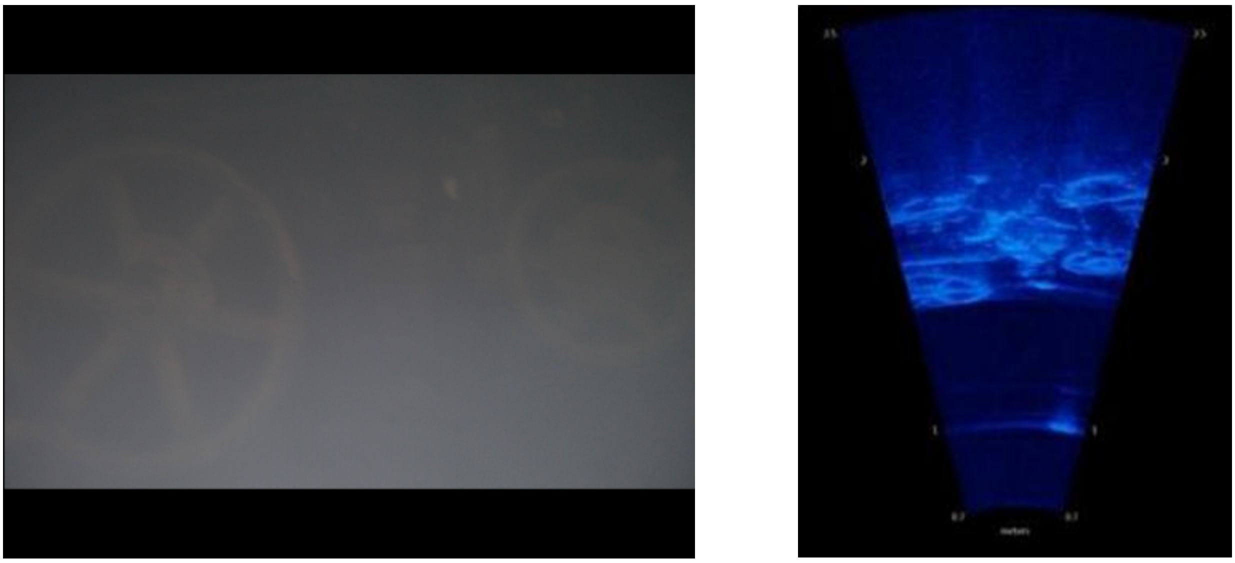
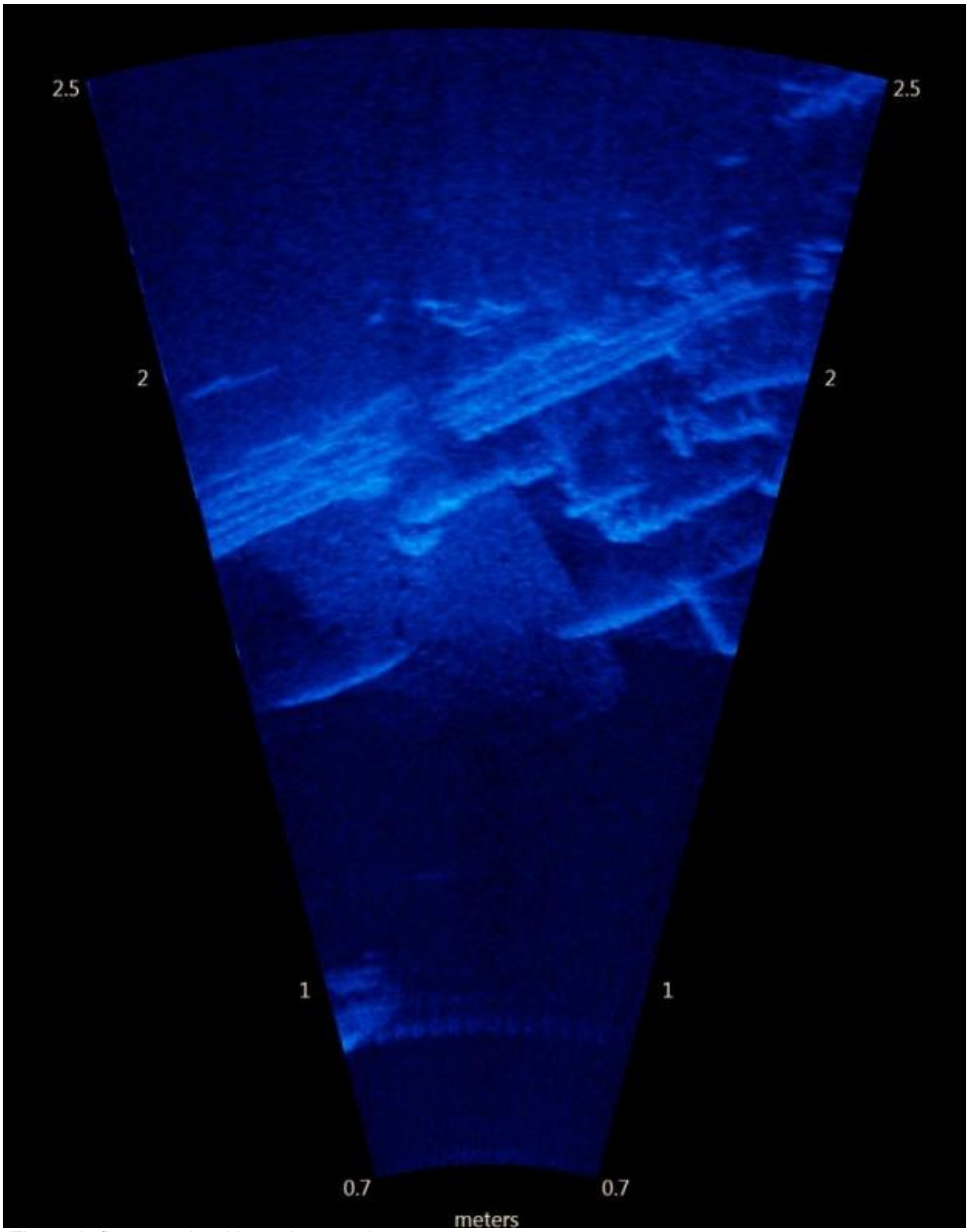


Figure 29 - ARIS Sonar Image of part of the Starboard-Side Ballast Control System

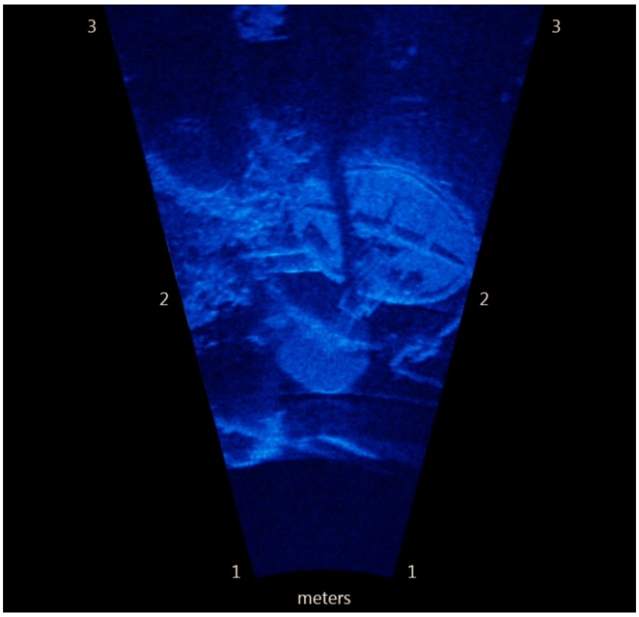


(The scale figures at the side are in metres)

A significant amount of the HD vision and ARIS sonar data were obtained from the SeaBotix vLBV in the conning tower. These data highlighted one of the limitations of the sonar system. For much of the time the distance between the sonar and the sides of the conning tower was closer than the 0.7 metre minimum range which the sonar could resolve, resulting in no displayed signal on the screen. Also the cramped confines and the shape of the conning tower resulted in multiple "bounces" of the sonar signal being received, distorting the displayed return signals. This in no way negates the potential value of utilising sonar data - it simply highlights the fact that acoustic systems have characteristics which must be accommodated, just as video imagery does. As a case in point, the video imagery in Figure 28 is degraded by turbidity of the water, whereas the sonar image is quite unaffected.

Figure 30 is another ARIS sonar image. This was recorded from outside the ROV, looking into the gap between the conning tower and the upper hatch while opening operations were being undertaken. The reader is reminded this is a ranging device – while it appears that the image is looking down on the hatch cover, in fact it shows the reinforcing ribs on the underside of the cover. Also visible is the base plate of the jack and part of the jack's winding mechanism.

Figure 30 - ARIS Sonar Image of *AE2* Top Hatch



3.5 Final Underwater Activities during MAA14

The final activities that were undertaken by the divers were to make check measurements of the corrosion potentials and to secure the upper hatch opening. Corrosion potential measurements, taken just two days after attachment of the final anode array, showed that the corrosion potential of *AE2* had already begun to shift in the desired direction. The shift, discussed in detail by MacLeod (5), from around -0.63 volts to approximately -0.68 volts was in line with predictions.

From both a maritime archaeological perspective and for the sake of the security of the wreck, it was important to restore the upper hatch opening to something approximating the original 10 cm gap. Given that the concretion, which had been effectively securing the hatch prior to the mission, had been dislodged it was not an option to simply close the hatch again. A fiberglass replacement hatch cover had been manufactured prior to the expedition. This cover, shown below, had slots cut into it to simulate the original opening. It was placed over the hatch opening and secured to a "strongback" (the grey object lying on top of the cover), that engaged with the underside of the hatch coaming.

Figure 31 - The "Top Hat" Replacement Hatch Cover

3.6 Examples of Analysis & Interpretation of Video Imagery

The four teams have reviewed all of the video imagery that was recorded from inside and outside *AE2*. The review of the imagery recorded from outside the submarine will be reported separately. In the case of the data imagery recorded from inside the boat, at the time of writing 300 items deemed to warrant further study had been entered into the Excel log, of which 214 were identifiable. The numbers of items identified in the various compartments were:

- Conning tower – 35;
- Control room (Aft) – 35;
- Control room (Fwd) – 118;
- Wardroom – 26.

Analysis of imagery recorded from the forward torpedo room and the midships spaces is underway.

Detailed interpretations have been undertaken on a number of the logged items and it is beyond the scope of this report to describe them all. The following sections are included to illustrate what has been done. Depending upon how much archival information is available; interpretations have been undertaken to varying levels of detail. In some cases it has been sufficient to confirm that an item accords with expectation – an example is the "Admiralty" Projector Compass in the conning tower. In other cases the imagery has provided answers to questions that had been baffling the science team for some time – for example where was the wheel from the upper steering position stored? Finally, in some cases the video imagery has confirmed particular pieces of specialised equipment on the boat were installed according to the plans (not always the case!), which has consequently allowed those plans to support detailed engineering interpretations. The following sections provide examples for each of these cases.

3.6.1 Conning Tower Survey

3.6.1.1 The Joint between the Ferrous and Non-Ferrous Sections of the Conning Tower

It was known that the upper portion of the conning tower was cast out of non-ferrous material and that the lower half was steel. A matter of considerable interest to the science team was to investigate how well the interface between the two parts of the conning tower had survived. As early as 1763 the Royal Navy frigate HMS *Alarm* had been used in an experiment on the use of copper sheeting for antifouling, with the result that iron fasteners were rapidly lost to corrosion (6). Clearly, in the case of *AE2*, the rivets joining the two parts of the conning tower have been carefully isolated from the brass, as they are still appear to be quite sound.

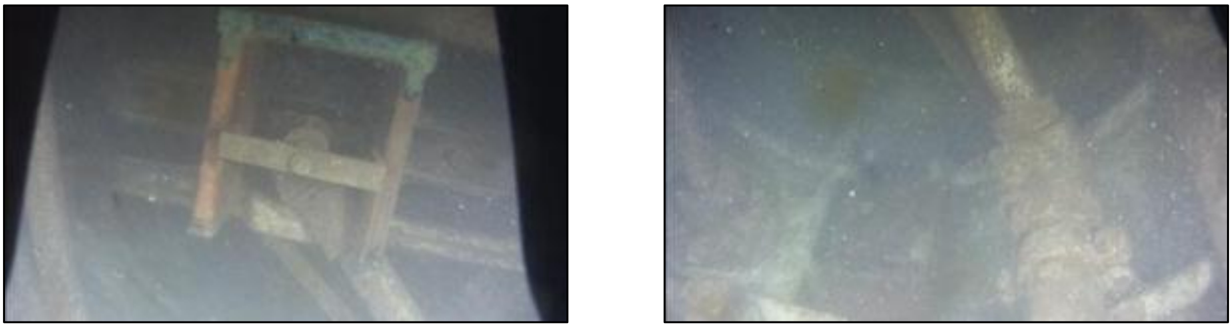
Figure 32 - This Image shows the Twin Lines of Rivets that join the Two Parts of the Conning Tower

3.6.1.2 The "Admiralty" Projector Compass[10]

The magnetic compass was mounted high up in the conning tower, where it was clear of ferrous metals. This compass is in good condition, it still has the soft iron spheres on either side of it and the light pipe, leading to the lower helmsman's position in the control room, is still in place.

Figure 33 - The Portside Soft Iron Sphere adjacent to the Housing for the Magnetic Compass

Figure 34 - Showing the Light Pipe that led down to the Control Room



*(Image at **left** is looking upwards towards the compass and image at **right** shows the "elbow" in the pipe mounted at the starboard side of the conning tower.)*

Figure 35 - The Open Box* at Upper Right is in the Control Room, pointing directly towards the Steering Position

*(*It is believed to have originally housed the ground glass projection screen of the compass)*

[10] The build specifications ([8], Paragraph 45) simply state that the magnetic projector compass will be supplied by the Admiralty.

3.6.1.3 The Mystery of the Upper Steering Wheel Solved

Plans and photographs of the bridge of *AE2* show a steering wheel whose diameter was too large to fit through the hatch. It had been obvious from the time the first dives were made on *AE2*[11] that the wheel had been unshipped and stowed somewhere, but the location was unknown. While it was known there were lockers under the external casing which would have been large enough to house the wheel, it did not make sense from an operational standpoint for the wheel to be stored there. In any case, the build specification ((8), Paragraph 29) stated that the bridge steering wheel should be "capable of being unshipped and taken on board through the conning tower hatch". The mystery was solved when it was realised objects stowed low down on the starboard side of the conning tower were, in fact, the components of a wheel that could be split into two parts.

Figure 36 - The Two Parts of the Bridge Steering Wheel are stored in the Conning Tower

(Note the spokes of the wheel. The cable lying on the rim of the wheel is three-core electrical cable, with insulation still relatively intact.)

3.6.1.4 Other Items in the Conning Tower

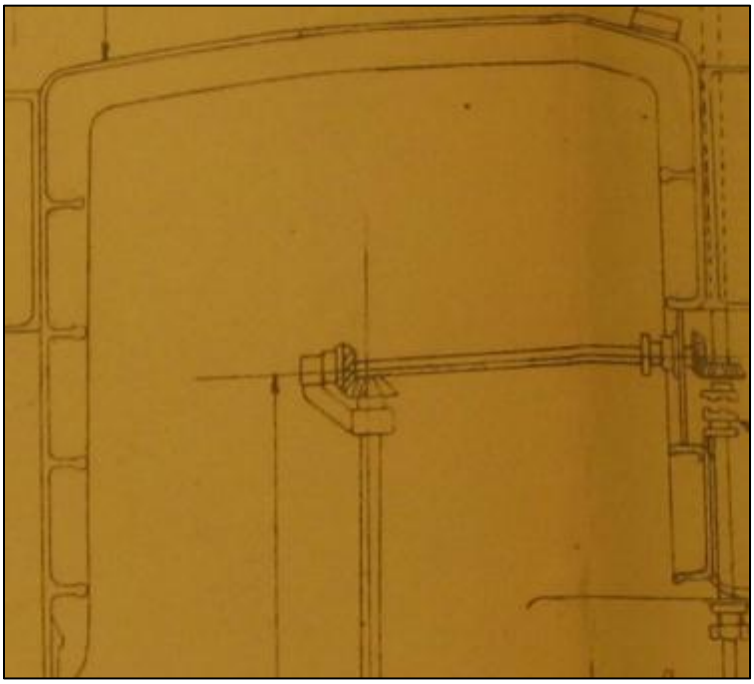
The following images give some idea of the large number of items of interest identified in the conning tower. The telegraph is identified in the plans (Drawing 11) as being an indicator for the starboard engine only. This is consistent with what can be seen on the instrument.

Figure 37 - Starboard Engine Telegraph

11 See, for instance, Mark Spencer's website which includes images from the 1999 dives - http://www.markspencer.com.au/ae2.php

The following example highlights the manner in which MAA14 has expanded upon existing knowledge of *AE2*'s hardware. The only plan which the team has been able to locate, indicating the manner in which the steering actuation was transferred from the two upper steering positions down to the control room, shows a very simple right-angle drive system with exposed gears.

Figure 38 - The Right Angle Drive for the Steering System – Mounted off the Port Side Wall of the Conning Tower

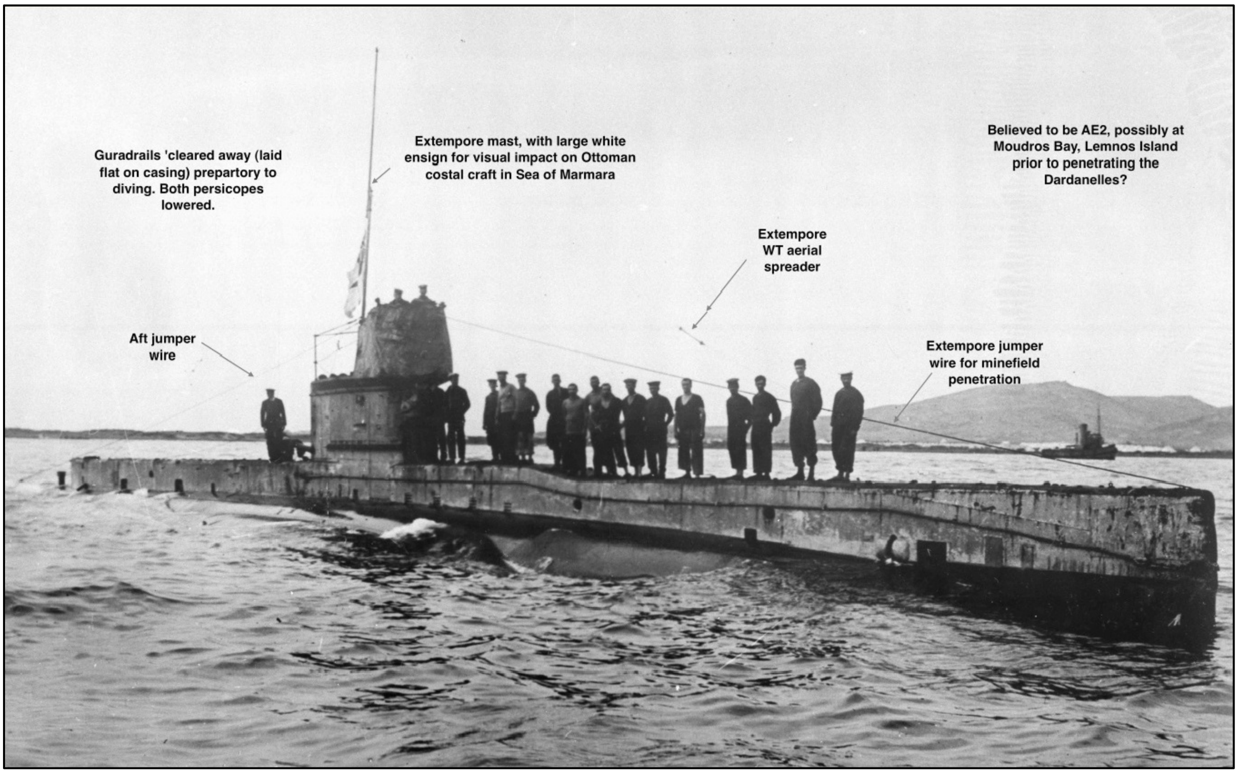


The reality was that the gearbox was totally enclosed, but it carried external grease pots which could be filled with grease and then progressively screwed in, enabling the unit to be charged with grease without the need to use a separate grease gun.

Figure 39 - Two Views of a Right-Angle Drive in the Steering System

One of the enduring matters of interest relating to the *AE2* story relates to her wireless telegraphy message, which was passed to General Hamilton in the early morning of 26th April, 1915 (7). There is no evidence remaining of the permanent radio mast, which the E-class submarines nominally carried. Certainly the evolution involved in standing, staying and connecting the permanent radio mast would have been very time consuming. One possibility is that the crews saved time by using jury-rigged masts. There is at least one photograph of another E-class boat using such an arrangement.

Figure 40 - An E-Class Boat operating a jury-rigged Radio Telegraphy Antenna



A number of items were found inside the conning tower which could potentially have been used to make such a temporary radio antenna. A steel plate was found on the floor, with a hinged bracket attached to it. Lying on top of that was a coil of wire and there were at least two poles stowed in the space. While it is not claimed that these were the components of a jury-rigged radio transmission system, further study into their potential uses is certainly warranted.

Figure 41 - A Hinged Bracket with Coil of Wire lying on top of it

(There were also at least two poles in the conning tower which were not part of its permanent equipment)

Figure 42 - The Conning Tower Steering Position, with a Second Pole lying immediately Aft of the Steering Wheel

3.6.2 Wardroom Survey

The wardroom is very different from the rest of the submarine in that it is the only space which is essentially domestic in nature. In all other spaces the equipment came first and the crew "made do" around it. While the wardroom did house some specialised ship's gear, in essence it was a space for the officers to retreat and to work. Because of the different nature of the space, it was found to be necessary to use a different strategy in undertaking the analysis.

One factor which contributed to the need to follow a different analytical approach was the large amount of loose material lying on all surfaces in the space. The wardroom had a great deal of organic material in it - items such as bedding and mattresses. It was also the place where the paper charts were kept. As these materials have degraded, they have broken down into flaky remnants. Whenever the ROV approached any horizontal surface, its prop-wash threw up a "snow storm" of debris. This made the survey challenging for the ROV pilot during the survey, and it means that the analysts were (and will be) forced to work with data presenting a very limited field of view. Another factor was that it rapidly became obvious to the analysts that the GA drawings were indicative rather than accurate.

The approach which was developed in analysing the wardroom data was to use a pencil and a graphing sheet and to progressively sketch the space. This was a labour-intensive process, involving many repeat viewings of the imagery, played at speeds ranging from frame-by-frame to high speed. Indicative scales were estimated from the GA drawings. For example, it was assumed that, even though the arrangement for the bunks was different from what is shown, the dimensions would be approximately the same. Once the general layout had been sketched, as shown in Figure 43, it was found that a number of objects could be used to improve the accuracy of the scaling of the drawings. In places the interframe spacing was visible. This was a good scaling aid. But it was also found that the domestic nature of the space worked in the favour of the analysts. What is meant by this is that many of the objects in the wardroom were quite widely used in non-naval environments. It was found, therefore, that the toggles used for opening drawers could be accurately dimensioned, as could the timber beading surrounding doors and drawers. Taking advantage of these various dimensional references, it was possible to generate a reasonably accurate model of the wardroom. The computer 3D design package SolidWorks®[12] was used to develop a model of the wardroom.

Figure 43 - The Analyst's Initial Sketch of the Starboard Side of the Wardroom

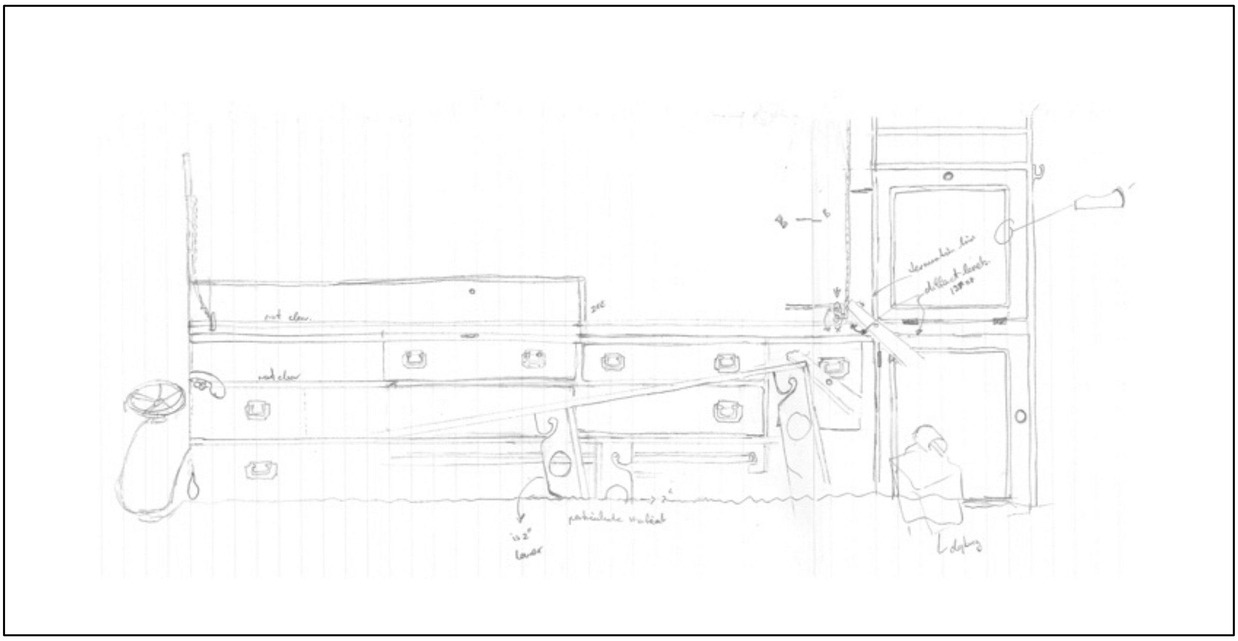
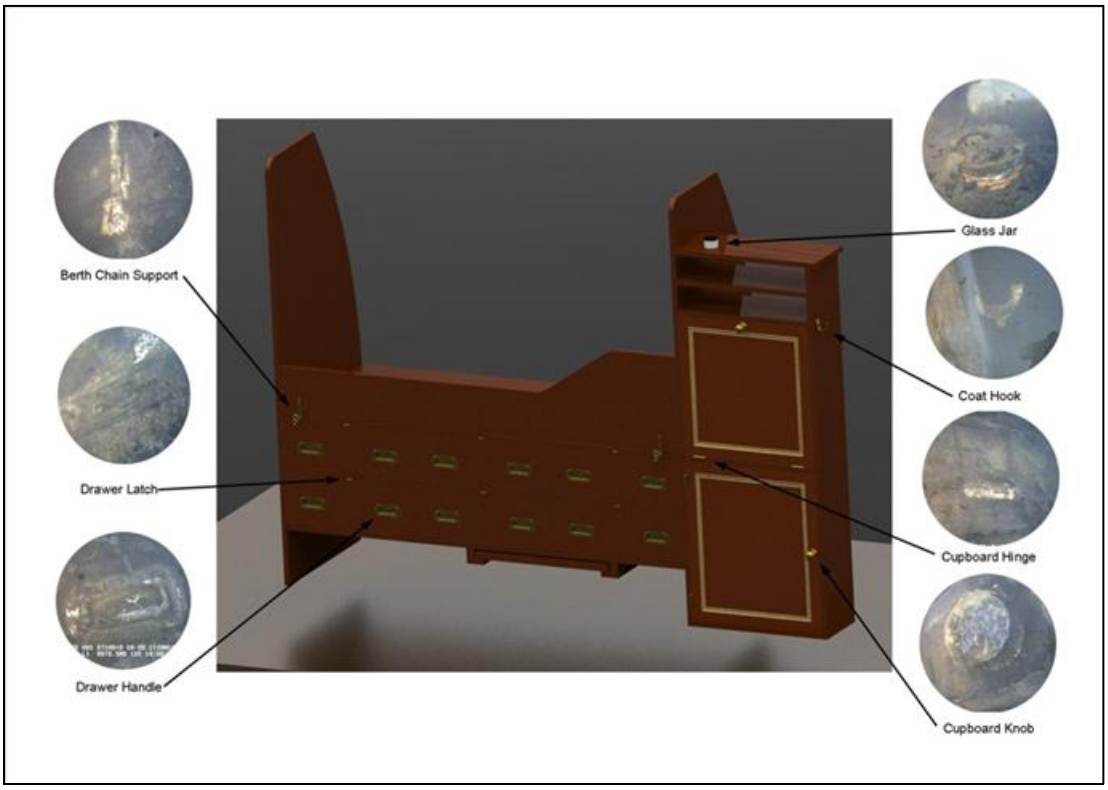


Figure 44 shows the 3D model of the wardroom, along with a number of thumbnail images of various items of interest. In 1915 items such as the coat hook, cupboard doors, drawers and fittings and the overhead light fittings could have been seen in many places other than *AE2*. They would have also been used in ships, defence facilities and other buildings. The reader should not draw the inference, however, that the analysis of the wardroom has been completed. As was the case with the rest of the submarine, the wardroom presented the science team with many as-yet unsolved problems.

12 SolidWorks is a product of Dassault Systèmes

Figure 44 - A 3D Model of the Wardroom showing a Number of Items of Interest



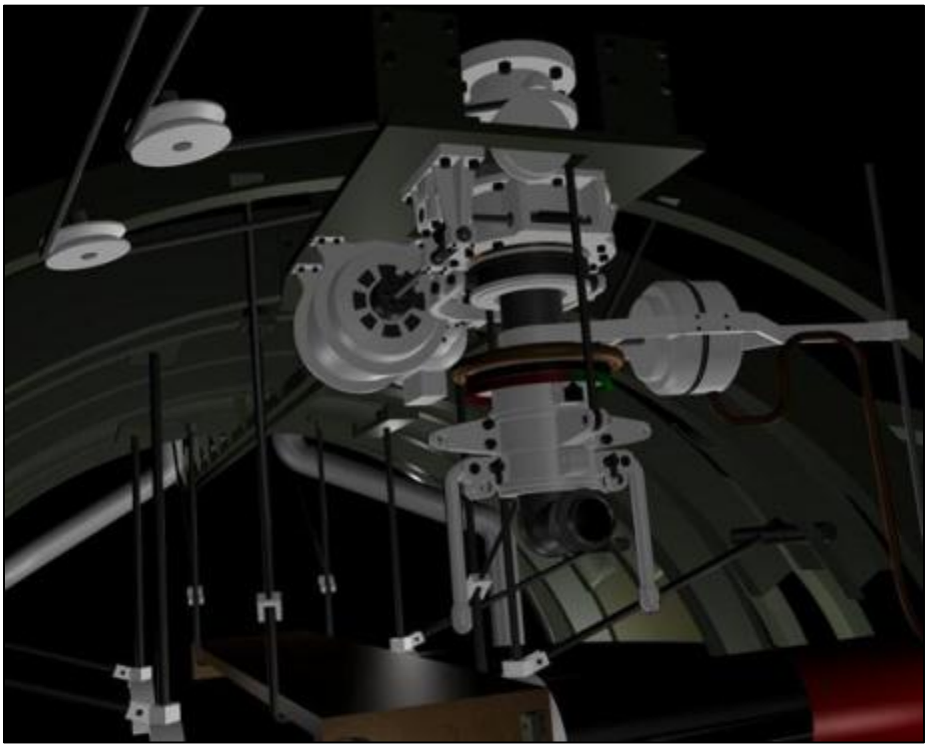
3.6.3 Periscope Interpretation

The two periscopes have dropped down into their wells, but in both cases the fall was checked by the control unit of the periscope training mechanism, which are lying on or close to the decking. Figure 45 is an image of the forward periscope, with the "training ring" and control unit near the bottom of the image and showing that the lifting wires are slack. These controller units appear to have had a very short production run – in fact the authors have been unable to locate any photographs of such systems deployed in any other submarine, including other E-Class boats. Mechanical plans are available for the periscopes on *AE1* and *AE2*, and these match what was found in *AE2*'s control room. The plans have therefore been used to make an interpretation of how the mechanical raising and training mechanisms worked on the boats (see the drawings list in Section 6). The build specification for the boats (8) yielded some further information on how the periscopes would function. It should, however, be noted that no details have been found to date on the optical arrangement of these periscopes.

Figure 45 - The Forward Periscope, which has dropped into the Periscope Well

A computer-based, 3D model was prepared of the periscopes, as they were shown in the original plans. Figure 46 is a rendering of the aft periscope. The training controller is on the right side of the image, corresponding to the port side of the boat. The reader should make reference to the image in following this interpretation.

Figure 46 - A 3D model of the Aft Periscope on board *AE2*



Starting at the bottom of the periscope the reader will notice the monocular eyepiece. Unfortunately no information is available regarding the optics of the periscopes, so no assessment can be made of its probable performance. There are reports that the periscopes installed on later E-class submarines were able to be trained in the vertical direction. This was presumably a response to the introduction of observation balloons? Certainly internal photographs of submarines E23 and E41, to which we have access, indicate that the periscopes were different to what is shown in the plans for *AE1* and *2*.

The next feature that can be seen is the training handles. These could be set in two positions, with simple locking pins used to secure them in position. There is no evidence that the handles had any controls incorporated into them. The exact shape of the handles is somewhat indeterminate. Different plans show different configurations.

Moving up the periscope the next item is the upper crosshead. This contained four lifting points. Two of the lifting points were permanently attached to the main lifting wires, which led via a series of sheaves to a pair of windlasses mounted on the "ceiling" at the forward end of the control room. An additional pair of lugs could be used to attach stays for securing the periscope in the raised position. This was presumably necessary to enable the electric raising apparatus to be serviced. It was also necessary to allow the wire rope to be changed on the main lifting sheaves. The periscope had to be raised out of the well to allow the wire rope to be reeved around and secured to the crosshead.

The next items, moving upwards, were the indicator rings. These carried a coarse Port-Starboard scale (shown here as red and green) and a detailed scale inscribed in degrees, shown here in black.

Above the indicator ring was a hand wheel. This enabled the observer to control the electric training system. When the hand wheel was positioned in its central position, defined by a spring-loaded detent mechanism, the electric training mechanism was disengaged so that the periscope could be trained by hand. The hand wheel carried a 64-tooth radial gear that was linked, via a tapered gear, to a training control (the object which is visible in the video imagery taken inside the submarine). When the control wheel was turned away from the central position, the training system was engaged. The sequence of events that ensued will be covered in the following paragraphs. While there is no detail available, presumably the rate at which the periscope was trained by the electric training system could be increased by turning the hand wheel further from its central position. The actual electric training control is the unit that sits off to the right hand side of the hand wheel in the visualisation. The arrangement of this control included a locating rod and a flexible electrical cable. This allowed the training control to move up and down as the periscope was raised and lowered. In order to allow the periscope to be fully lowered into its well, however, the training gear was constrained in its vertical travel – it traversed only 4 feet while the periscopes had a full travel of 7 feet 9 inches. The manner in which the vertical travel of the training gear was limited was according to the following design: "limited by means of preventer wires fitted with balance weights". Position and lead of wires to be arranged at boat" (Drawing 5.)

As already stated, upon turning of the hand wheel, the Electric Training Gear was activated. A critical element of this system was the cone-clutch, the next item that is encountered as one moves up the periscope. Upon activation, the cone-clutch housing was driven upwards by a solenoid that was connected to the clutch via a linkage mechanism. The solenoid and some of the linkage mechanism can be seen at the rear of the periscope. As the clutch housing was engaged, it forced six cast iron pads against the shaft of the periscope. These pads were held captive within a phosphor bronze worm wheel, which was consequently locked onto the shaft of the periscope.

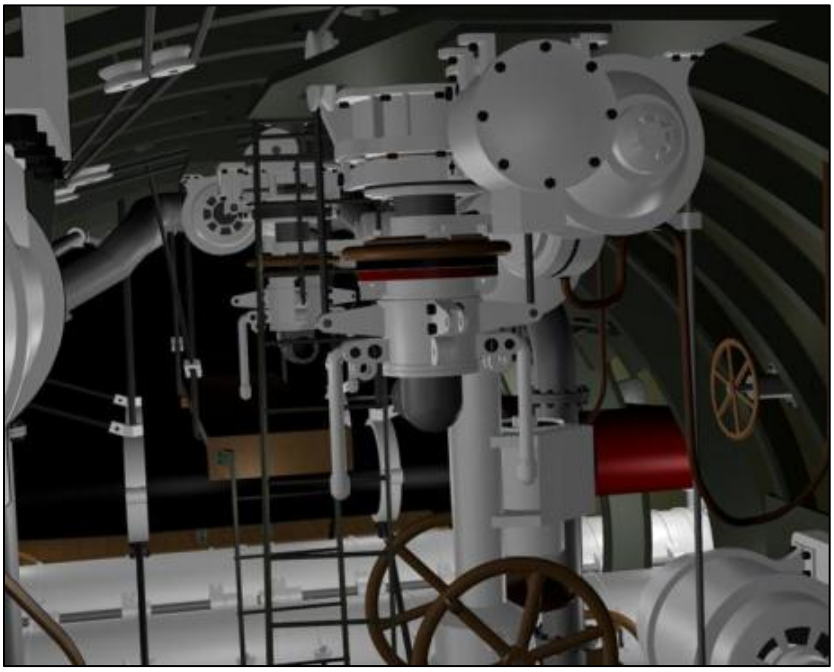
The final element of the electric training gear, clearly visible in the visualisation, was the actual drive mechanism. This comprised a half-horsepower electric motor driving a pair of drive shafts. The end of the final drive shaft carried a worm gear, which engaged with the worm wheel.

At the extreme top of the periscope, the hull penetration is visible. This comprised a two-part gland and stuffing box.

The physical structure of the forward periscope was very similar to the aft one. The only real differences were in the orientation of the lifting lugs and sheaves. Careful inspection of the second figure will allow these differences to be visualised.

It is interesting that, even so early in the submarine warfare, the need was recognised to have a power assist device to train the periscope, even though most of the time was spent surface running and, when dived, such a short length of main tube was exposed to water flow. This form of power assistance appears to have disappeared from British submarines shortly after *AE2* was built, and it did not reappear until after the Second World War. The reason may have been a result of the advent of sophisticated sonar (ASDIC) systems. The mechanical arrangement which was used on *AE2* would have generated very significant and very characteristic transient signatures. Perhaps the hiatus in the use of powered training mechanisms was caused by the need to develop arrangements with better acoustic performance.

Figure 47 - A Computer Model of *AE2*'s two Periscopes, looking Aft



3.7 "AE2 Explorer" — An Interactive History Lesson

This novel interactive computer application was developed at the Defence Science and Technology Organisation (DSTO) to provide an interactive display so that users can learn about the daring exploits of Australia's second World War 1 E-Class submarine HMAS *AE2* during the early stages of the Gallipoli campaign. It provides images of the *AE2* before its final mission, as well as never before seen images of its current state.

The success of the MAA14 enabled the collection of a broad and extensive range of information about the overall condition of the submarine. This included video footage of its interior, most of which has not been seen since the submarine was scuttled almost a century earlier. This internal footage is full of interesting information about the configuration of the *AE2* and records the current condition of the submarine as well as assessing the impact, if any, on the submarine's interior due the uncontrolled dive into the sea bed after being scuttled.

Most of the video footage is of good quality, however when viewing the video footage it can be difficult to maintain an awareness of the exact location of the remotely operated vehicle and its orientation in relation to the submarine's internal structure and equipment configuration. This limited situational awareness is likely to be worse for those who are not familiar with the vessel and many of its key features which can be used to identify where the camera is looking. This can make it difficult to process the available information without access to the *AE2* plans or strong familiarisation with a model of the *AE2*.

The AE2 Explorer is a program that uses a new style of user Interface to create interactive plans which can be overlaid with a range of information as shown in Figure 48 below. The plans allow the user to scroll around a digital copy of the declassified AE2 General Arrangement drawings and zoom in on areas of interest. Coloured buttons located on the drawings show where detailed information on an area or component is available. This may be detailed text, images, or video clips of the *AE2* before its final mission, or as it was observed at its current underwater location. Additional buttons to activate information overlays over the top of the physical structure of the submarine enhance the information provided. This interactive plan allows a user to easily follow where the *AE2* information relates to, so users do not need a separate copy of the *AE2* plans. Additionally, the program is not limited to a single plan because it is possible to switch between multiple annotated plans, or even to place the information inside a 3D model (although the *AE2* model requires some further development).

Figure 48 - AE2 Explorer User Interface

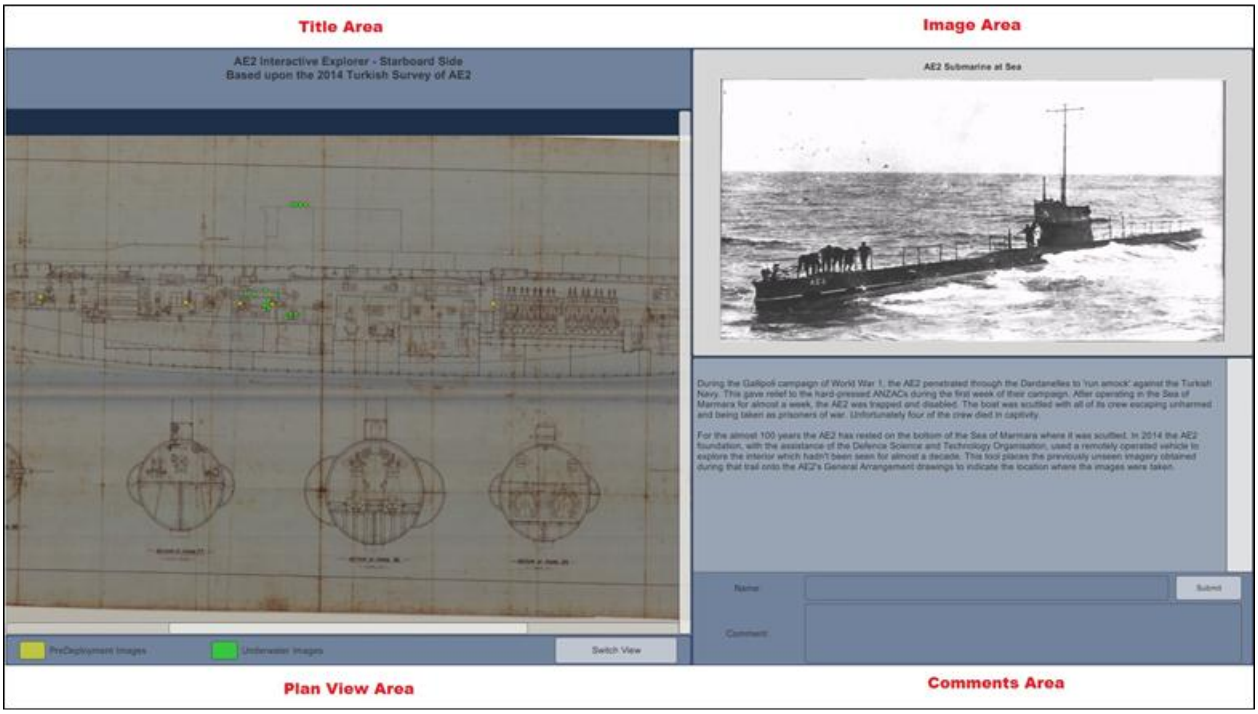
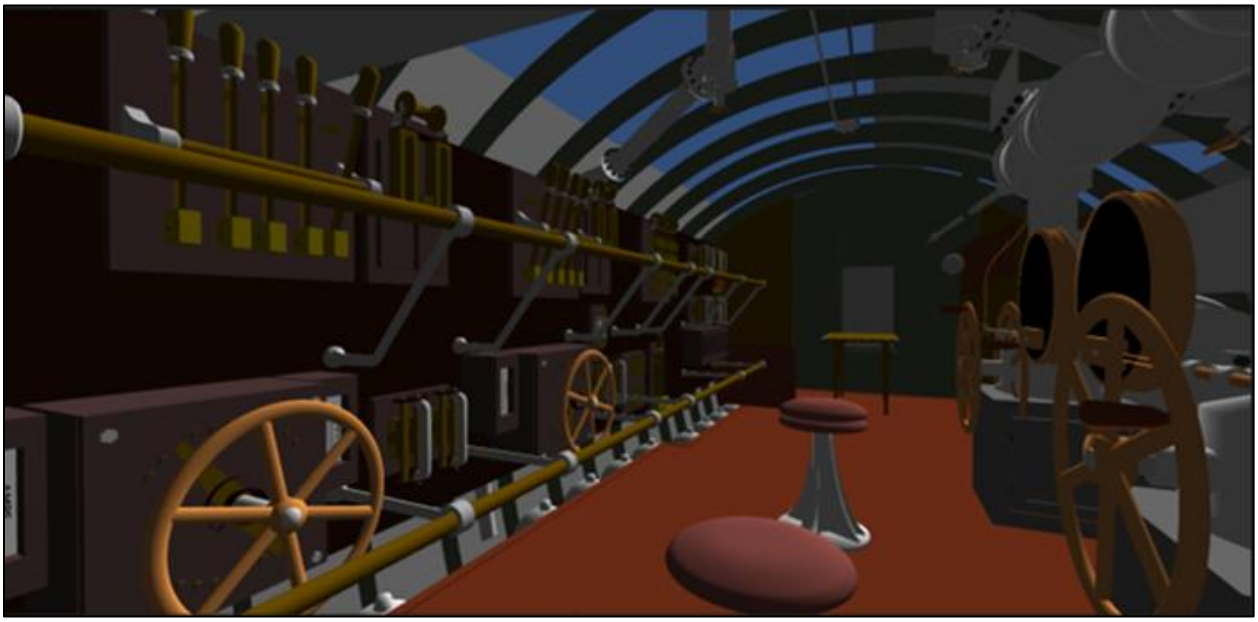
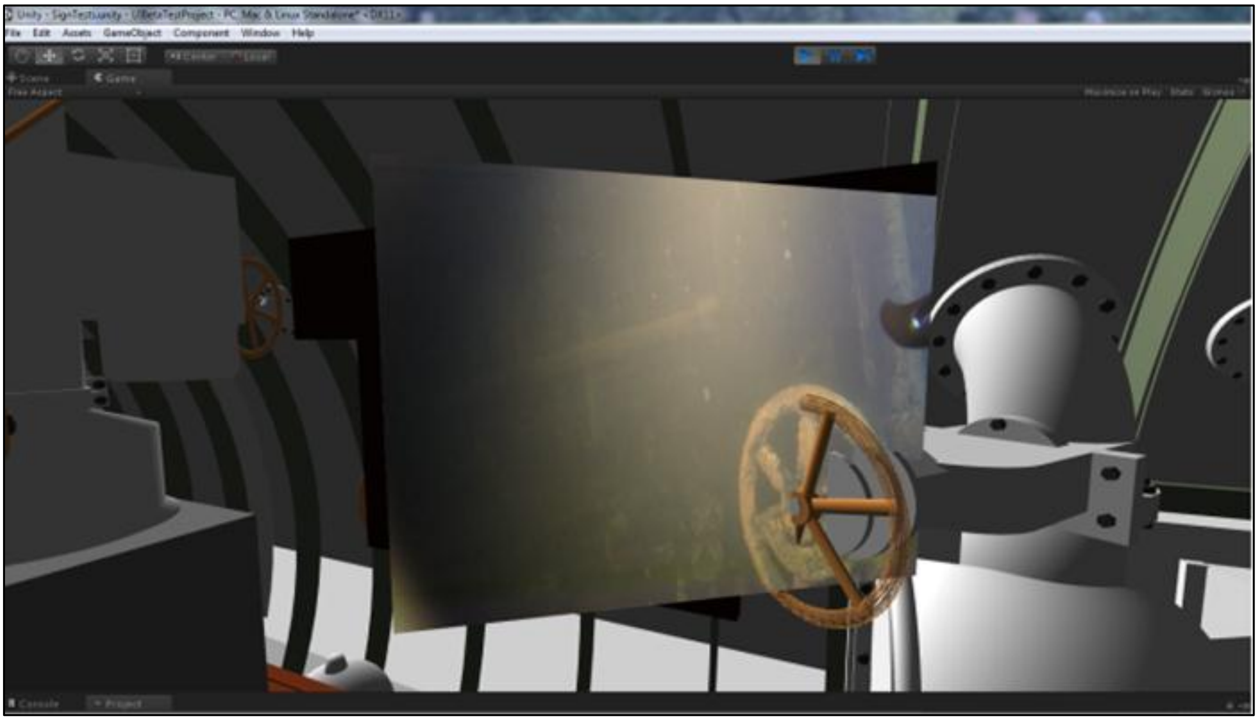


Figure 49 - 3D Characterisation of the *AE2* Control Room



A 3D walkthrough of the AE2 will be possible in this environment when the model is completed, with the prototype shown in Figure 49. Furthermore, images or text can also be placed in the 3D environment on display panels. Careful placement is required for the information to be accessible by the user, especially when overlaying images as shown below in Figure 50.

Figure 50 - Image Overlay in the 3D Environment



The AE2 Explorer interactive application was developed by Dr Chris Madden at Australia's Defence Science and Technology Organisation to explore new techniques for displaying information. Verification of the information derived from the MAA14 and included in AE2 Explorer has been verified by world experts on HMAS AE2. This method has also been applied on other projects of a more classified nature.

4. Discussion

The above report has sought to give the reader a good understanding of what the science team set out to achieve during MAA14, in direct support of Project Silent Anzac. It has detailed the infrastructure that was put in place to support the mission, and how the team planned to use that infrastructure. It is clear from the report that problems were encountered while the team was working on the Sea of Marmara, but in every case strategies were able to be developed to either overcome the problem, or work around it. At the conclusion of the mission the team had gathered a very significant body of data – a resource that will be of enduring value to the maritime archaeological community, physical scientists and historians alike.

The team decided that it was important to ensure the knowledge gained from first-hand experience was not lost. Therefore a methodology was developed to enable the team to undertake a preliminary review of the data. The latter half of 2014 was devoted to the development and implementation of the methodology. While this report does not fully document all of the outputs of the analyses to date, a number of conclusions can be drawn:

- The internal fabric of *AE2* is in excellent condition;
- Many of the mechanical systems that were revealed by the survey are either not documented in remaining plans, or are different from what was expected;
- There is considerable evidence that the crew modified or adapted the boat to enhance its operational capability;
- It was also evident to the analysts that the crew had maintained the vessel in a "ship-shape" condition during the week of their operation in the Sea of Marmara.

Overall, the vast majority of the mission objectives were achieved. There were clearly lessons learnt and it is worth capturing some of these in case future expeditions are considered:

- A more conservative estimate should be made regarding the maximum size of any materiel which are to be inserted into the submarine;
- It was clear that the conning tower retains excellent structural integrity. Future expeditions could consider using it to support a much lighter (and hence easier to deploy) DSP. This may reduce the requirement for the support ship to carry a high-capacity crane;
- Despite the fact that provision had been made for some loss of time due to bad weather, this provision did not adequately account for other unplanned, mission-related events. One rule of thumb for working at sea is to double the anticipated time to complete all activities.
- Despite the non-optimal manner in which the ARIS sonar imagery was collected, the data shows considerable promise. Insufficient effort was devoted to "working up" this system prior to MAA14. Any future mission should prove the concept before incorporating this type of technology into the operational plan.

The excellent results can in large measure be attributed to the collective breadth and depth of prior experience of the team. As the various challenges arose during MAA14, the value of having such a diverse and skilled team came to the fore. For many of the members, having the opportunity to work in such a team proved to be a unique and rewarding experience.

5. References

1. AE2 Commemorative Foundation (2014): "100th Anniversary of Australian Submarines: HMAS AE2 - Project Silent Anzac". http://www.aussubs100.com/ae2-commemorative-foundation.html; Accessed 1 December, 2014.
2. Briggs, P. (2014): "Project Silent Anzac – Maritime Archaeological Initial Assessment Report". AE2 Commemorative Foundation Ltd.
3. Neill, R. and Graham, P. (2008): *ROV Operations, Drop Camera and Seabed Bearing Strength Characteristics* in "Report of Operation Silent Anzac Maritime Archaeological Assessment of HMAS AE2", Annex F. AE2 Commemorative Foundation Ltd.
4. Neill, R., Gilbert, J., Graham, P., Mart, P. Grandison, C. Rowan, M. and Winter, N. (2013): "Survey of HMVS *Cerberus*, December 2012", DSTO-CR-2013-0092.
5. MacLeod, I. (2015): "Conservation of AE2. A report on the 2014 Marine Archaeological Assessment". AE2 Commemorative Foundation Ltd: Annex C of this Report.
6. Tretheway and Chamberlain (1988): "Historic Corrosion Lessons". http://corrosion-doctors.org/Corrosion-History/Lessons.htm. Accessed 23 January 2015.
7. Masefield, J. (1916): "Gallipoli". Available as a reprint from New Holland Publishers, 2011.
8. "Specification for Building The Hull of A Twin Screw Submarine Boat". Australian Archives.

6. Drawings

1. Submarine of E-Class – General Arrangement.
2. Submarine of AE 1 & 2 – General Arrangement Drawing.
3. Submarine of AE 1 & 2– General Arrangement Drawing - Starboard. Elevation and Sections.
4. Submarines AE 1 & 2– Periscope Electric Elevating and Training Gear – Details of Crosshead & Indicator rings.
5. Submarines AE 1 & 2– Arrangement of Periscope Electric Elevating and Training Gear.
6. Submarines AE 1 & 2 – Periscope Electric Elevating and Training Gear – Details of Worm Gear Brackets, Clutch, Hanging and Elevating Sheaves.
7. Submarines AE 1 & 2– Periscope Electric Elevating and Training Gear – Details of Worm & Hand Gear.
8. Submarines AE 1 & 2– Periscope Electric Elevating and Training Gear – Details of Shell Connections and Stuffing Boxes.
9. Submarines AE 1 & 2 – Periscope Electric Elevating and Training Gear – Details of Clutch Levers, Worm Gear & Training Control.
10. Submarines AE 1 & 2– Periscope Electric Elevating and Training Gear – Details of Lifting Barrel & Brackets, Guide Brackets & Sheaves etc.
11. Arrangement of Bridge Steering & Telegraph Gear, Drawing Number 2S23. Australian Archives.

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