Abstract

In order for man to return to space or extra terrestrial bodies for long duration missions it is important that adequate habitat volume be defined early to avoid costly delays and redesign. To properly define a habitat volume two major factors need to be considered. The first factor is the free or open space. This is the space that allows the crew room to move about the habitat. This space will vary based on crew size and length of the mission. The second major factor is the stowage space required for equipment and supplies. This includes both fixed volumes and consumables. Fixed volumes include items such as tools, communication equipment, Advanced Life Support (ALS) equipment, and support equipment. Consumables include items like filters, food, water and oxygen. This space is also dependant on crew size and mission length. A review of past missions into alien environments, such as deep sea habitats as well as space based habitats will be used to validate the assumption made in this paper. Once these key factors are defined trades must be run to optimize the overall volume of a habitat. This includes trades of disposable vs. reusable for items such as clothing, dishes, and water. Another factor to consider is the availability of in situ resources to aid in the construction of the habitat structure as well as re-supply of consumable items. A review of past missions into alien environments, such as deep sea habitats as well as space based habitats will be used to validate the assumption made in this paper. The result is a habitat sizing tool to provide a first order estimate of habitat volumes for extended mission to the surface of the moon and Mars.

Introduction

Since President Bush's announced Exploration Initiative, NASA and its contractors have been involved in a flurry of activities to define exploration vehicles, habitation and supporting technologies. One of the driving requirements for the design of habitats as well as launch vehicles is "How much room does the crew require?" The two key requirements that drive this question are: "How many crew?" and "How long do they stay?" In order to properly assess this volumetric requirement a method of quickly evaluating the impact of crew size and duration is needed to avoid schedule delays and cost over runs. The Habitat Sizing Tool (HST) was developed to quickly assess the impact of varying crew sizes and mission durations on the habitat size and to define a baseline habitat to support the In Situ Fabrication and Repair (ISFR) Habitat Structure trade study for construction methods using in situ materials. Since man is the "primary payload", his personal space needs to be larger due to the psychological aspects and increased storage associated with longer missions. The HST accounts for not only the crew's personal space, but the major support systems, crew accommodations, equipment, consumables and other items.

Materials and Methods

The sizing of a Lunar or Martian habitat can be approached from two avenues. The first is a historical approach looking at previous missions into hostile environments such as deep sea habitats and space based habitats or vessels. The second approach is to compile a list of what is needed based on the number of crew members and duration of the mission. The masses and volumes of each item will be tallied. Both of these approaches are utilized and reviewed.

Historical Approach

Reviewing man's quest to explore hostile environments takes us down two separate roads. First is man's quest to explore the depths of the oceans here on earth. The second is his quest to explore outer space. Each path has its own unique set of issues relating to the environment. However the living space required could be similar.

From 1962 to 1977 world-wide, over 65 undersea habitats were built. Some of the key drivers for the size were the number of crew and the duration of each mission. Due to the ease of re-supply, the proximity to a safe natural environment and the abundance of resources, long term storage was not a major requirement. However Mission durations were limited due to long term exposure to the elevated partial pressures of various gasses and the extreme high pressures at various depths. A normalized plot of volume per crew member as a function of mission duration can be found in Figure 1.

In comparison only 12 types of spacecraft have carried man out of our environment and into the vacuum of space. Mission durations have been severely limited due to the extreme cost and difficulty of access to outer space including re-supply activities. Figure 2 shows a normalized plot of spacecraft volumes per crew as a function of mission duration.

Model Approach

After reviewing several models for sizing various aspects of space based habitats, the decision was made to integrate several of these models into a single habitat sizing tool. This tool takes fixed masses and volumes for key equipment, personal storage, and consumables and adds this to the requirement for personal free space to derive an overall mass and volume based on the number of crew and the mission duration.

Model Introduction

The Habitat Sizing Tool (HST) is a conceptual-level design tool for sizing a surface habitat structure. The tool uses a series of inputs to determine the mass and volume of a surface habitat for the Moon or Mars. The inputs can be divided into two major categories: primary and reference. The primary inputs are mission parameters such as crew size, mission duration, and the number of Extra-Vehicular Activities (EVAs) and the habitat configuration. The reference inputs derive the masses and volumes for the structure, crew accommodations and equipment, thermal control system, power, life support, avionics and consumables.

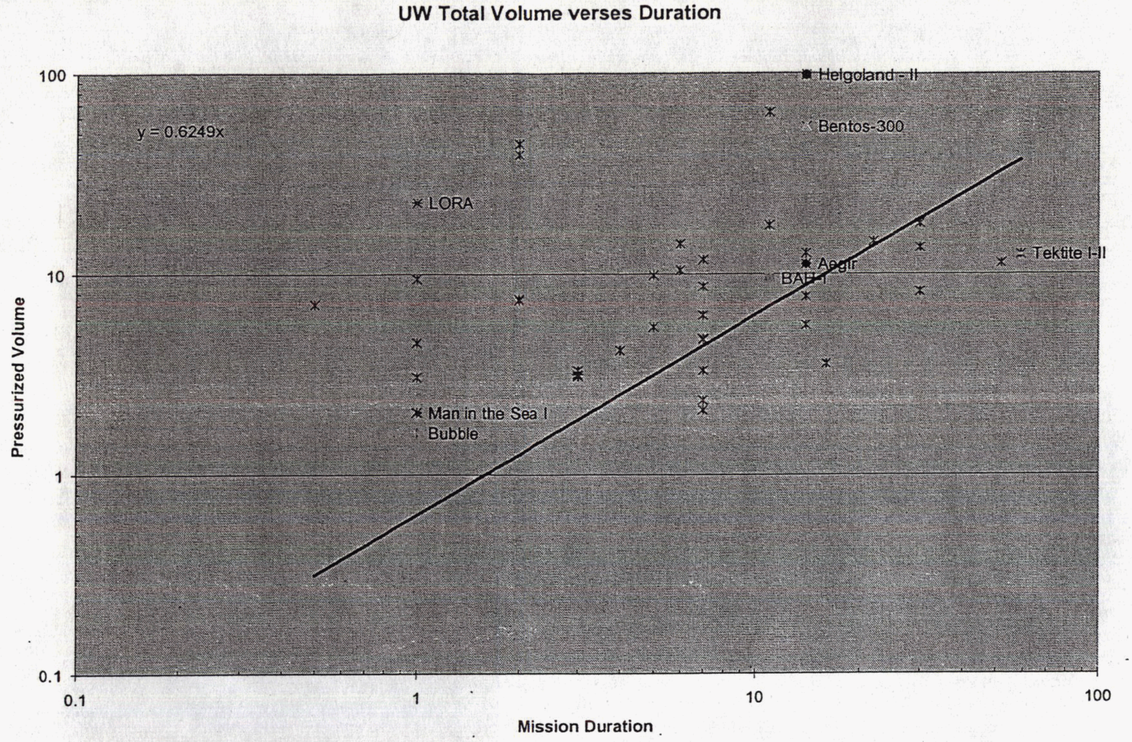

Figure 1 Under Water Habitats

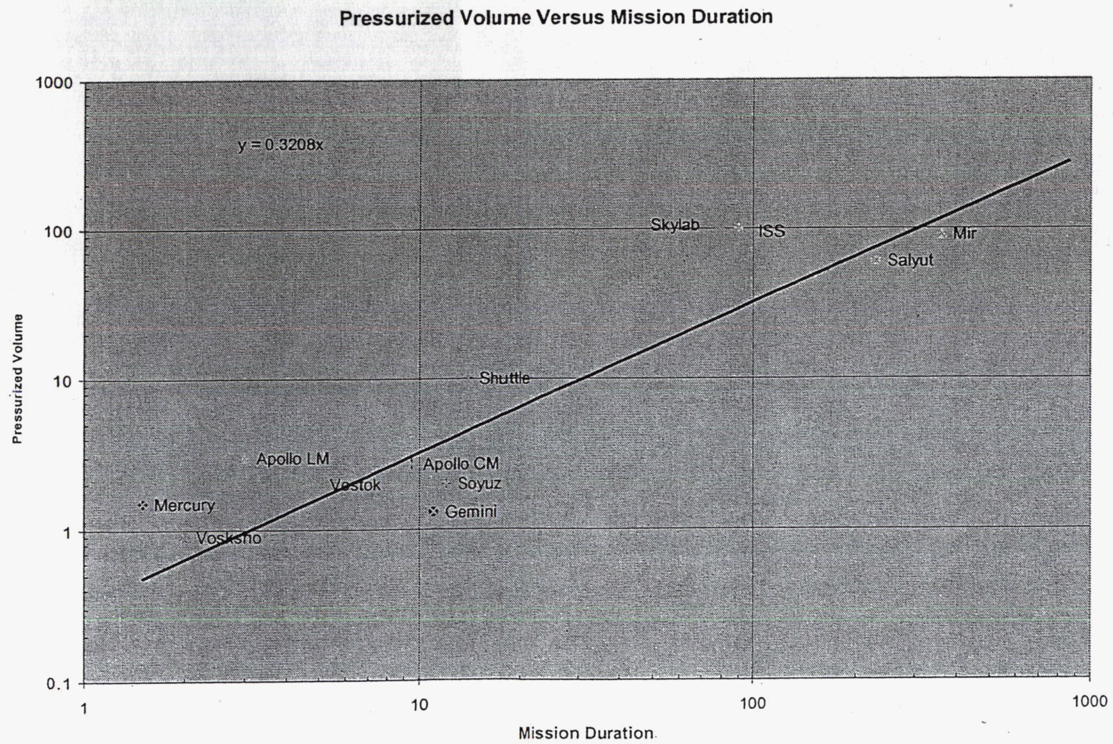

Figure 2 Space Habitats

Results

Historical

By reviewing Figures 1 and 2 and performing a linear regression, two linear equations are developed; one for underwater habitats and a second for space-based habitats. The equations are as follows:

$$\text{Volume} = (0.6249 * \text{duration}) * \text{Number of crew} \quad \text{(underwater)}$$

$$\text{Volume} = (0.3208 * \text{duration}) * \text{Number of crew} \quad \text{(space based)}$$

Figures 3 and 4 show a graphical representation of these equations respectively. Each figure is a family of curves for volume as a function of duration and crew size.

Model

The HST was run with varying duration of up to one year with a crew from 2 to 10. The results are shown in Figure 5. A sample output is shown in Table 1.

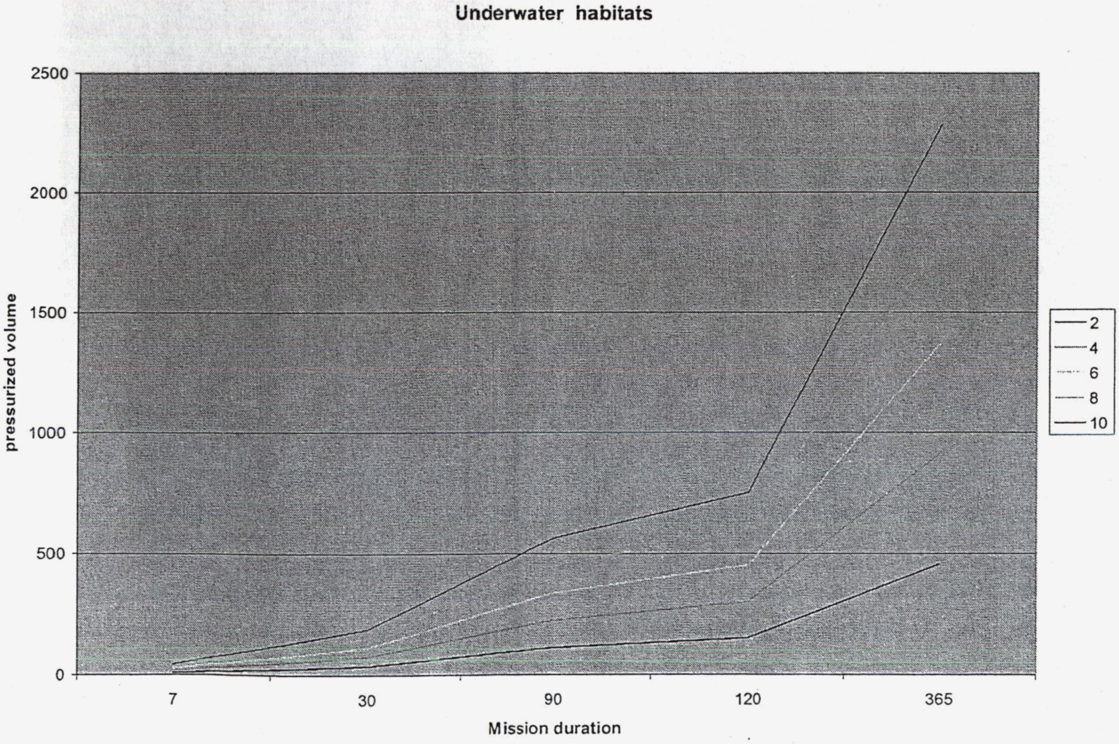

Figure 3 Historical Underwater Model

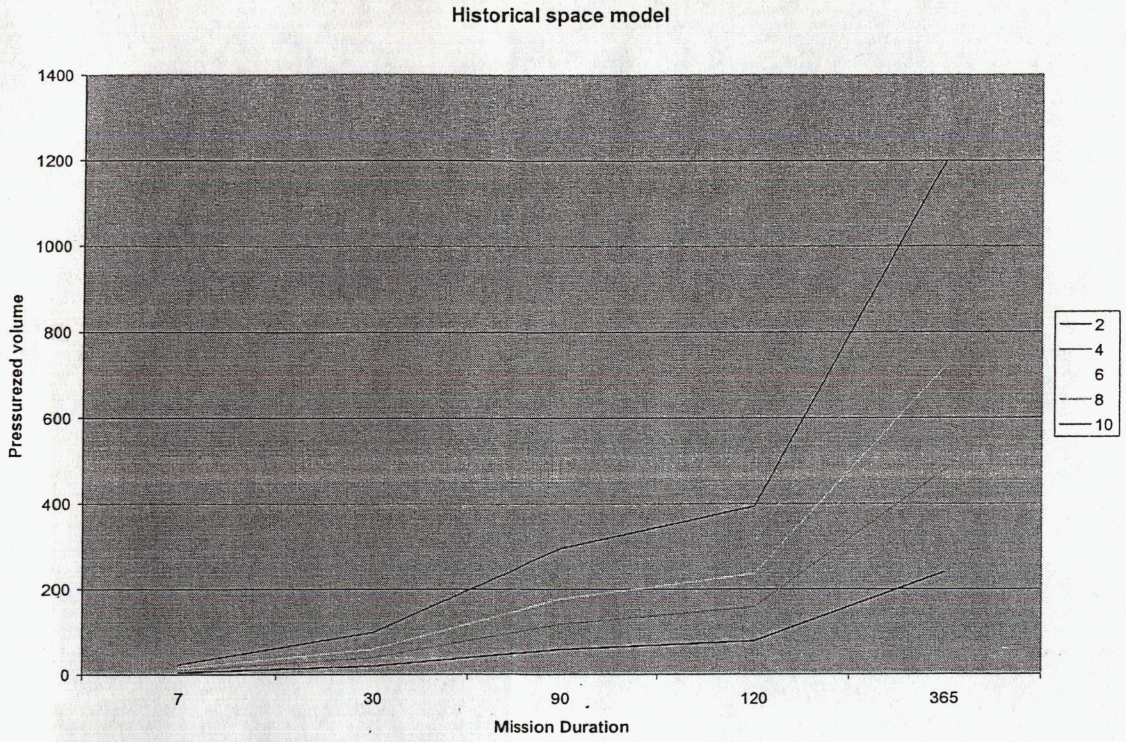

Figure 4 Historical Space Model

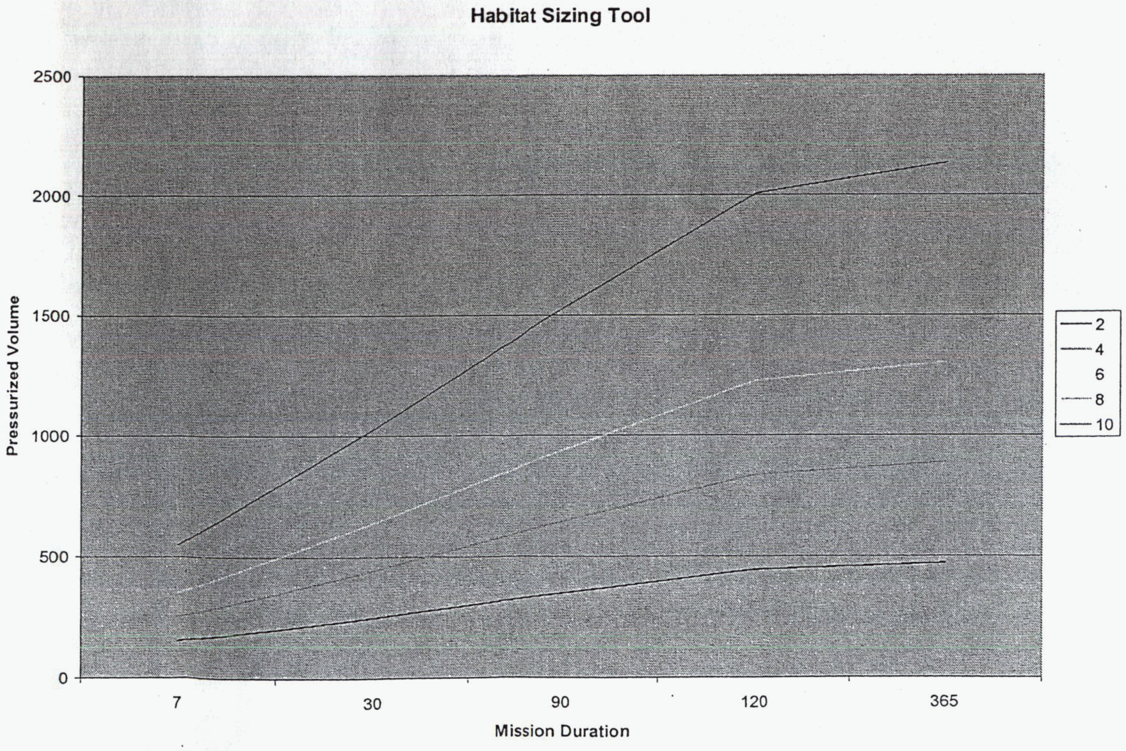

Figure 5 Habitat Sizing tool

Table 1 HST Sample output

1.1	Structure	13,745 lb	8,000 ft3
1.2	Crew Accommodations / Equipment	8,803 lb	827 ft3
1.3	Thermal Control System	2,004 lb	
1.4	Power	954 lb	
1.5	ECLSS	1,323 lb	
1.6	Avionics	209 lb	
	Dry Weight	27,037 lb	12,827 ft3
1.7	Consumables	6,172 lb	175 ft3
	Gross Weight	36,181 lb	13,088 ft3

Conclusions

In reviewing the results of the three models there are distinct differences. The underwater habitats yield the smallest living space, most likely because it has the easiest access to our own natural environment. Many resources are in close proximity and the environment is moderate with the exception of high pressures. If the pressures are ambient this limits the time man can spend in this environment due to the increased risk of oxygen toxicity. If the pressure is held at atmospheric (sea level), this creates issues with access of the environment due to the long decompression time to exit the environment, and on the equipment used for the mission due to the huge pressure differential. The impact of pressures could be lessened by placement of the underwater habitat in shallower waters

The linear space model is based on known fixed systems. However the missions are quite different. The early missions were just quick visits to the void of space. Not until Apollo program was the spacecraft designed as a habitat instead of a transportation vehicle. The mission time was short due to the re-supply intervals (i.e. not much storage was required). Another restriction of the previous missions is that, with the exception of the International Space Station, each vessel was a single launch. For Lunar and Mars bases multiple launches can be used to build the habitat.

The HST Model is versatile due to its wide range of inputs. The model can aid in conducting trades such as for determining the best options for each mission. One example is clothing, do you send clothing for the whole mission or do you provide a clothes washer and a limited set of clothing. The HST can aid in mass and volume requirement definition and allocation for each onboard system. Additionally, the HST can be used to optimize the free space for each crew member, and to determine the re-supply time based on consumable storage.

In conclusion, the more detailed a system can be modeled the better its requirements can be defined. Models can be used to predict and aid in the development of any large system where cost and schedule need to be controlled. The HST model provides the level of fidelity required to accurately assess mission definition.

Acknowledgements

Moonraker, Jon Wallace, 2004, Spaceworks Engineering
ECLSS Model, Monsi Roman, Greg Schunk, 2005, Marshall Space Flight center
Crew accommodation model Human Spaceflight: Mission Analysis and Design, Wiley J.Larson, Linad K. Pranke, 1999,McGraw-Hill

References

Subsea Manned Engineering, Gerhard Haux, Jorg Hass, Anthony Lovell Smith, 1982, Best Publishing Company
Living and Working in the Sea, James W. Miller, Ian G. Koblick, 1995, Best Publishing Company
Human Spaceflight: Mission Analysis and Design, Wiley J.Larson, Linad K. Pranke, 1999,McGraw-Hill

Further Information

For more information about the Habitat Sizing Tool please contact

Walter L McGregor
MSFC/Qualis Corporation
256-544-6758
Walter.L.McGregor@nasa.gov