Proceedings American Academy of Underwater Sciences Diving For Science 2016

Editors
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In: Lobel L.K., Lombardi, M.R. eds. Diving for Science 2016.
Proceedings of the American Academy of Underwater Sciences 35th Symposium.

Proposed Standards of Practice and Recommendations for Inclusion of Atmospheric Diving System (ADS) End-User Training and Operations within the Scientific Community

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Abstract

There is limited existing literature describing the utility of Atmospheric Diving Systems (ADS), and further, any widely accepted standard of practice. For working dives, the practice has been for ADS owners/operators to draft and adopt internal safe practices manuals (i.e. J.F. White 2010). These usually reflect particular circumstances and specific operations, with procedures derived from the manufacturer's general recommendations or end-user manuals. These protocols are then vetted to meet health and safety requirements for individual private companies or organizations and their insurance underwriters, and thus often deal with limited sub-sets of operational conditions rather than diving science applications as a whole. This specificity is among the points of failure in providing guidance for a broader population of future end-users. Further, the outlying classification somewhere between wet diving and manned submersibles as a mode of human intervention is just one of the several factors causing barriers to entry for more routine, and more broadly reaching market opportunities for ADS technology. However, isolated successes have been demonstrated across both scientific (Earle 1983) and commercial sectors (Clark 2013). Other factors include accessible training opportunities, dexterity and human ergonomics considerations, and [mis]perceptions of risk in human intervention at an institutional or regulatory level. This paper reviews a case study involving acceptance of the Nuytco Research Ltd. Exosuit ADS for use in both scientific and industrial applications, and subsequently sets forth a proposed standard of practice and recommendations for ADS inclusion within scientific programs. This standard of practice has been derived through practical and demonstrated use of the Exosuit ADS during training efforts at Woods Hole Oceanographic Institution and subsequent field deployment in Antikythera, Greece.

Keywords: Exosuit, ADS, atmospheric diving system, scientific diving, ocean exploration

Introduction

The first end-user training activities for the Exosuit Atmospheric Diving System (ADS) were conducted in July 2013 at Nuytco Research Ltd. in North Vancouver, British Columbia, Canada (Figure 1), and went documented (Lombardi & Clark 2013) with the intent of addressing areas for probable future standardization.

Subsequent delivery of the Exosuit ADS to J.F. White resulted in challenges in implement the technology within their occupational diving programs given that operational, technical, and health and safety documentation supporting the Exosuit was non-existent. Therefore, previous manned submersible vehicle standards and references including IMCA 1984, GL 2009, ASME 2007, and UNOLS 2009 were reviewed and operational documentation was collated (Lombardi ed. 2014). While the Exosuit is designed and constructed to meet the Lloyd's Register (1989) standards of construction for classification as a 'manned submersible',

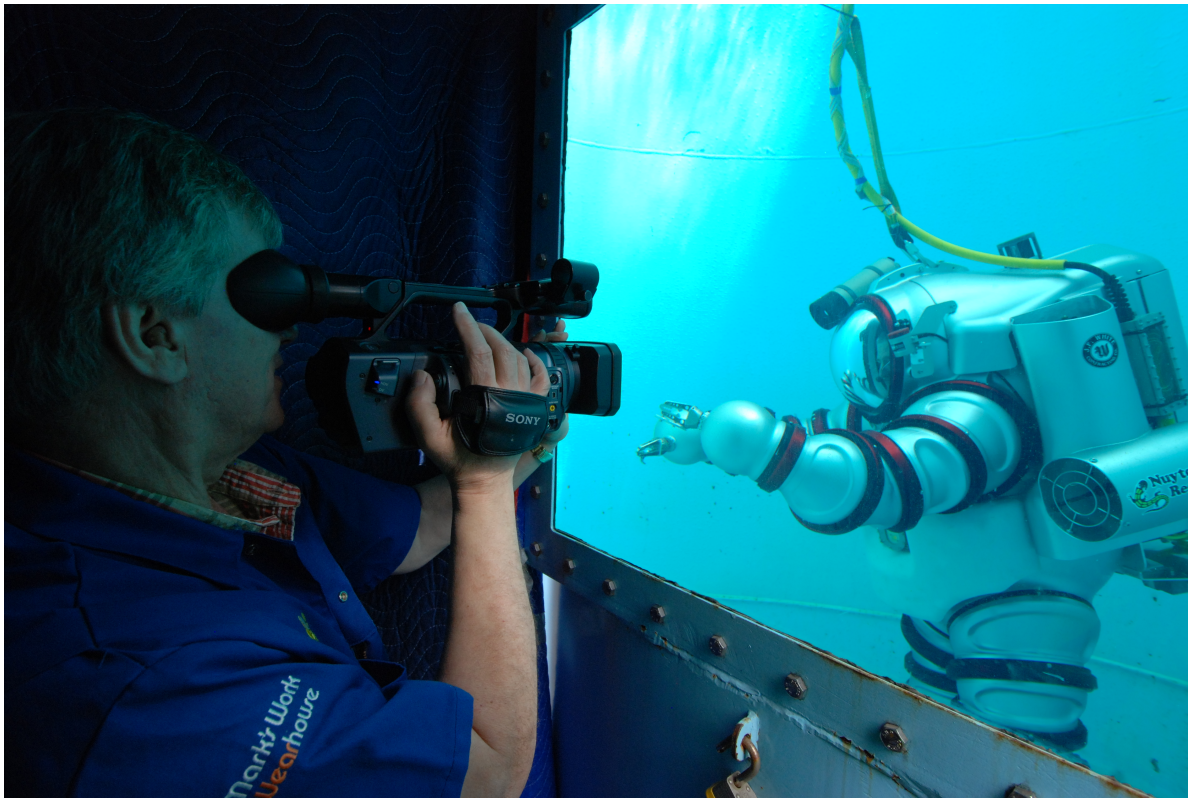

Figure 1: Dr. Phil Nuytten films an Exosuit ADS training dive in a test tank at Nuytco Research Ltd. Photo by M. Lombardi.

review of Nuytco 2013 and practical training experiences revealed that actual ADS operations do not fall within the specific scope of any single set of the manned submersible regulations cited above. In short, ADS stands as an outlying mode for human intervention, with both manned submersible and wet diving considerations needing to be met for regulatory compliance.

Access to training opportunities for scientific end-users presented itself as the critical bottleneck to early program development activities. IMCA 1984 provides a training regimen for submersible pilots, and further distinguishes ADS pilots citing that "physical demands made on the occupant of an atmospheric diving suit require his general standard of fitness to be in some respects the same as that applied to commercial divers." Lloyd's Register 1989 does not specifically detail an ADS training regimen, however does cite that "Detailed knowledge is required of the effects of buoyancy, heel and trim, equipment handling…together with the medical effects of gas mixtures. Considering this, one can logically deduce that an ADS trainee and prospective pilot would be most effective if first trained as a wet diver, maintained some degree of diving proficiency and fitness to dive, and had a modest understanding of diving physics and physiology as it applies to atmospheric management (Lombardi 2016).

Methods

In cooperation with Technical Diving International, the author developed an Exosuit ADS training standard (Lombardi 2014a) reflecting primarily IMCA 1984 but also while reflecting upon practical

experiences during the 2013 training regime (Lombardi & Clark 2013). This training standard was followed with publication of an Exosuit end-user training and proficiency guide (Lombardi 2014b). Technical Diving International approved and sanctioned this program in early 2014. In Spring 2014, this training program was implemented at Woods Hole Oceanographic Institution (WHOI) during four week-long successful and incident free training and proficiency sessions. WHOI granted approvals for this training regime under the auspices of their scientific diving program, establishing the precedent of ADS as a mode of diving [as opposed to manned vehicle] within the institutional and academic setting (Lombardi 2016).

Generally, while the consensus of those participating in training activities was that the Exosuit was simple and intuitive to operate at the end-user level (Figure 2), it is critical for end-users or prospective end-users to understand the full scope of operational support required and degrees of operational complexity that may need to be introduced [or mitigated] to ensure actual mission-specific tasks are completed (Lombardi 2016).

This manuscript proposes a standard of practice that highlights items required for a basic ADS operation, which has been derived from practical experience at both WHOI and subsequent fieldwork in Antikythera, Greece. While the onus for implementation lies with the owner/operator of the system, this manuscript is intended to educate prospective end-user groups on minimum operational standards required for safe and effective ADS operations within the scientific or academic setting such that effective partnerships can be formulated between ADS operators and scientific end-user groups.

Results: ADS Proposed Standards of Practice

The below sections propose the minimum standards of practice and field operations protocols for diving Atmospheric Diving Systems (ADS) for scientific purposes. This material is only part of the complete documentation and reference information required for ADS operations, and are presented here as framework for program development considerations within scientific programs. Specific technical operations, repair and maintenance, and training information can be found within the references to this manuscript.

Briefly, the proposed standard is inclusive of the following sections:

1.0 General Equipment Description
2.0 Health & Safety
3.0 Communication & Documentation
4.0 Manning Levels
5.0 Operational Procedures
6.0 Emergency Procedures
7.0 Field Maintenance

Responsibilities for immediate action to ADS health and safety conditions.

	Responsible Party for Immediate Action	
Health and Safety Conditions	**Topside/Supervisor**	**End-User/Pilot**
Emergency Conditions and Response Protocols		
Lost Communications	Shared	Shared
Entrapment	Shared	Shared
Structural Damage/Joint Seizure	N/A	Primary
Life Support System Faults	N/A	Primary
Unconscious or Disabled Pilot	Primary	N/A
Electrical Supply Failure	Shared	Shared
Thruster Pack Failure	Shared	Shared
Umbilical Damaged/Severed	Shared	Shared
Water Ingress - Drowning	N/A	Primary
Fires and Fire Extinguishing Methods	N/A	Primary
Emergency Recovery Procedures		
Controlled Emergency Ascent	Primary	N/A
Back-Up Recovery System	Primary	N/A
Emergency Recovery using the Original Umbilical	Primary	N/A
Emergency Procedures for Attaching the Secondary Lifting Line	Primary	N/A
Open Water Vessel Support	Primary	N/A
Free Ascent or Controlled Free Ascent	N/A	Primary
Handling System Failure	Primary	N/A
Pilot Welfare		
Medical Well-Being	N/A	Primary
Medical Considerations	N/A	Primary
Medical Hazards and Conditions		
Inadequate Oxygen Supply - Hypoxia	N/A	Primary
Oxygen Poisoning - Oxygen Toxicity	N/A	Primary
Carbon Dioxide Poisoning - Hypercapnea	N/A	Primary
Soda Lime Chemical Burn	N/A	Primary
Cold Exposure - Hypothermia	N/A	Primary
Dehydration	N/A	Primary

Figure 2: ADS Pilot and Dive Supervisor Responsibilities for Health & Safety. From Lombardi 2016.

1.0 General Equipment Description

When referencing the 'ADS' throughout, this refers to a complete dive ready system inclusive of the following:

1. Completely assembled pressure hull including limbs and dome
2. Life Support System
3. Communications System
4. Thruster Pack
5. Tether (when applicable)
6. Winch (as required)

7. Power Control Unit (PCU) & Power Supply
8. Surface Control Modules
9. Handling/Launch & Recovery System

1.1 Certification

The ADS must be built and tested according to an established regulatory body for manned submersibles, such as the Lloyd's Register of Shipping. To maintain this certification, regular maintenance and annual surveys must be performed according to the regulatory body. Documentation of each survey shall be maintained by the owner/operator of the ADS and be available for inspection on request.

1.2 Maintenance

The ADS will be maintained in accordance with the requirements to maintain the above certification. Specific maintenance procedures will be carried out, at a minimum, as described by the manufacturer.

2.0 Health & Safety

Any situation that could present a risk should be dealt with immediately and brought to the attention of supervisory personnel. Regular meetings are to be held throughout the course of the dive operation to address any concerns and to maintain a high level of performance and safety.

The following minimum documentation must be prepared to ensure appropriate Health & Safety requirements are met during an ADS operation:

2.1 Health & Safety Plan (HASP)

A detailed Health & Safety Plan (HASP) will be prepared for every ADS field operation. This document will be available to all project personnel, and will be reviewed prior to commencing the dive operation. This document will include, at a minimum, the following; a Dive Operations Plan, Critical Lift Plan, Life Support Assessment, Activity Hazard Analysis, Emergency Management Plan including a Back-Up Mobilization Assessment, and Project Contact List.

2.2 Life Support Assessment

Foremost consideration must be placed on assessing ADS life support capacity as it applies to safe mission planning and rescue capabilities. For each mission, a Life Support Assessment must be conducted and included in the mission's Health & Safety Plan (HASP).

2.3 Back Up Mobilization Assessment

Foremost consideration must be placed on assessing back up mobilization as it applies to mission planning and rescue capabilities. For each mission, a Back-Up Mobilization Assessment must be conducted and included in the mission's Health & Safety Plan (HASP).

3.0 Communication & Documentation

3.1 Chain of Command

The ADS Supervisor serves as the communications conduit for the ADS operation and directs the chain of command. The ADS Supervisor may delegate certain essential communications or tasks to take place on his or her behalf. These delegations and any deviations from the established chain of command must be reviewed during safety meetings.

3.2 Safety Meetings

At the beginning of each ADS operation there will be a safety meeting to ensure that all personnel understand the scope of work and related safety requirements. All personnel should have the opportunity to express any concerns they may have relating to the safety of the operation. Standard on-site meetings will include the following: Pre-Mission Brief, Pre-dive Brief, Post-dive Brief, and Post-Mission Brief. These meetings will be attended by all personnel involved in the ADS activities.

3.3 Documentation

Standard forms or other reporting requirements will be defined by project management in advance of the field operation. Actual field documentation check lists, which are used to guide personnel through set operational and maintenance procedures are provided by the owner/operator of the system and are developed per manufacturer recommendations.

4.0 Manning Levels

The total number of required personnel may vary between projects depending on work scope, shift length, and number of required shifts. The following are the minimum manning levels for ADS operations:

- ADS Supervisor (1)
- ADS Pilot (1)
- ADS Tender/Technician (1)
- LARS Operator (1)

Additional personnel may be required to assist in the launch and recovery of the ADS and to operate any surface equipment or tools used in conjunction with the dive operation.

A sufficient number of qualified personnel are required to provide a back-up system in the event of a need to recover a disabled or otherwise trapped ADS. These personnel could be part of the additional personnel required to operate surface equipment providing they are reasonably familiar with the ADS and are adequately trained with the response intervention mode. This designation is at the discretion and direction of the designated ADS Supervisor.

4.1 Duties and Responsibilities

Specific delegation of duties and responsibilities for field operations are provided by the ADS Supervisor.

4.11 ADS Supervisor

The ADS Supervisor is the person in charge of the ADS operations at the work site. He or she is responsible to the client, project manager, and ADS owner/operator for the safe and efficient conduct of the operation.

He or she will ensure that the dive is carried out in accordance with the scope of work as outlined in the HASP and pre-dive meeting and is responsible for directing the launch, recovery, task execution, communications, record keeping, and safe conduct of a specific dive.

4.12 ADS Pilot

The Pilot is responsible to the ADS Supervisor for the safe and efficient operation of the ADS. The ADS Pilot will:

- Take all possible steps to ensure the safety of him/herself and the equipment.
- Carry out pre and post dive checks in conjunction with the technicians and return signed copies to the ADS Supervisor.
- Ensure that he is properly briefed on the purpose of the dive, the procedures to be carried out, and the relevant safety and emergency procedures.
- Conduct the dive in accordance with this operations manuals, and the project HASP.
- Perform all planned maintenance which he is assigned.
- Perform any other duties which may be assigned to him by the ADS Supervisor.

Note: The Pilot has the authority to abort the dive or refuse to dive at any time should he consider that the ADS or his/her own self are at risk.

4.13 ADS Tender/Technician

The tender and/or technicians assigned to the ADS operations team are responsible for the repair and maintenance of the suit and support equipment. The tender/technicians report to the ADS Supervisor. The ADS tender/technician will:

- Maintain the ADS and support equipment in accordance with maintenance schedules and manufacturer's technical documentation.
- Immediately report any defective equipment to the ADS Supervisor.
- Complete and sign the pre and post dive check lists with the Pilot.
- Assist during the ADS launch and recovery.
- Tend the ADS umbilical (when applicable).

4.14 ADS LARS Operator(s)

The Launch and Recovery System (LARS) operator is responsible for the safe launch and recovery of the ADS during the dive operation. The LARS Operator will be designated by the ADS Supervisor. Multiple operators may be required depending on the specific LARS system used. The LARS Operator will:

- Facilitate the launch and recovery of the ADS at the direction of the ADS Supervisor.
- Assist with other topside operations as directed.

- Immediately report any defective equipment to the ADS Supervisor.
- Maintain the LARS to the applicable standards and manufacturers requirements.

4.2 Training & Proficiency Qualifications

Essential personnel are required to undertake training and maintain proficiency on the ADS per current industry training standards, and as required to meet the occupational safety and health and requirements for diving of their employer.

All essential personnel must be able to:

- Follow procedures and specifications and work efficiently.
- Perform work to a high standard, ensuring the safety of all personnel and equipment.
- Communicate effectively with the ADS Supervisor, and work effectively as a team.

Personnel selection is based on having worked with analogous dive systems and operations. Team members are chosen for particular skills that they may have as especially applicable to the specific mission.

5.0 Operational Procedures

Protocols for specific tasks to be completed within the scope of work will be defined within the HASP.

Operational procedures specific to the ADS dive are guided by a series of checklists. These checklists include the following:

- Pre-dive checklist
- Electrical Pre-dive checklist
- Launch & Recovery checklist
- ADS Dive Log worksheet
- Post-dive checklist

Additionally, logs will be maintained to record project consumables and field maintenance or repair.

Check lists and logs are to be completed by trained and qualified personnel and submitted to the ADS Supervisor. All check lists become a permanent record of the work operation.

Check lists should not be altered in the field. Recommendations for alterations and improvement should be forwarded to the office of the owner/operator and/or manufacturer for review and processing. As checklists are altered or improved, they will be reviewed for inclusion within working operations.

5.1 Pre-dive

A pre-dive checklist and electrical pre-dive checklist must be completed prior to each dive. This can be considered valid for up to 8 hours if the equipment is left in a secure and sheltered area. After a longer period of time and or if some activity is carried out with the system, the check should be made again.

5.2 Launch and Recovery Procedures

Launch and recovery procedures and corresponding check lists will vary based on the specific launch equipment used for each operation. Lift plan worksheets will be completed as part of the HASP.

At a minimum, equipment used to lift, deploy, and recover the ADS must be rated or otherwise approved for a manned lift according to applicable industry standards.

5.3 Dive Log

A dive log worksheet will be kept for every ADS dive. This worksheet provides for logical record keeping of pilot to topside interfacing and communications of system status and pilot well being.

5.4 Post-dive

A post-dive checklist must be completed following each dive. Post dive maintenance will be carried out in accordance with the recommendations of the manufacturer.

6.0 Emergencies

Prior to each operation, a specific HASP must be developed to identify specific equipment and activity hazards that may be encountered. Procedures to mitigate these hazards will be well defined and will be reviewed during safety meetings under the direction of the ADS Supervisor.

In non-life threatening situations and where the problem has been created by equipment failure, reference should be made to the manufacturer's technical manuals and documentation. Where a problem has been created by failure with the handling system, reference should be made to the manufacturer's and/or operator's technical manuals and documentation.

6.1 General

ADS emergency operation status conditions are defined as follows:

ALERT	Potential problem but severity has not been determined. Monitor condition and proceed with corrective action.
EMERGENCY	Operator is at risk and corrective action is required. Begin immediate recovery operations.
EXTREME EMERGENCY	Immediate and rapid recovery or intervention

In all cases the crew will immediately prepare the back-up system to be ready to launch on notification of the ADS Supervisor.

Note: ADS are typically equipped with the ability to jettison equipment to achieve positive buoyancy and make a free ascent. A free ascent is to be avoided where recovery by a controlled means is possible.

6.2 Back-up System

All diving operations require a back-up system capable of rendering assistance in the event of an emergency. This is to be selected based on the requirements and conditions as established for each particular operation and as outlined in the HASP.

6.3 ROV Guidelines

Remotely operated vehicles (ROVs) are commonly utilized as back up vehicles and can offer assistance to the ADS operation in a number of different ways including:

1. Conducting a site survey.
2. Provide additional lighting.
3. Assistance with various tasks.
4. General ADS observation and assistance in emergency situations.

ROV personnel should be familiar with ADS operations, capabilities and emergency procedures.

If the ROV has been approved for use as a back-up system, the ADS Supervisor and Pilot must ensure that all operations are restricted to those conditions in which the ROV can perform. The dive operation is always restricted to performing within the limitations (depth, duration, etc.) of the lesser capable vehicle.

6.4 Emergency Equipment

All operations will maintain the following equipment as a minimum, in addition to typical work site safety equipment. Reference is to be made to the relevant manufacturer's technical manuals for operating instructions.

6.41 Topside Equipment

- Through water communications (TWC)
- Compatible underwater directional pinger/receiver (mission-specific consideration)
- Suit support stand
- Hand powered cable cutter of size suitable for umbilical

6.42 Subsea Equipment

- Through water communications (TWC) in push-to-talk mode.
- Accessories may include
    - Xenon strobe

- RF beacon operates at 160.78 mHz
- 37 kHz pinger

6.43 Pilot Equipment

- Oral Nasal Mask
- Survival kit recommendations:
  - second pair of wool gloves
  - wool head gear/ balaclava
  - energy bars
  - heat packs
  - emergency response and procedure cards
  - 2 long duration light sticks
  - 2 liters of fluid replacement
  - Head set and ear piece in a sealed bag

6.5 Emergency Procedures

Emergency conditions due to equipment malfunction or failure and their corrective actions are described by the manufacturer's technical documentation and rehearsed during training activities. Maintaining proficiency in these procedures is required for end-users.

Both potential equipment hazards and potential environmental/work site hazards will be assessed prior to the dive operation with response protocols and corrective actions detailed in the HASP.

7.0 Field Maintenance

Routine inspection and service is carried out during pre-dive and post-dive checks to ensure all systems are examined and serviced on a regular basis, reducing the potential for failure. Field repairs and maintenance includes the following:

- o-ring replacement
- oxygen sensor replacement
- joint oil addition
- cylinder filling
- scrubber refilling
- e-batt recharge or replacement

Planned and scheduled service is to be done by competent personnel who are trained and are familiar with the relevant procedures outlined in the manufacturer's technical documentation and as it complies with maintaining certification of the system.

The owner/operator is responsible for the maintaining a record of service schedules for each piece of equipment.

Discussion

The precedent set by establishing Exosuit ADS operations as a mode of diving, rather than the historical convention of a manned submersible, lends itself well to developing scientific programs (Lombardi 2016). Within the United States, most academic institutions and many private companies incorporating diving as a tool for underwater research operate to a scientific exemption to OSHA 29 CFR 1910 Subpart T (Commercial Diving) and leverage a community consensus standard for safe practices defined by the American Academy of Underwater Sciences (AAUS). This affords a vehicle for relatively easy adoption of new technologies and techniques for scientific programs, with the Organizational Membership of the AAUS bearing responsibility for introducing new standards of practice as technologies and techniques for scientific diving continue to evolve.

It is the recommendation of the author that scientists seeking to utilize ADS for scientific programs work with their home dive programs or health and safety managers to adopt these proposed standards, with prospective end-users meeting the minimal requirements of their home organization's scientific exemption, followed with undertaking the training regime cited herein, and then formulating cross-sector partnerships with ADS owner/operators such that the technology can become within reach.

Acknowledgements

The author acknowledges the J.F. White Contracting Company and Nuytco Research Ltd. for their cooperation in developing the Exosuit ADS as a scientific tool. Also, many thanks to the first group of early Exosuit ADS end-users and trainees for their critique and evaluation of this developing program including representatives of Woods Hole Oceanographic Institution, John B. Peirce Laboratory at Yale University, the American Museum of Natural History, the Unites States Naval Academy, the Hellenic Ministry of Culture, and the Greek Navy.

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