Safe Haven Configurations for Deep Space Transit Habitats

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Throughout the human space flight program there have been instances where smoke, fire, and pressure loss have occurred onboard space vehicles, putting crews at risk for loss of mission and loss of life. In every instance the mission has been in Low-Earth-Orbit (LEO) with access to multiple volumes that could be used to quickly seal off the damaged module or escape vehicles for a quick return to Earth. For long duration space missions beyond LEO, including Mars transit missions of about 1000 days, the mass penalty for multiple volumes has been a concern as has operating in an environment where a quick return will not be possible. In 2016 a study was done to investigate a variety of dual pressure vessel configurations for habitats that could protect the crew from these hazards. It was found that for a modest increase in total mass it should be possible to provide significant protection for the crew. Several configurations were developed that either had a small safe haven to provide 30-days to recover, or a full duration safe haven using two equal size pressure vessel volumes. The 30-day safe haven was found to be the simplest, yielding the least total mass impact but still with some risk if recovery is not possible during that timeframe. The full duration safe haven was the most massive option but provided the most robust solution. This paper provides information on the various layouts considered in the study and provides a discussion of the findings for implementing a safe haven in future habitat designs.

I. Introduction

FUTURE Mars mission will require a transit habitat that can support a crew of 4 for about 1000 days without major mishaps or failures. Smoke and fire on board are a concern, but the Space Station experience has provided great insight into designs and technologies that mitigate that risk. Another concern for Mars missions is pressure loss due to a small asteroid strike or a collision with another spacecraft during docking or undocking operations. Collision concerns at the International Space Station are somewhat mitigated by the availability of multiple modules and multiple return vehicles. Neither are available for current Mars mission scenarios and so a collision during these deep space missions could yield disastrous results. Figure 1 depicts one of several Mars mission scenarios with crew docking operations in Earth and Mars orbits. This includes docking and undocking operations of an Orion vehicle for crew transfers to the Mars habitat in Earth orbit; docking the Mars transit habitat to a return propulsion stage in Mars orbit; docking with a crew taxi vehicle for transfers to and from Phobos; docking to a descent vehicle for crew transfer to the surface of Mars; docking to an ascent vehicle for crew return from the surface of Mars; and finally, docking to an Orion vehicle in Earth orbit for crew transfer back to the surface. These operations yield up to 13 docking / undocking operations in a single mission where a collision at any step along the way could yield both loss of mission and loss of crew.

The safe haven concept was inspired to resolve this issue by determining the mass impact for providing a second pressure vessel that the crew could move into to give them time to recover from a mishap and designed in a configuration that could be launched efficiently on the Space Launch Systems (SLS). Multiple approaches were

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explored to provide a variety of configurations for the safe haven concept. Configurations considered included a single pressure vessel with an internal bulkhead, dual pressure vessels of the same size, and a primary pressure vessel with a second smaller unit for the safe haven. Life support options included duplicate closed loop life support systems for full duration in either volume, and a single closed loop life support system in the primary volume with an open loop life support for 30-day duration in a smaller secondary volume.

The starting point for the safe haven concepts developed in this study came from the Mars Transit Habitat baselined in the Advanced Exploration Systems (AES) Evolvable Mars Campaign (EMC). Internal layouts were developed along with subsystems sizing and mass estimates that could then be compared to the variety of alternative layouts planned. Figure 2 provides of graphic showing the EMC baseline monolithic habitats (1a and 1b), and the four safe haven habitats (2-5) developed in this study. Configuration 1a represents the standard single volume monolithic habitat currently planned for Mars missions that includes a closed loop life support system designed to support 4 crew for 1000 days. Configuration 1b is a maturing of that same design providing more detailed internal layout options, a little more volume for stowage, and end domes based on current SLS manufacturing capabilities. Configuration 2 is the same as configuration 1b but creates a safe haven by installation of an internal bulkhead with intra-vehicular activity (IVA) airlock, and a duplicate closed loop life support system for full duration capability. 1b and 2 are compared to determine basic bulkhead and life support system mass. Configuration 3 has two pressure vessels of the same size that have a total volume equal to configuration 2 with duplicate life support systems. When configuration 3 is compared to configuration 2, it yields a better understanding of using dual pressure vessels of equal size vs. the internal bulkhead approach in a single pressure vessel. Configuration 4 is a new concept utilizing the pressure vessel volumes planned for the Exploration Upper Stage (EUS), which yielded a convenient large volume habitat with a closed loop system paired with a smaller volume using a 30-day open loop systems. Configuration 5 then matches the total volume of configuration 4 with two equal pressure vessels and duplicate closed loop life support systems for full duration in either volume.

Conclusions include a variety of findings from the study indicating a need for further research and the development of concepts of operations for various risk scenarios. One issue is that the full duration safe haven configurations required transfers of consumables from the damaged volume to the duplicate volume, which presented concerns over the survival of some consumables in the vacuum of space. The mass delta can be found by comparing configuration 1b to 2, with a total mass delta on the order of 6000 kg due primarily to the structural mass required to create duplicate volumes, duplicate avionics, and duplicate life support systems. The 30-day safe haven has operational concerns as to whether repairs to the primary habitat be accomplished in the time allocated. The mass delta can be found by comparing configuration 4 to the other configurations noting a 3000 kg reduction is life support mass when using a 30-day open loop system in lieu of a second closed loop life support system.

Mars Mission Docking and Undocking Operations. (Graphic to be developed.)

1. Orion docks to HAB
2. HAB undocks from Orion
3. HAB docks to return propulsion stage
4. HAB docks to crew taxi
5. Crew taxi undocks from HAB and goes to Phobos
6. Crew taxi docks to HAB upon return from Phobos
7. Crew taxi undocks from HAB for disposal or storage in orbit
8. HAB docks to Mars lander
9. Mars lander undocks from HAB and goes to surface
10. Mars ascent vehicle docks to HAB
11. HAB undocks from Mars ascent vehicle
12. HAB docks to Orion
13. Orion undocks from HAB

Figure 1. Mars Mission Operations. Depicted are the sequence of possible docking and undocking operations for a typical Mars mission where a safe haven could protect the crew from pressure loss in the event of a collision. (Graphic to be developed.)

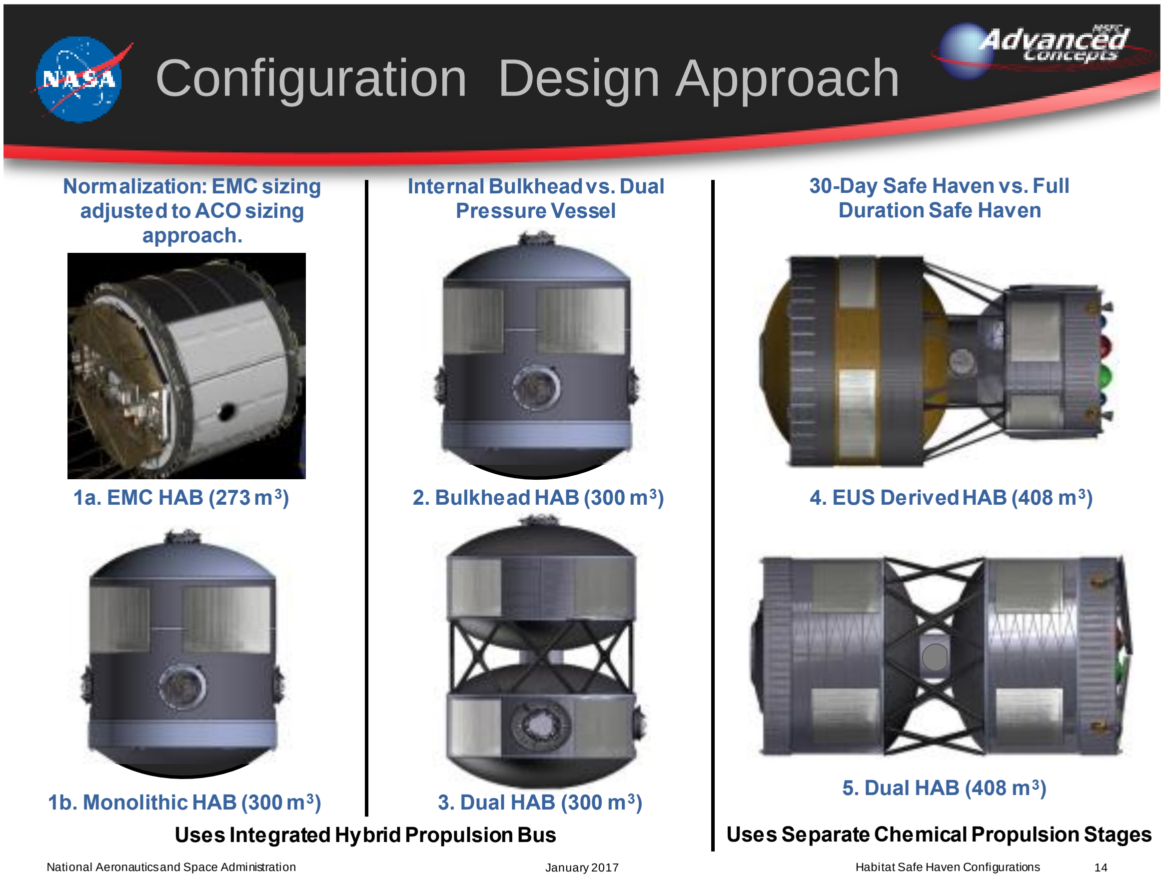

Figure 2. Habitat Configurations. Two monolithic habitats were used as a baseline for the development of four habitat safe haven configurations. (Graphic to be further developed.)