2004-01-2532

MOM: Media & Observation Module

Maijinn Chen, R.A.
Graduate student, Sasakawa International Center for Space Architecture, University of Houston, Houston, Texas

ABSTRACT

This paper describes the design of a Media and Observation Module (MOM) for a future space orbital facility. MOM is based upon the idea that media operations can *coexist* with some of the station's primary operations through design interventions. MOM would take the place of a space cupola, supporting station-keeping and observational operations while meeting media and commercial goals of the orbital facility.

Advanced wearable technologies in display, sensing, and control are being proposed as the means to integrate seemingly opposing operations within MOM. The paper provides a general summary of these technologies. In addition to designing the technological and environmental subsystems of MOM, the author conducts systematic analyses, including an evaluation of all target operations based on their human, operational, and technological requirements. These analyses generate design concepts for both the module exterior and interior, and provide insights into a technologically augmented operational environment that improves upon the way astronauts work and live in space.

INTRODUCTION

The idea of outer space as a consumer haven has been around for a long time. It is the ultimate unique environment where innovative ideas, methods and practices can be nurtured and tested. In fact, commercialization of Earth's orbital space has been a priority goal of the United States, as declared in the Commercial Space Act of 1998.

Unfortunately, human exploration of space has always remained in the hands of the selected few. The relationship between space endeavors and the public they are supposed to benefit has been indirect and minimal, and sometimes as a mere afterthought. Media and creative operations should play a more active role in space to strengthen this relationship, thereby helping to enhance the habitability and the economic value of our future space enterprises.

Generally, past attempts to bring media and creative operations to space facilities involved proposing dedicated media modules to separate media operations from station-related operations. An example is the Enterprise module, proposed in 1999 by Spacehab and RSC Energia for the ISS. MOM represents an alternative way of thinking, where technical operations are not physically segregated from creative endeavors. This makes MOM a more integral and necessary element of the orbital facility. As habitable volume is a highly valued commodity in space, this also helps to increase the usability and flexibility of a confined environment.

Such an infusion of media and creative operations must take care not to compromise the mission goals and the technical demands that keep the space environment safe for the astronauts. One way to achieve integration of media and station operations within a confined space may be to provide greater operational control to the user, and create a greater degree of interaction between the astronaut, the operating technologies, and the data. This human-machine-data coupling may be achieved via two ways:

1. Through advanced technologies capable of ubiquitous computing, enhanced visualization capabilities, and advanced user interface to establish a more intimate human-data interaction.
2. Through the use of body wearable technologies, which are physically compact systems with body-wearable computers, head-mounted displays, and wearable sensors and controls.

These technologies can increase efficiency in precise technical pursuits such as conducting experiments and station-keeping operations, by reducing time and effort in task performance. **(Dooris et al., 2000)** They can also help create a visually compelling, data-rich environment to support human collaborative and creative pursuits, in forms of art, entertainment, education, or any media-related endeavors.

Technical and creative pursuits need not be irreconcilable. After all, data and image processing is a task performed by scientists and engineers, as well as by artists. The difference lies in the nature of the data and its manipulation. Advanced technologies may be a way to provide a smoother transition between the science and art of space operations.

Proper technology implementation for space use will require detailed analyses on the technological systems, the target operations, and also the complex human factors considerations within an orbital environment. Project MOM focuses on how these three fundamental aspects interact to achieve a more efficient utilization of the operational environment within the designed module.

PROJECT BACKGROUND

Project MOM was a three-month-long individual project in the 2003 fall semester design studio at the Sasakawa International Center for Space Architecture, University of Houston. The author designed the project structure and methodology, the detail of which is explained throughout the paper. For information on advisors see the "Acknowledgements" section.

Key project goals for MOM are as follows:

1. Identify and evaluate target media and station operations.
2. Provide a survey of the advanced enabling technological systems to be used in MOM.
3. Provide design of the supporting technological and environmental systems.
4. Initiate interior concepts for the designed module.

TECHNOLOGY ANALYSIS

MEDIA

To establish a concise media program for MOM, key questions are raised: how do we define "media" as applied to MOM? What constitutes media work? What technologies would enable its operations?

Media in essence embodies the acquisition, processing, and transmission of audio, visual, and textual data for a mass audience. MOM provides the users, on a reimbursable basis, the following utilizations in Earth orbital space:

1. An environment in which to conduct multimedia projects of commercial and artistic nature.
2. Full editing and broadcasting capabilities for the production of documentaries, real-time broadcasts, educational and other public outreach programs.
3. Gaming and entertainment for the astronauts.
4. A test-bed facility for advanced technologies in display, sensing, and control for space use.

The media system used in MOM must be versatile and physically compact to easily incorporate into its equipment racks. Although not built for operations in space, terrestrial precedents may serve as a preliminary baseline design for MOM. For instance, there exist today end-to-end media production systems that can pack all the capabilities of a TV station or a production company into a single, physically compact rack. Examples of such systems include, but are not limited to, the Sony DVLince products and the DaletPlus News Suite. These systems share the following characteristics **(Sony & DaletPlus websites):**

- An IT infrastructure using Gigabit Ethernet, offering shared, server-based immediate access to video, audio, wires, feeds, scripts, computer graphics, and stills.
- Built-in workflow management programs allowing the operators to easily ingest video, edit, write scripts, add graphics and feeds even during recording, and broadcast with one click.
- Flexible broadcast content that can be easily re-purposed for alternate media services, including website, radio, or print.

A conceptual layout for MOM's Media Console is illustrated in Figure 15, in the "MOM Design: Utilities" section.

AUGMENTED REALITY TECHNOLOGIES

There have been important recent advances in technologies that aim to augment natural human perceptive capabilities and increase user control over the environment and the data. In such a technologically savvy environment, the mediation of reality can come in differing degrees, depending on the nature of the combination of the real and the virtual. **(Fig. 1)** The kind of mediation most applicable to MOM is the one created by Augmented Reality (AR) technologies, in which the user can see superimpositions or composites of virtual objects with the real physical world. Thus, AR technologies enhance the human senses, rather than completely replacing them.

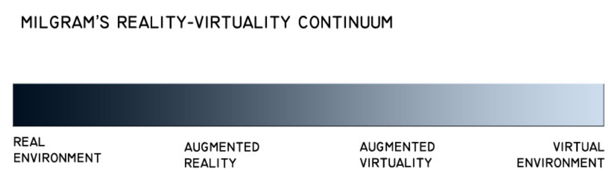

Figure 1: Milgram's reality-virtuality continuum (Adapted from Milgram and Kishino, 1994)

In addition, to serve the operational goals of MOM and complement the microgravity environment of space, the implemented technologies must not be cumbersome or stationary. The technologies used in MOM shall be body-wearable where possible. **(Fig. 2)**

A wearable technology may be defined as one that is integrated into the personal space of the user. **(Dooris et al., 2000)** The increased human-computer interactions offered by a mobile tech environment provide constant access to computing and communications resources, and respond more intelligently and continuously to user needs, even in a changing environment. **(Starner et al., 1997)**

Figure 2: Examples of body-wearable technologies: MIT Media Lab's MIThril Project (left) and the Battlefield Augmented Reality System (right)

There are many kinds of enabling technologies that can be used to construct a *mediated* and *wearable* environment in MOM:

Displays

MOM operators will employ Head-Worn or Head-Mounted Displays (HWD or HMD), which provide visual representations that merge physical and digital entities. The HWD can be categorized as follows:

- *Optical see-thru displays*, which use head-mounted projectors and partially transmissive / partially reflective lenses to enable the user to look at the real world and see virtual images superimposed upon it. **(Fig. 3a)**
- *Video see-thru displays*, where the user's view is a combination of the real world view provided by head-mounted video cameras, and graphic images created by the head-mounted scene generators. **(Fig. 3b)**

Optical see-thru displays are in general simpler and cheaper than video see-thrus. As well, the user's view is not dependent entirely on the quality and stability of the technology. If the power is cut, the user can still have a direct view of the real world. This adds safety. Video see-thru displays, however, allow better blending and merging of real and virtual, since both are available in digital form. **(Azuma, 1997)** For these reasons, optical see-thrus are better when used in situations where overlay of information is paramount, such as in mechanical assembly and repair tasks. Video see-thrus are better for precision tasks such as tele-robotic or surgical operations, where simulation of reality and alignment are important.

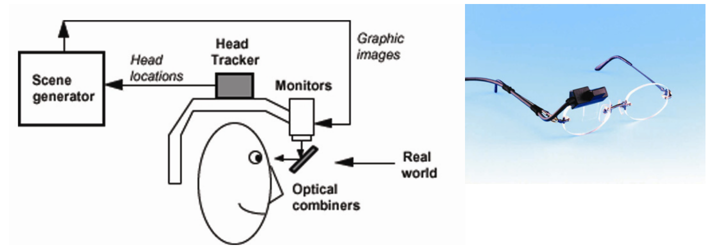

Figure 3a: Optical See-thru HMD

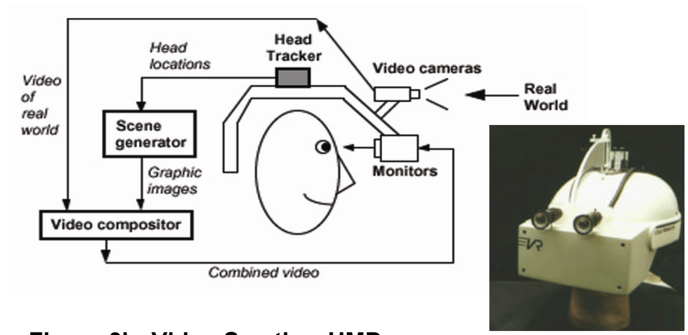

Figure 3b: Video See-thru HMD

Controls

MOM's controls can be wearable to increase mobility, and haptic to augment the tactile experience of the operation.

Wearable controls may include wearable keyboards, touchpads, and even the user's own finger whenever a pointing device is desired. **(Starner et. al, 1997)** Recent development in haptic controls includes devices that can take tactile "pictures." For example, a haptic interface is being developed at Stanford University by Kenneth Salisbury and Francois Conti, where a spider-like robot records and plays back the operational forces it experienced. **(ForceDimension website, 2003)** Other devices include gloves and finger-holders that allow the user to experience the force and texture of the operation.**(Fig. 4)**

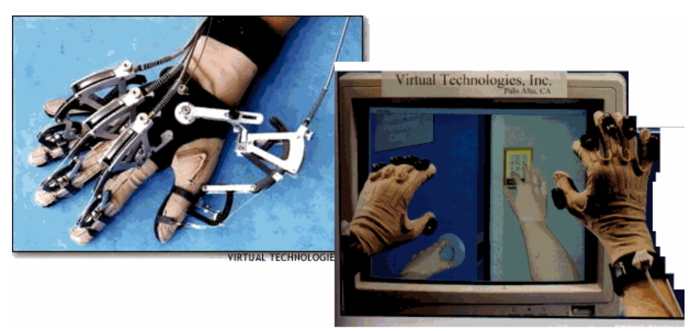

Figure 4: Haptic Control - The CyberGrasp Force Feedback Glove by Immersion Corporation.

Tracking & Registration

To precisely superimpose the virtual to real objects, the display technologies must be able to accurately and speedily track physical objects in space and align them to those in the virtual world. This is a difficult technological feat, and it is further complicated by the mobility of the user.

In general, tracking sensors include optical and video sensors that track a user's viewing orientation and position with respect to the real scene. Recent efforts are being made to increase the accuracy of tracking in AR to better respond to the mobility of the users. For instance, accelerometers and video tracking are being combined to provide accurate registration even during rapid head motion. **(Azuma et al., 2001)** Software has also been developed for calibration-free renderers for faster computations to increase the accuracy of registration. Much testing is required to see how tracking and registration will work in a microgravity environment. Increased mobility in weightless conditions can compound registration problems by creating spatial and temporal misalignment of virtual and real objects. This may be minimized by keeping the operational environment small, and by further advances in the technologies briefed above.

Potential Applications

AR technologies are already being used today on Earth, in the medical field for training or as guiding aids for precise surgical tasks. They are also being used in manufacturing and repair, robotic tele-operations, and navigation in poor visibility conditions such as underwater or fog. **(Fig. 5)**

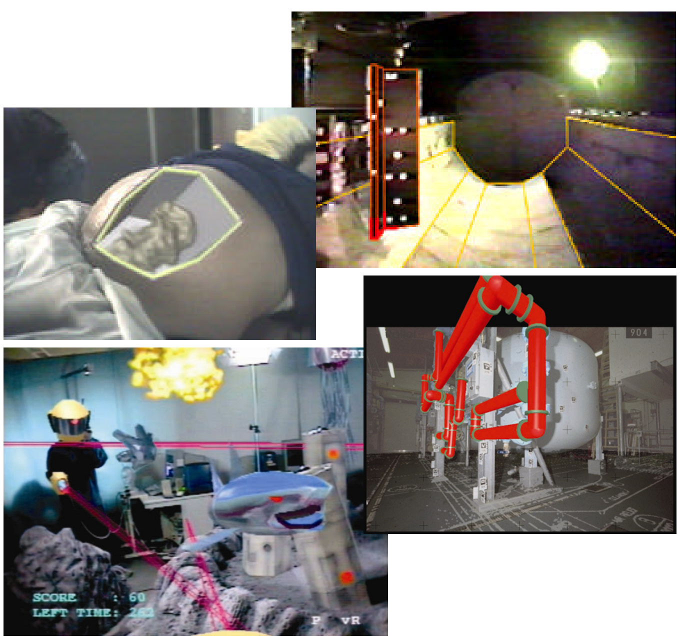

Figure 5: Current applications of AR, clockwise from top left: medical, aerospace, construction, and entertainment

Conceivably, these Earth-based applications may translate to space-related operations. Astronauts can use AR for faster and more precise docking and tele-robotic operations. They can be used in performing station repair, and annotating stowage in the crew's visual field to help track items onboard. They can provide navigation and flight information to the astronauts, and help them see better in deep space, where visual cues for depth of field are absent and lighting conditions are extreme. On another front, these technologies can provide a collaborative and interactive platform on the space station for educational and entertainment purposes. They can even be used in the crew's mission task and psychological training programs.

It is important to be aware that there exist limitations to the current AR technologies, including size, weight, and cost issues. Such limitations may be particularly unforgiving in the extreme environment of space. Fortunately, many problems of AR are surmountable as technological advances will no doubt continue into the future.

OPERATIONAL ANALYSIS

MOM's target operations are evaluated according to their human and technological requirements, to determine how they can be best integrated and supported by the technological systems. The target operations are divided into three main categories:

1. Station Operations – which include proximity, docking, payload bay, EVA, and tele-robotic operations.
2. Observation Operations – which include station-related, scientific, and recreational observational activities.
3. Media Operations – which include commercial and educational broadcasting, interactive gaming and entertainment, and post-production activities including data and image processing.

Preliminary analysis brings forth several important issues. **(Figure 6)** First, station and observation operations for the most part can be seamlessly integrated, as they share many similar human and technological requirements. For instance, for both payload bay operation and scientific observation operation, a local vertical must be established within the operational environment. The user must be oriented within ~45 degrees of this local vertical to properly perceive and operate the displays and controls of the workstations. **(NASA STD-3000/Vol.1/Rev.B/4.0)**

In terms of technologies, AR systems can be used in these technical operations. An optical see-thru head-worn display, for instance, allows the overlay of 3D CAD views of docking ports or payload bay areas, to augment an operator's view of outside where it may otherwise be obstructed or impaired. However, with their main emphasis on precision and efficiency, station and observation operations will require traditional display and control technologies as the back-up system to fulfill safety and redundancy requirements.

		Human Requirements																		Technological Support																		
		Orientation			Visual				Noise			Kinesthesia			Strength			Habitability			Controls							Displays					Sensors				Operation Rqmt		
		Fixed Local Vertical	Multiple Local Verticals		Short Distance Viewing (Display/Projection)	Multiple Distance Viewing (Display/Projection)	Window Viewing		Low Level Noise Required During Operations	Sound Attenuation Required		Fast Reaction-Response Time			Body Restraints	Mobility Aids		Vibration Attenuation	Task Lighting and Dimming		Hand Control Input Device: Knobs/wheels/switches	Foot Control Input Device: Switches/Pedals	Tangible Interface for Direct Manipuation: Keyboard	Tangible Interface for Direct Manipuation: Joystick	Others: Trackball, Light Pen	Touch-Sensitive	Voice-Activation	CRT Display screens	Head-worn Optical/Video See-Thru	Hand-held Video See-Thru	Projection Display	Integrated Multiple Displays Interface	Exterior Camera / Sensors	Internal camera / Environmental sensors	Body-wearable / bio-sensing	Tracking, Registration, Calibrations	Unified Work Surface	Multiple Surfaces required	Portability and reconfigurability
Station Operations	Proximity Operations	●	✖		●	✖	●		●			●			●			●	●		●		●	●		✖	✖	○	●			○	●			●	●	✖	●
	Docking Operations	●	✖		●	✖	●		●			●			●			●	●		●		●	●		✖	✖	○	●			○	●			●	●	✖	●
	Payload Bay Operations	●	✖		●	✖	●		●			●			●			●	●		●		●	●		✖	✖	○	●			○	●			●	●	✖	●
	Equipment Tele-operations	●	✖		●	✖	●		●			●			●			●	●		●		●	●		✖	✖	○	●			○	●			●	●	✖	●
	EVA Monitoring and Control	●	✖		●	✖	●		●			●			●			●	●		●		●	●		✖	✖	○	●			○	●			●	●	✖	●
	Ground Communications	●	✖		●	✖			●						●				●				●		○			●									●	✖	●
	Ingress & Egress															○																							
Observation Operations	General Recreational Observations	●	✖		●	✖	●		●			○			●			○	○		●		●		●	✖	✖	○	●			○	●			●	●	✖	○
	Earth Scientific Observations	●	✖		●	✖	●		●			○			●			●	●		●		●		●	✖	✖	○	●			○	●			●	●	✖	○
	Celestial Scientific Observations	●	✖		●	✖	●		●			○			●			●	●		●		●		●	✖	✖	○	●			○	●			●	●	✖	○
	Station Observations	●	✖		●	✖	●		●			○			●			●	●		●		●		●	✖	✖	○	●			○	●			●	●	✖	○
	Ground Communications	●	✖		●	✖			●						●				●				●		○			●									●	✖	
	Ingress & Egress															○																							
Media Operations	Post-production work (Data / Image Processing)	●	✖		●	○	✖		●	●		●			●			●	●		●		●		●			●	●			●					●	○	●
	Interactive / Gaming / Entertainment	✖	●		○	●	○		●	●		●			●	●			●					●			●		●		●	●	●	●	●	●	✖	●	●
	Educational / Public Outreach	✖	●		○	●	●		●	●					●	●			●				●		○			○	●		●	●	●	●	●	●	✖	●	●
	Augmented Broadcasting	●			●	○	●		●	●					●			●	●		●		●		○			○	●			●	●	●	●	●	●	○	●
	Test-bed of AR Technologies	✖	●		○	●	●		●	●		●			●	●		●	●		●	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	✖	●	●

● Required
○ Recommended
✖ Not Recommended

Preliminary Analysis:
1. Interactive, Education, Test-bed : spatial separation required
2. Post-production work : Can be integrated, but requires sound attenuation and away from window
3. Augmented Broadcasting : Can be integrated, but requires sound attenuation

Figure 6: Operation-Human-Technology Matrix

Media operations, on the other hand, must encourage human intuitive and creative endeavors. A media operational environment should provide flexible and reconfigurable work surfaces, and be operable in multiple local verticals to take full advantage of the mobility afforded by the wearable AR technologies. This will be especially appropriate in gaming and entertainment operations.

As expected, conflicts exist between media operations and the station- and observation-related operations. By implementing wearable AR technologies, however, the user maintains the control over information input and output, and the nature of its manipulation. The need for workstations becomes diminished. The operator has effectively become the bridge connecting operations of diverse nature.

MOM must provide an environment where the astronauts are able to effortlessly move from a station- or observational-related task to a media- or creative-related one, without sacrificing the quality of operation of either activity. To achieve this, a closer look is required to see how the human body interacts with the physical volume of the space in microgravity.

PERSONAL VOLUME ANALYSIS

The analysis of the "human impact" of microgravity is based on a study of NASA's Man-Systems Integration Standards on Anthropometry and Biomechanics. **(NASA STD-3000/Vol.1/Rev.B/3.0)** The first thing to consider is the impact of the neutral body posture in microgravity - a result of the balancing of muscular forces acting on various body joints in weightlessness. The neutral body posture therefore predetermines much of the dimensioning of human-machine interface in MOM. **(Figure 7)**

There is the human reach volume, derived from the functional reach data provided in the NASA manual. Tasks that require strength and dexterity should be located within the perimeter of this envelope. The user range considered is also specified by NASA: 5th percentile Japanese Female to 95th percentile American Male. The range of body motion by the crew using hand or foot restraints is also studied.

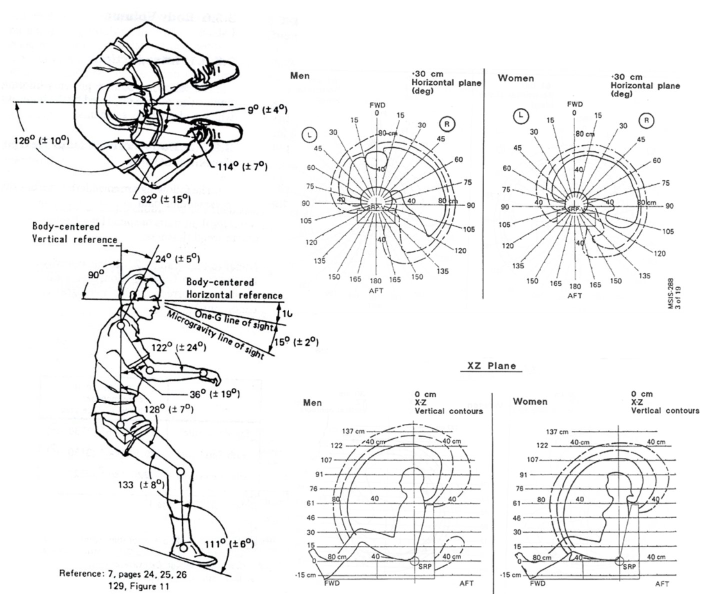

Figure 7: The Neutral Body Posture (left), and an example of the Strike & Grasp Reach Data (right)

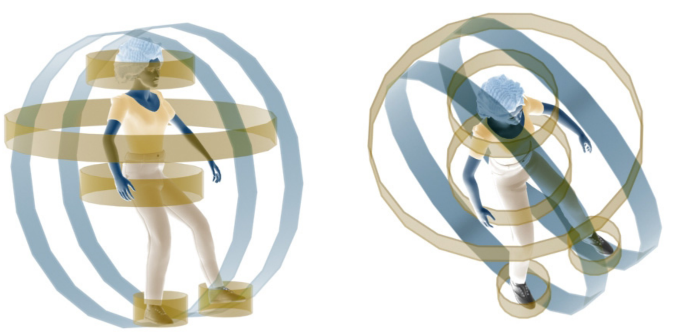

Figure 8: Human Reach Envelope reinterpreted

Two design clues arise during the analysis. First, a key physiological effect of microgravity is known to be the increased locomotion in space. There, movement such as rolling, tumbling or spinning, is accomplished with minimal effort. It is possible for the human body to achieve stabilization in microgravity using a wide range of body positions. Another clue involves a study of the strike and grasp-reach data. Here, it is imagined that the body in microgravity moves in a series of arcs in its effort to balance itself. **(Figure 8)** These clues help to generate concepts for MOM's physical form and its interior systems.

MOM DESIGN

The design of MOM aims to synthesize prior analyses. The utilization needs as determined in the operational analysis require a physical volume that allows for each operational area to be integrated, yet physically distinct. This inspires a layout with separate operational areas interconnected via a central volume. **(Figure 9a)** Furthermore, the increase in user locomotion and the use of multiple local verticals in MOM indicate a need for better use of the full volume of a space; while the arc motions by a body's extremities inspire the design of a spherical environment. **(Figure 9b)**

What eventually guides the design decisions on the module form is the desire to keep MOM realistically within the space-proven structural and manufacturing technologies of our time. The module envelope for MOM is determined to be a spherical body with hexagonal alcoves, both elements finding solid precedence in previously built space modules. **(Figure 9c)**

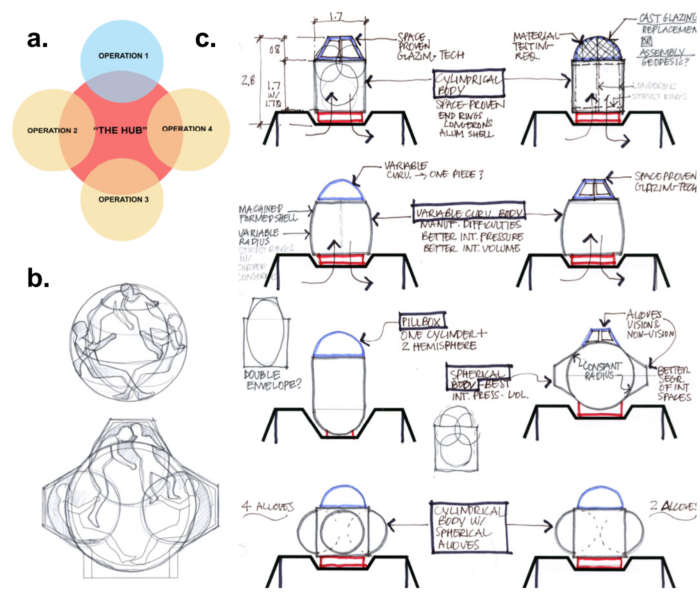

Figure 9: Concept development for module form

MOM is physically compact, with exterior dimensions of 3.4 m in height, and 4.0 m in breadth. The exterior dimension of the spherical body is 2.8 m in diameter. MOM can be reconfigured as either a 3- or 5-alcove module, to suit the evolutionary nature of the media capabilities of the orbital facility. **(Figure 10)** The alcoves are in turn interchangeable, and can be retrofitted into either window alcoves or equipment alcoves, to reflect the evolutionary nature of the technologies. In fact, it is envisioned that one day, all the alcoves will be window alcoves, as the enabling technologies become fully body-wearable and equipment racks become obsolete.

MOM can be launched inside the Orbiter Cargo Bay. The module is designed to launch and dock to the orbital facility in an outfitted, dry and un-pressurized configuration. It will then be pressurized, connected with station systems, and outfitted with portable equipment.

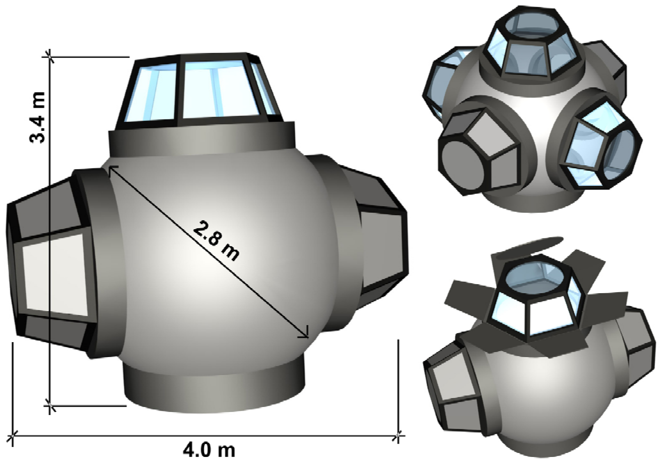

Figure 10: MOM - 3-alcove & 5-alcove configurations. Alcoves are interchangeable to suit mission needs

PRIMARY STRUCTURE

<u>Spherical Body Shell</u>

The spherical body of MOM calls for two distinct manufacturing approaches: segmented or monolithic shell. The segmented approach involves rigid components such as aluminum shell, reinforcing structural rings and longerons. The monolithic approach seems simpler and possibly requires less material weight. However, a monolithic spherical shell may be more difficult to manufacture, requiring casting or molding of the pressure vessel. New material research and development, including composites, may make the monolithic approach preferable in the future.

The design of MOM's primary structure is based on the proven concept of cylindrical rigid modules, modified for a spherical module. MOM's shell is primarily aluminum, with 6 structural rings, and reinforced with longerons at the corner interface. Other components include a corrosion-resistant and lightweight aluminum shell, protected with Micrometeorite and Debris Protection System (MDPS) made of composite materials such as Kevlar and Nextel, and passive thermal protection with Multi-layer Insulation (MLI). **(Figure 11)** The shell is connected to the structural rings and longerons via intermittently spaced brackets. To ensure against pressure leaks, welding and sealants may be used to seal all joints.

Preliminary sizing of MOM's structural elements is done by comparing MOM's estimated primary loads with those of known space modules such as the ISS Lab module. Structural elements are then proportionally reduced in all three coordinate directions. As MOM is smaller than ISS Lab, this will lead to a conservative design in terms of stress analysis. The density of the built volume of the ISS Lab module is also used to estimate the structural mass of MOM, which is determined to be ~4.0 tons.

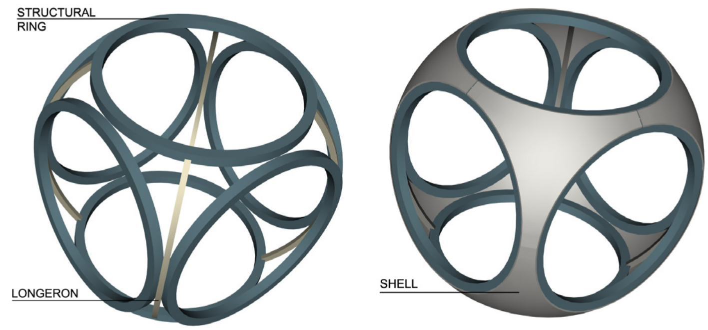

Figure 11: MOM Primary Structure w/ & w/o shell

MOM, like all space modules, will require stringent structural tests before launch. For instance, the Proof Pressure Test, in which one takes the internal pressure up to 110% to 125% of the intended maximum pressure, is needed to establish the "Leak Before Burst" requirement. Other before-launch verifications may include performing acoustic and vibration tests.

<u>Alcove Assembly</u>

MOM's other structural assemblies include the alcove structure, whose design is based on the ISS cupola. **(Brambati et. al, 2000)** It is made of single forged and machined aluminum frame at least 50 mm thick, to ensure high structural strength and stiffness. The alcove structure is then connected to the spherical body via the Passive Common Berthing Mechanism (PCBM).

MOM shall be equipped with at least one window alcove in order to support observation operations. The window alcove will be outfitted with 6 trapezoidal window assemblies, with a round optical quality window at the top, permitting high quality photography of Earth. The window assembly will also be similar to that of the ISS cupola. It includes a scratch pane on the pressurized side, two 25 mm thick load-carrying pressure glass panes, and a debris pane on the outside for micrometeoroids and debris protection. **(Figure 12)** The window assembly will also include heating units, and protective shutters capable of internal and external operation.

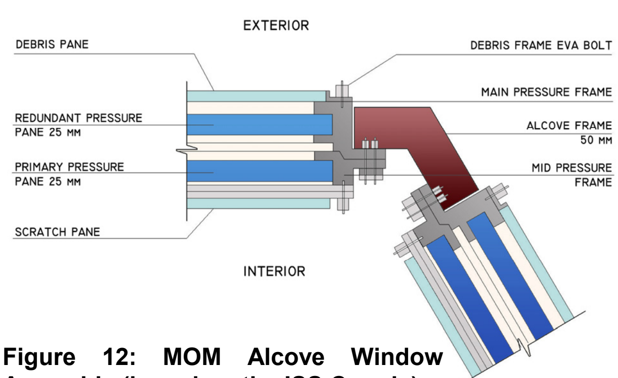

Figure 12: MOM Alcove Window Assembly (based on the ISS Cupola)

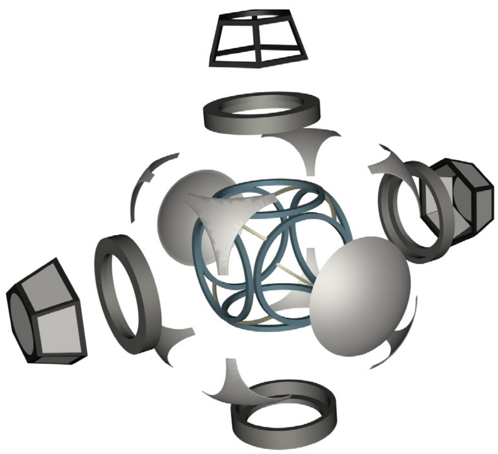

Figure 13: Exploded view of a 3-alcove MOM, showing the relationship of all the structural components

UTILITIES

The secondary structure of MOM will support a plenum space for air circulation and utility runs. **(Figure 14)** Internal closure panels will be provided for easy access to the utilities. There will also be interface provisions for the Human Restraint and Mobility Systems, to be discussed later.

At each alcove, there will be data, power and fluid interface with the station to which MOM is attached. To facilitate interchangeability of window and equipment alcoves, universal panel connect is required. Care should be taken at the connections to ensure safe integration of the fluid and electrical lines.

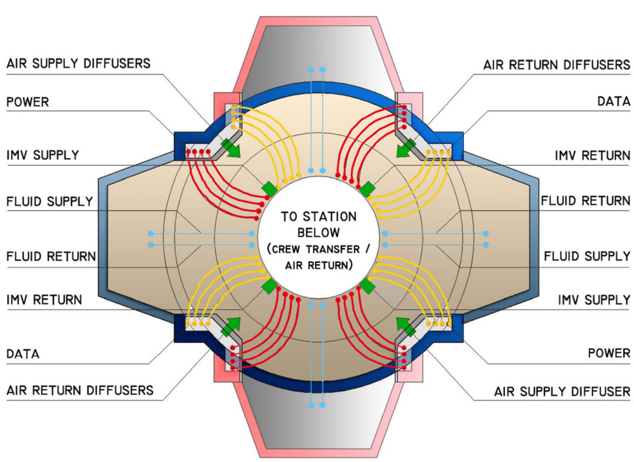

Figure 14: MOM Utility Plan

The main Electrical Power Systems (EPS) Rack of the orbital facility will provide secondary power distribution to MOM's equipment alcoves as well as to its non-rack equipment, including the robotic workstations at the window alcove, and housekeeping units such as lighting, environmental sensors and control, emergency back-up systems, shell heaters, window heaters, and power outlets. Each equipment rack in MOM will have two separate power feeds for redundancy.

MOM's equipment alcoves will also interface with the station's Data Management Systems (DMS) Rack, allowing MOM to access the station network. Ports are also provided at MOM's window workstations to allow plug-in access. Despite the interconnections, MOM must provide separate data storage independent of the station's for redundancy.

The project also assumes the existence of a privately owned communications satellite system for dedicated tracking and data relay for all its media and observational operations. This will also allow MOM to bypass central mission control and provide direct broadcast to individual user/homes. A dedicated antenna will be needed for the additional Command Data Handling and Communications/Tracking operations.

At least one of MOM's equipment racks shall be a Media Console, equipped with an end-to-end media production system similar to what was described in the "Technology Analysis" section. **(Figure 15)** All of MOM's equipment racks will interface with the main Audio/Visual Rack of the orbital facility, and provide control and communications access to other parts of the station, other spacecrafts, and to the ground.

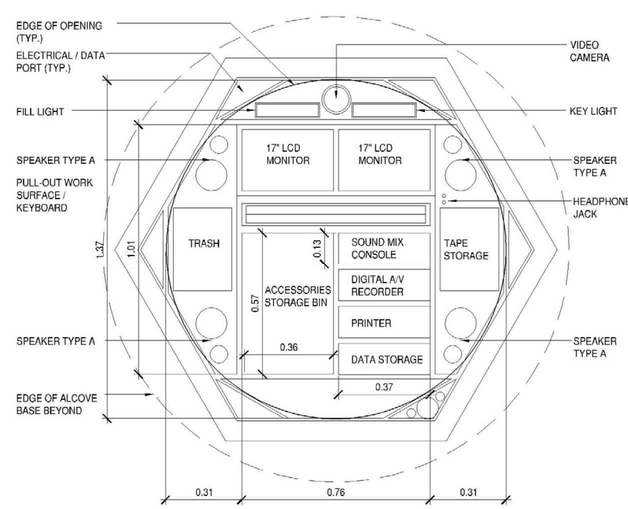

Figure 15: Media Console Elevation

The temperature within MOM is maintained via a passive system with the MLI at the module shell, as well as active systems such as window and shell heaters, and equipment rack cold-plates. In addition, MOM's compact interior can be outfitted with environmental sensors that can interface with astronauts' body-wearable systems for monitoring and warning purposes.

Air is supplied and returned via the InterModular Ventilation (IMV) fans located at the MOM hatch. MOM's plenum created by its secondary structure distributes the air via intermittently located air diffusers. **(SSP-41142, Rev. C, 2001)** Atmospheric control is actively monitored and maintained through the atmosphere exchange with the station's ECLSS system. Air velocity is maintained between 15 and 40 fpm inside MOM, similar to the ISS cupola. **(Brambati et. al, 2000)** Air temperature is adjusted by a temperature control and air mixing valve in the adjoining station module that diverts cooled air toward MOM.

Lighting provided in MOM includes general background lighting, as well as specific task lighting located at the alcove workstations. **(Figure 16)**

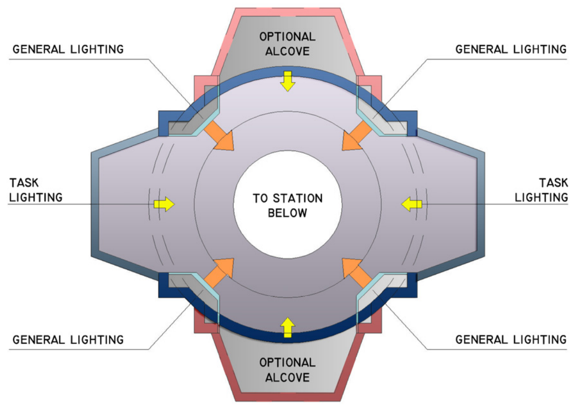

Figure 16: General Lighting Plan

Portable and plug-in lighting system should be provided throughout MOM to accommodate astronauts working with wearable technologies. At the window alcove, the lighting system should be integrated with the robotic workstations and allow reconfigurability. To support broadcasting activities, the Media Console must provide three types of lighting: *key light* for target lighting, *filler light* to reduce shadows, and *background lighting* for general illumination. These can be integrated into the Media Console as illustrated in Figure 15.

INTERIOR DESIGN

<u>Human Restraint and Mobility System (HRMS)</u>

The design of the internal volume of MOM is inspired by human body, and derived anthropometrically. All interior surfaces are within the reach range of most astronauts, providing continual physical support for a wide range of body positions. **(Figure 17)**

However, additional restraint systems will be required for longer-duration tasks. Operational and personal volume analyses both help generate the design concept for MOM's Human Restraint and Mobility System (HRMS). The main design goals include providing a system that fully utilizes the unique spherical volume of MOM, takes advantage of the increased mobility of the body in microgravity, and complements the use of wearable AR technologies.

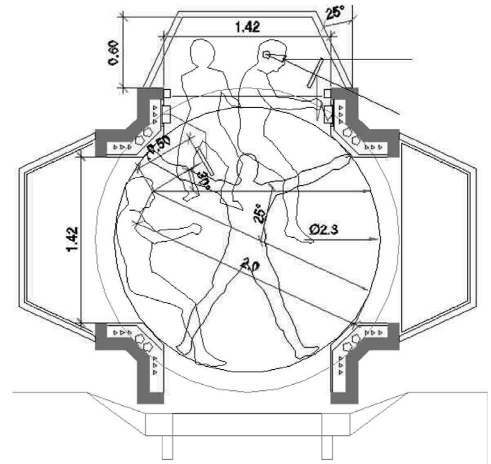

Figure 17: Interior Concept - Human Dimensioning

One interior concept under investigation is the idea of rotating double arcs. **(Figure 18)** Two sets of double arcs are connected to MOM's structure; each set turning in one axis only. The astronauts will only have frontal control of the arcs, making them safer to maneuver. The double arcs rotate on a turn-knob mechanism, and can click and lock into position at intermittent intervals along their paths.

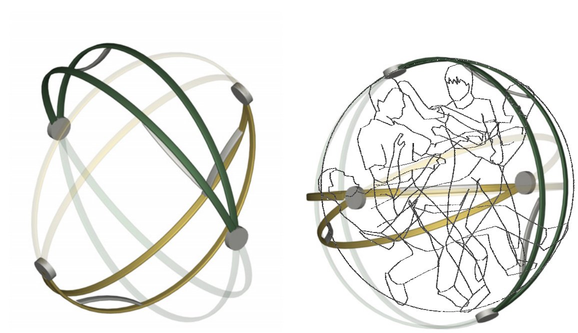

Figure 18: Rotating Double Arcs

By having each set of arcs moving in opposite axes, in combination they can create multiple configurations, supporting the astronaut in different orientations and body positions. The double arcs allow the astronaut to "wedge" different parts of his/her body to achieve differing degree of restraint. For instance, the astronaut can "sit" in between the double arcs, with the buttocks on top of one arc and the thighs restrained under the other arc. Or the astronaut can be more restrained by being wedged "tighter" nearer the turn-knob. He can also be positioned along the length of the arcs, and use them as shoulder straps to further stabilize the body but leave the hands free for use.

In addition to being handholds themselves, the arcs provide additional small handholds, giving the astronaut further opportunities for stabilization or movement. The two sets of arcs create an interlacing structure for the astronauts to hang on, hang off, wedge, hold, and move about. Imagine kids on monkey bars in playgrounds. This is a similar idea, except in microgravity these acrobatic feats are far less physically demanding.

With these arcs, the astronauts can make full use of the volume and surfaces of MOM in their operation of advanced technologies. In addition, these arcs create a maneuverable infrastructure to attach props and lights in multimedia productions. This well complements the AR display technologies, with their capabilities of blending graphics with physical objects to create an enhanced visual environment.

Finally, in an effort to provide flexibility, the turn-knobs are designed to be the common interface mechanism for other conventional restraint systems such as handholds and foot restraints. **(Figure 19)** All systems will be capable of rotating to accommodate different needs of the astronauts. Astronauts are thus given control over the interior arrangements and the nature of use in their operational environment.

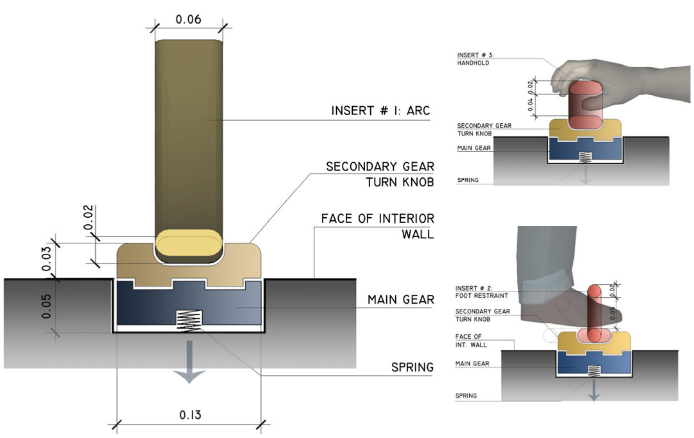

Figure 19: Common interface attachments

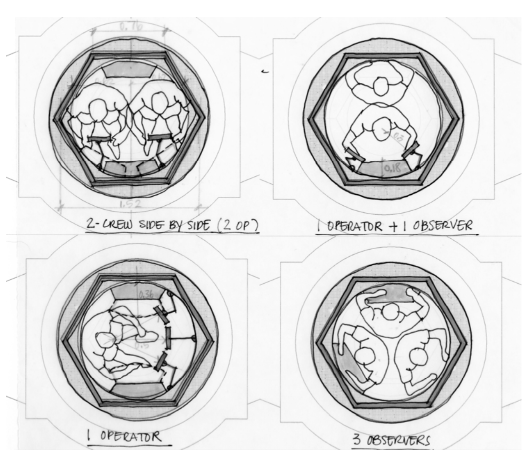

Figure 20: Window alcove plan – possible configurations

The HRMS described above can also be used to support station-keeping and observation operations at the window alcoves. However, the emphasis here is not so much multiple orientations or mobility, but consistency and stability for long-duration tasks requiring precision. Therefore, a back-up HRMS is required at the window alcove. This may include an independent thigh restraint system integrated with the robotic workstations.

As with the rest of MOM, the window workstations must provide some maneuverability so the crew can reconfigure the space according to the task at hand. Figure 20 shows some sketches of the possible configurations at the window alcove.

<u>Operational Scenarios</u>

Several operational scenarios are envisioned to further illustrate the nature of utilization in MOM. During the scenario-building process, it is important to consider the general operational requirements such as orientation and visual needs, as well as the information architecture such as data flow, body zones of control, and main technological support.

In the work scenario, 1 or 2 astronauts conduct payload or tele-robotic operations at the window alcove, with visual access to the exterior body of the orbital facility. Meanwhile, another astronaut can be at the Media Console, conducting film recording or post-production work, either in connection with the station operation at hand, or on a separate project. One may also imagine a distance learning program being broadcasted real-time, with the astronaut in MOM reporting on a scientific experiment being conducted elsewhere in the orbital facility. Here, the end-to-end media system allows the media operator to switch between different visual inputs, record, edit, and broadcast with a click of a button.

The window and media operators will be positioned in different local verticals. They will require active, two-way visual, audio and data communications. In terms of technological support, both operators will require access to conventional displays such as LCD screens. The window operators can also be equipped with optical see-thru displays that are linked to the station's exterior cameras for precision tasks or visualization of hard-to-observe scenes. In terms of controls, window operators will require access to keyboards. They may also be equipped with wearable input devices to increase user mobility. Force-feedback haptic devices can also benefit window operators for tele-operation tasks.

In the play scenario, one astronaut is at the window alcove, observing Earth in solitude, equipped with only a handheld camera, and a pad of paper and a pen. Meanwhile, two astronauts are conducting experimental multimedia projects, directed by principle investigators on the ground. Alternatively, the astronauts can be in an immersive gaming and entertainment environment, for recreational or even training purposes.

In play, active two-way visual, audio and data communications between the media operators are essential. They will need full access to the racks, but require all wearable AR display and control technologies to conduct their experimental projects. The bodies of the operators now act as foci of data flow, and their movements as part of data processing. The flexibility offered by MOM's HRMS will support multiple orientations, and allow the astronauts to utilize every available surface of MOM for display and projection.

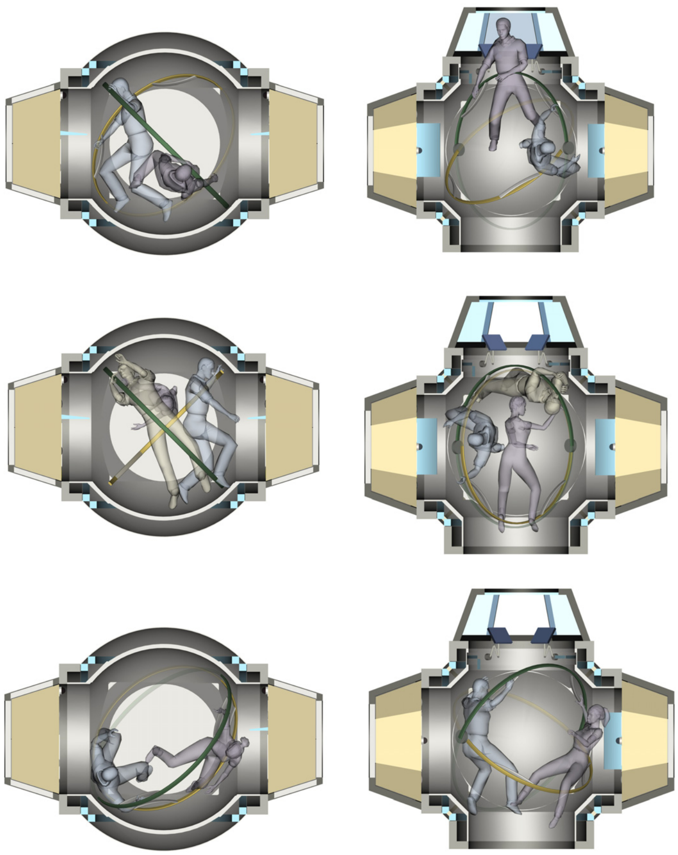

Figure 21: A montage of different interior configurations possible in MOM. The HRMS shown is based on an earlier concept.

CONCLUSION

This paper describes the design of a space module that can replace a standard space cupola, supporting not only station-keeping and observational operations, but also providing media functions. It is conceivable that once the media operations are fully established in the space station, production companies like CNN, the Weather Channel, MTV or Sony, as well as private multimedia design companies or experimental artists, may desire to rent space in Earth's orbit for commercial, educational, and artistic productions.

The project offers a design solution to converge technical and creative operations by appropriately implementing wearable Augmented Reality technologies in conjunction with operational and human factors considerations in an orbital environment. This coupling of human-data-space via technologies is already beginning to be practiced by progressive architects and designers in terrestrial projects, as well as by multimedia artists. Project MOM takes these terrestrial experiences further, and attempts to illustrate possible applications of these technologies in space.

ACKNOWLEDGMENTS

The author gratefully acknowledges the expert advice and support of the following people:

Design Advisors

Larry Bell, SICSA Director, UH
EunSook Kwon, Professor of Industrial Design, UH
Bonnie Dunbar, Assistant Director, NASA

Media

Marty Kirkland, Director of Engineering, Houston PBS
Michael Carr, Producer, Houston PBS

AR & Wearable Technologies

Blair MacIntyre, Professor, Georgia Institute of Technology
Steve Mann, Professor, University of Toronto

Structure

Pam MacVeigh, Structural Engineer, Boeing Company

ISS Cupola

Margarita Sampson, NASA

Power/Data

Scott Stover, NASA

REFERENCES

Azuma R., "A Survey of Augmented Reality," Presence: Teleoperators and Virtual Environments 6, 4, August 1997, pp. 355-385.

Azuma R., Baillot Y., Behringer R., Feiner S., Julier S., MacIntyre B. "Recent Advances in Augmented Reality," IEEE Computer Graphics and Applications, December 2001, pp. 34-47.

Brambati, G., Basile, L., Ferrari, G., Laurini, D. "Innovative Cupola Design for the International Space Station," 51st International Astronautical Congress, Rio de Janeiro, Brazil, October 2000.

Dooris, M., Moorman, M., Gregory, B., Brown, M., and Wright, H., "A Preliminary Comparison of Body-wearable Computers to Modern Audio Equipment in a Microgravity Environment," ACM SIGCHI, Volume 32, Issue 1, January 2000, pp. 57 – 62.

DaletPlus News Suite System
http://www.dalet.com/19.html accessed October 2003.

ForceDimension Haptic Controls
http://www.forcedimension.com/ as viewed in Sept 2003.

Hamilton, D. Loads and Structural Dynamics Branch Report. NASA-JSC-2054, Rev. A, April 1988.

Mann, S. Intelligent Image Processing, John Wiley and Sons, Inc., 2001.

NASA Man-Systems Integration Standards -STD-3000 Volume 1, Revision B, Section 3.0 Anthropometry and Biomechanics, Section 9.0 Workstations.

Sony DVLince Media System
http://bssc.sel.sony.com/infocomm/DVLINCE.html accessed October 2003.

SSP-41142
Node Elements to Cupola Element: Interface Control Document, Part 2, International Space Station Program, Rev. C June 2001

Starner, T., Mann, S., Rhodes, B., Levine, J., Healey, J., Kirsch, D., Picard, R. and Pentland, A., "Augmented Reality Through Wearable Computing", Presence, Special Issue on Augmented Reality, 1997.

LIST OF FIGURES

Figure 1

Milgram's Reality-Virtuality Continuum:
Courtesy Paul Milgram, U of Toronto.

Figure 2

MIThril Project by MIT Media Lab:
Credit: MIT Media Lab
http://www.media.mit.edu/wearables/ as viewed in August 2003.

Battlefield AR System:
Photo provided courtesy of the Naval Research Laboratory.

Figure 3a

Optical see-thru conceptual diagram:
Courtesy of Ronald Azuma, HRL Laboratory.

Minolta Eyeglass Display:
Credit: Hiroaki Ueda, Minolta, Japan

Figure 3b

Video see-thru conceptual diagram:
Courtesy of Ronald Azuma, HRL Laboratory.

HMD Prototype:
Courtesy of Jannick Rolland, UNC-Chapel Hill Department of Computer Science.

Figure 4

The CyberGrasp Glove:
Reproduced by permission of Immersion Corporation,

Figure 5

Virtual fetus inside womb of patient:
Courtesy of UNC-Chapel Hill Department of Computer Science.

Shuttle Bay seen in orbit:
Courtesy Paul Milgram, U of Toronto.

2D floor plan and 3D pipe model superimposed on an industrial pipeline:
Courtesy of Nassir Navab, Computer Science Department, Technical University of Munich.

RV Border Guards, an AR Game:
Courtesy of MR Systems Lab.

Figure 7

Neutral Body Posture:
Figure 3.3.4.3-1, NASA STD-3000/Vol.1/Rev.B/3.0

Grasp Reach Limits:
Figure 3.3.3.3.1-1, NASA STD-3000/Vol.1/Rev.B/3.0

CONTACT INFORMATION

Maijinn Chen is a registered architect and a recent graduate of Master of Architecture at the Sasakawa International Center for Space Architecture (SICSA). She can be contacted at:

mchen@sicsa.uh.edu

ACRONYMS AND ABBREVIATIONS

ECLSS: Environmental Control and Life Support System

HMD / HWD: Head-worn Display / Head-mounted Display

HRMS: Human Restraint and Mobility System

ISS: International Space Station

MLI: Multi-layer Insulation

MOM: Media and Observation Module