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Variable Depth Capability for Portable Inflatable Habitats

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Abstract

In 2012, a portable inflatable habitat was deployed in the Bahamas, adjacent to a precipitous vertical wall drop off to provide a controlled space to augment shallow decompression following deep mixed-gas dives within the Mesophotic zone. The habitat space was utilized successfully and without incident. However the habitat functioned in an independent manner and did not provide essential life support functions. In recent years, the habitat's form and functions have evolved to accommodate variable deployment strategies. A 2015 deployment in Hong Kong demonstrated life support dependence successfully and without incident, as well as the habitat's ability to be deployed-in alternate environments. The newly acquired life support dependence presents an opportunity for vast range extensions by scientific divers where primary life support carried by the diver can be used to its fullest extent prior to beginning decompression within the habitat structure, as opposed to primary life support being depended upon for both the working phase of the dive and decompression. While these static deployments have proven successful, the addition of reliable variable depth capability remains a bottleneck for more widespread wet diving range extensions. Depth adjustments throughout required decompression stops require careful control of a buoyant load, coupled with atmospheric management considerations for the occupants. Standards and procedures for related operations are being developed to effectively implement this emerging technology into the scientific divers' tool box.

Keywords: habitat augmented decompression, extended range diving, mesophotic exploration

Introduction

Previous development efforts in underwater habitation have focused on large, permanent structures. These 'Man in the Sea' programs from the 1960's and 1970's have all but vanished due to several reasons, including but not limited to massive infrastructure required for deployment and operations, as well as significant expense.

While human physiology does set practical limits in undersea exposures, the authors believe there is an incremental step in undersea habitation that has been overlooked in practice. This being short (hours) to middle duration (a day or overnight) stays in a portable structure to provide respite during lengthy immersion.

This type of human intervention can quite easily be justified with recent work within mesophotic coral ecosystems (MCEs). MCEs, encompassing depths of 200 to 500 feet of seawater (fsw), are a recent international priority in the ocean sciences as they are believed to account for a vastly overlooked region of ocean space, harboring new biotechnological discoveries, novel biodiversity, and clues into global climate change. Manned scientific diving to these depths is generally disregarded as the best tool for the job given the [mis]perceived liabilities and inefficiencies of humans working at these depths. However, commonplace practices in 'technical diving' do afford a cost-effective vehicle for a broad population. The challenge remains in efficient use of limited bottom time (Lombardi and Godfrey, 2011) and/or reducing idle time spent during decompression (Lombardi et al., 2013).

One noteable success in carrying out this type of deep Mesophotic scientific work was the discovery and collection of a new species of fish, *Derilissus lombardii* (Sparks and Gruber, 2012). This collection was the result of scouting reef outcroppings as sampling targets and further establishing multiple rotenone stations along the vertical wall, followed by collection of cryptic fishes. This burdensome process left only minutes for actual collecting – leaving an opportunity for improved efficiency during the work phase of the dive, and the obvious benefit to science should more time at depth be afforded for systematic exploration.

Background

The lengthy decompression for these few minutes at depth while collecting *D. lombardii* was uncomfortable at best, and provided justification for the development, construction, and experimental deployment (Figure 1) of a simple portable underwater habitat in Spring 2012 in waters off of the Bahamas Marine EcoCentre (Lombardi et al., 2013). This system afforded the divers respite from lengthy environmental exposures and subsequently shed light on the ability to carry out longer working bottom times. During this deployment, the system itself remained deployed for 72 hours.

Thereafter, development of the Ocean Space Habitat^{SM} (Lombardi, 2016) continued with an emphasis on integrating dedicated life support with a capability of providing up to 8 hours of life support for one diver, plus 50% reserve. This second generation system was deployed in 2015 at the Kat O Island Research Fish Raft operated by the City University of Hong Kong. This allowed student researchers to visit the habitat, learn about basic atmospheric management principles, and experience open water aquaculture from the perspective of a captive within that environment. During this deployment, the system remained deployed for 48 hours.

Research and development has continued with the intent of establishing a commercially viable product and method (Lombardi and Burleson, patent pending) with improvements to human ergonomics, payload and life support management, and more efficient deployment strategies (Figure 2).

In parallel with hardware refinements, early efforts are underway to establish standard operating procedures, health and safety contingencies, and to identify realistic dive exposures that can be reasonably accommodated with this type of technology. An early assessment of extended range profiles made possible with Ocean Space Habitat^{SM} technology reveals that the ability to traverse shallow decompression stop depths may provide significant future benefit (Figure 3). Hardware for this capability is being evaluated (Figure 4).

Continued and Future Developments

Incremental developments have been made to evolve the Ocean Space Habitat^{SM} technology platform to meet the specific demands of extended range scientific diving. Figure 1 depicts the Gen 1 system, which offered a primitive dry shelter only, with the divers' primary life support used for decompression. In this instance, the full dive profile must be accounted for within the limitations of the primary life support, nominally 4 hours per most COTS rebreather systems. The Gen 1 envelope was in excess of 5,000 pounds buoyant but provided space for 3 divers plus ancillary equipment.

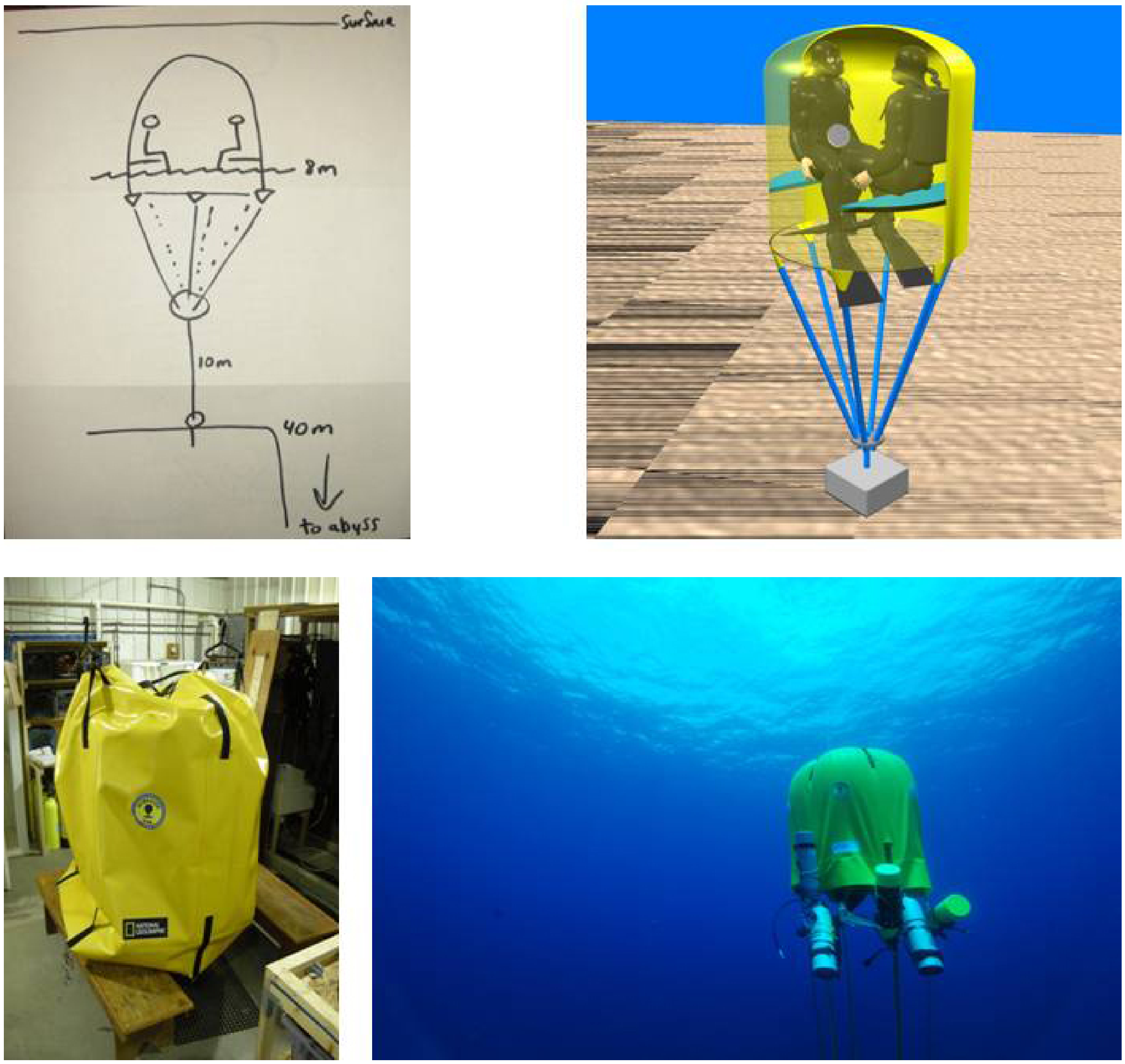

Figure 1: (top left) Concept sketch of habitat deployed along vertical wall. (top right) Rendered solid model of Gen 1 system, courtesy Anthony Appleyard. (bottom left) Prototype Gen 1 system prepped for deployment at University of Rhode Island. (bottom right) Gen 1 system deployed in Bahamas at 20 fsw, photo courtesy of National Geographic Society/Waitt Grants Program.

The Gen 2 system is considerably smaller, with a buoyant displacement force of 2,200 pounds. This system (Figure 2) was designed to accommodate two divers in close quarters, but reasonable comfort. This version incorporated dedicated life support such that the divers' primary life support could be removed prior to entering the habitat. In this configuration, the dive excursion up to habitat ingress can consume the primary life support (i.e. up to four hours), with the habitat providing the necessary life support and redundancies for the balance of the dive.

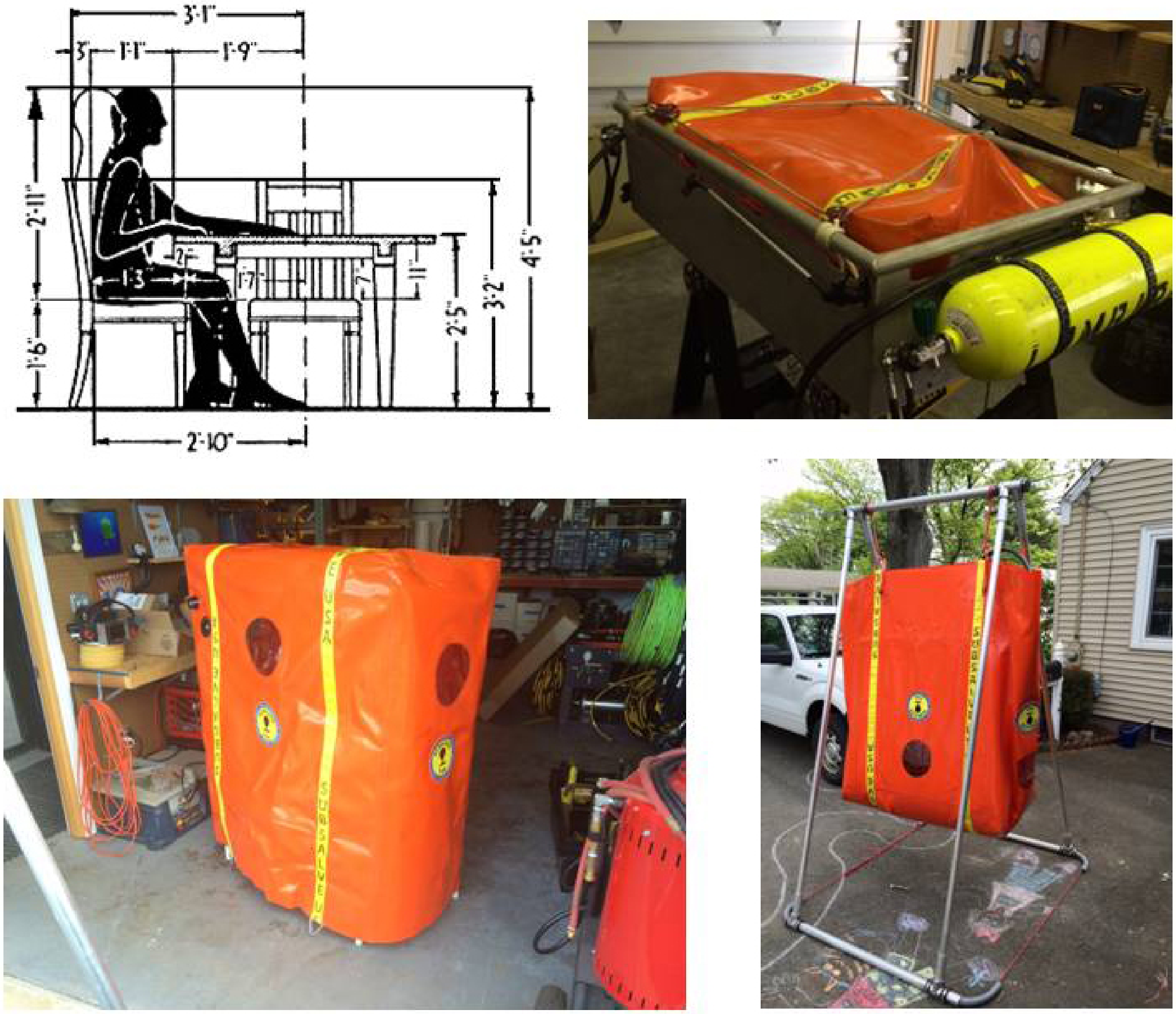

Figure 2: (top left) Average human ergonomics considered for Gen 2 design. (top right) Gen 2 system stowed for deployment within frame. (bottom left) Gen 2 system prepped for deployment at Lombardi Undersea Resource Center. (bottom right) Scaffolding ballast test using water filled habitat in preparations for deployment beneath floating docks in Hong Kong.

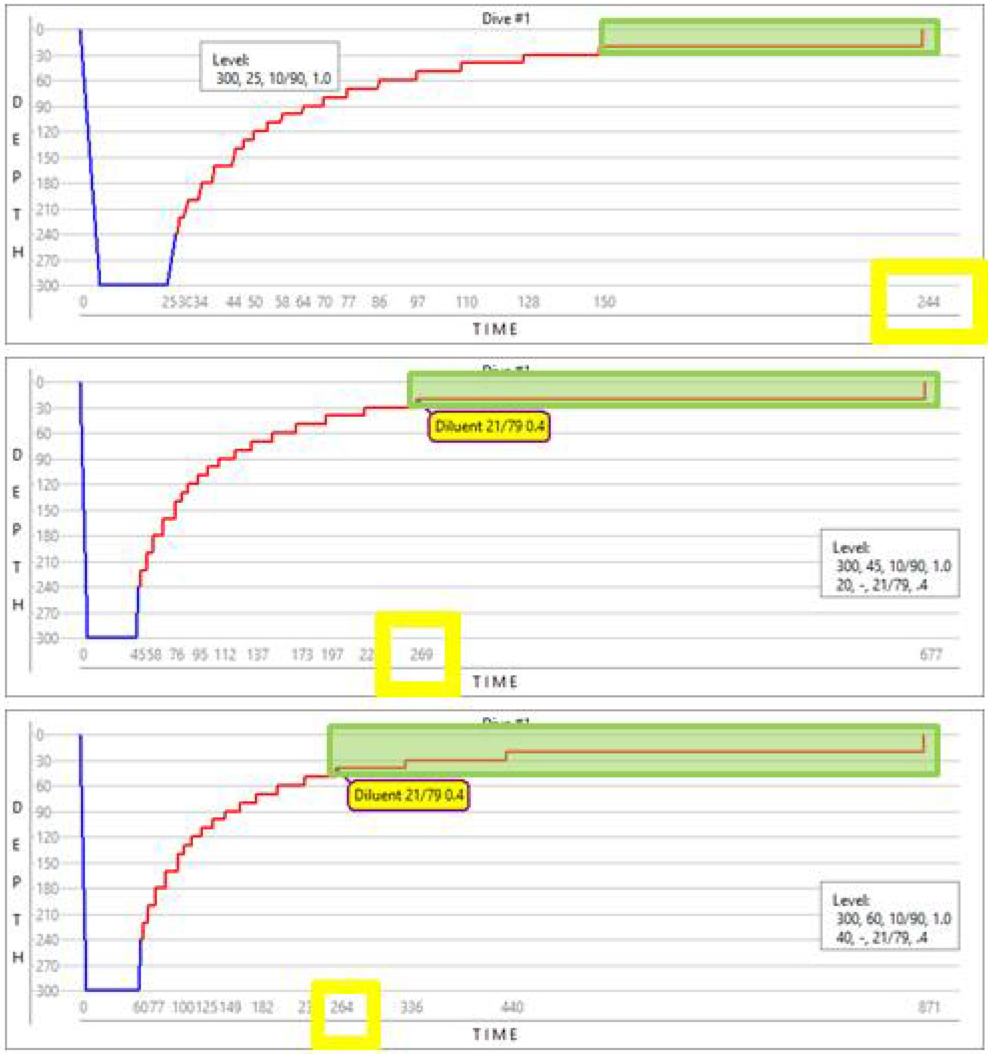

Figure 3: Three hundred foot (300 fsw) dive profiles for conceptual use only. (top) 300fsw for 25 minutes bottom time. (middle) 300fsw for 45 minutes bottom time. (bottom) 300fsw for 60 minutes bottom time. Times indicated in boxes represent time spent while maximizing personal life support (~4 hours). Decompression phases of dive profile highlighted indicate time spent within habitat. Note that the 200/45 and 300/60 profiles require habitat life support dependence. Profiles generated using V-Planner and do not necessarily reflect the optimized approach for the depths/times stated.

Figure 3 provides three sample dive profiles to 300fsw depth. The first profile is representative of a relatively commonplace 300fsw excursion for 25 minutes bottom time. The entire profile can be conducted within the nominal 4-hour duration of most primary life support. The shallow 20fsw decompression stop requires a stay of 94 minutes, which is generally considered within the margins of reasonable comfort for a wet excursion depending upon water temperature. Use of a simple shelter, however, could allow these 94 minutes to be used for carrying out work such as a preliminary processing of samples, taking notes, or dictating dive results to topside support via a communications system. Further, in extremely cold conditions, such as diving beneath ice, these 94 minutes could be spent within a habitat that is warmed using re-circulated warm water.

A 300fsw dive for 45 mintues bottom time requires 269 minutes of wet dive time before the 20fsw stop. This profile maximizes nominal life support for COTS systems of approximately 4 hours. By entering the habitat at the 20fsw stop, divers can shed their primary life support, and then depend on the habitat's life support for the remainder of decompression. For this particular dive, 408 minutes are required within the habitat. Note the PO_2 within the habitat has been significantly reduced from the wet dive setpoint so as to reduce elevated pulmonary oxygen exposures. This type of profile fits well within the current Ocean Space Habitat^{SM} design and life support capabilities.

A 300 fsw dive for 60 minutes bottom time requires 264 minutes of wet dive time before the 40fsw stop. This profile maximizes nominal life support for COTS systems of approximately 4 hours. By entering the habitat at the 40fsw stop, divers can shed their primary life support, and then depend on the habitat's life support for the remainder of decompression. Variable depth capability (Figure 4) of the habitat system allows the occupants to traverse their 40fsw, 30fsw, and 20fsw decompression stops within the habitat envelope while being reasonably comfortable and otherwise productive. For this particular dive, 607 minutes are required within the habitat. This duration exceeds the 8-hour life support package currently fit within the habitat's modular payload, and illustrates the need for the ability to 'hot-swap' the modular payload for additional life support capacity. This can be carried out by support divers, or a second dive team that will cycle through the habitat system during the scientific mission.

In effect, portable inflatable habitat technology can effectively double the time spent conducting scientific work at the 300fsw depth contour when utilizing wet diving techniques, and affords an opportunity to make use of otherwise idle, but highly valuable, decompression time.

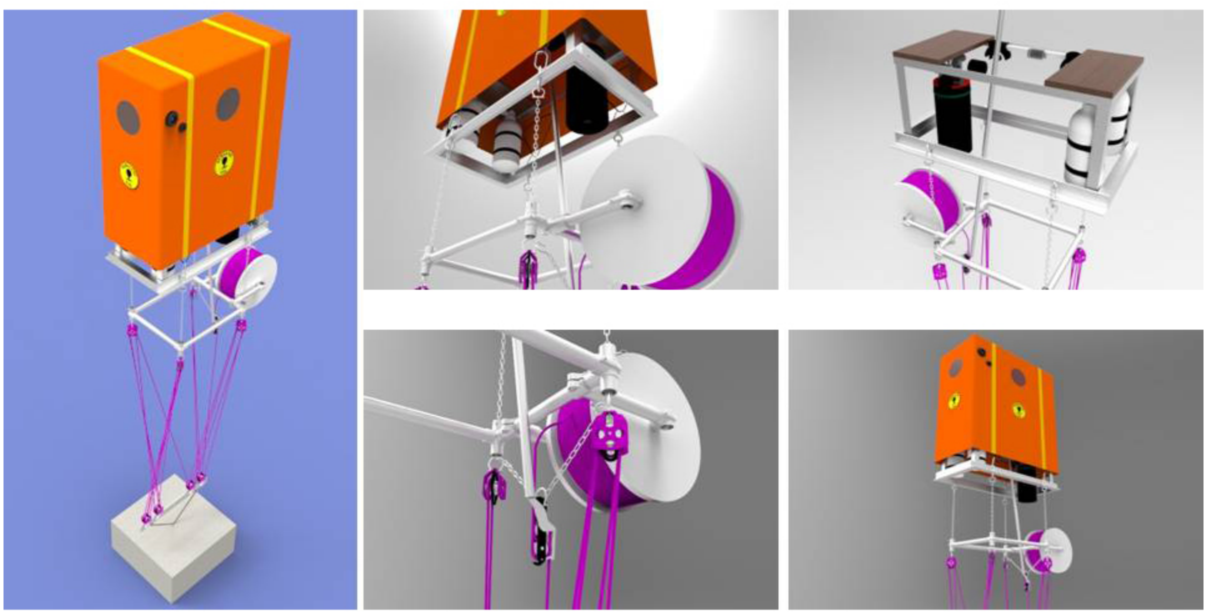

Figure 4: Variable depth configurations using a rigging strategy focusing on pulley reduction of the buoyant payload to within forces reasonably managed by the habitat occupants. In this concept, a standard climbing descender is utilized as the braking mechanism with the winch free-spooling slack during the controlled ascent. Note the bench seat array configured as framework for the 'modular payload', which includes necessary life support. This can be hot-swapped with a refreshed payload when consumed to provide provisions for the next cycle of divers.

Discussion

The Ocean Space Habitat[SM] has followed an incremental development path with demonstrated success at critical milestones. Forthcoming milestones include supporting an 8-hour (overnight) stay by the habitat occupant, and then traversing decompression stop depths.

The system integration approach to development allows an assemblage of largely commercial off the shelf (COTS) and familiar items to be implemented within the standard technical diving regime and affords vast range extension capabilities. This technology puts near-saturation diving excursions within future reach of the everyday diving enthusiast.

The authors acknowledge that previous efforts have been successful in the use of small, portable decompression habitats, though principally within the cave diving community within recent years. As development continues, it is critical to establish standard operating procedures, understand activity hazards, and better define the limitations of the technology such that redundant measures can be properly incorporated for safe and efficient future scientific work in a variety of environments.

Further demonstrating the capability afforded by portable inflatable habitats will result in valuable and currently unattainable scientific data to be acquired within alien ocean environments, and contribute to justifying continued incremental steps to a more permanent human presence on the seafloor in this century at much broader scales than today.

Acknowledgements

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