A Crew Seat for Human Exploration in Multiple Gravity Environments

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Abstract— **This work attempts to develop a single crew seating solution that is applicable across a range of gravity environments encountered by spacecraft proposed in several conceptual spacecraft architectures. All of these spacecraft will need to provide some sort of stationary accommodation for the crew for performing various activities such as work in science laboratories, maintenance and repair facilities, medical care facilities, and spacecraft operations centers, as well as for basic habitation in crew quarters, entertainment / relaxation facilities, and crew dining facilities. Depending on the spacecraft or architecture, this stationary accommodation may be experienced continuously in microgravity, such as would be the case for the Deep Space Exploration Vehicle. Alternately, it could be in continuous lunar or Martian gravity, such as the Common Habitat base camps. It could experience fractional gravity, such as a Pressurized Rover for In-Space Missions at a Near Earth Asteroid or one of the Martian moons. It could alternate between artificial gravity and microgravity, such as the Nautilus-X. It could alternate between microgravity and lunar or Martian gravity, such as the SpaceX Starship Human Landing System or the Blue Origin Blue Moon Block 2 Human Landing System. Or it could be in continuous Earth gravity, such as ground trainer systems. Prior human spaceflight systems for stationary accommodation have been focused on microgravity applications. These systems have their own limitations and cannot be used in a gravity environment. A public crowdsourcing campaign generated dozens of ideas, which ultimately generated a Gecko Mobility Aids system for crew translation and the Multi-Gravity Crew Seat (MGCS) for stationary accommodation. The MGCS functions in gravity as a traditional terrestrial seat, performing functions of load for the overall body and forearms, as well as head and neck load relief while positioning the body within range of an intended task. In microgravity, the MGCS functions as a body restraint, securing the body against inadvertent drifting by applying a restraining pressure at the front and back of the thighs, shoulders, and back. The initial MGCS concept was developed in a NASA hackathon and was refined through a review of dozens of terrestrial seating styles. Additionally, a review of anthropometry and biomechanics data related to the neutral body posture was conducted to help inform the microgravity configuration of the MGCS. A series of CAD models were iteratively developed, with subject matter expert reviews leading to design improvements. A scale model was constructed and used with a humanoid model to demonstrate MGCS accommodation of a human-like body in both gravity and microgravity modes. Work to develop a full-scale protype of the MGCS is discussed, including design and fabrication of the headrest, arm rest, seat back, seat pan, seat base, and the conversion mechanisms. A 1-g human-in-the-loop evaluation of the prototype assessed the acceptability of performing seated activities in the MGCS, collecting data on the usability, comfort, and ease of ingress/egress. Based on the evaluation results, design modifications needed for reduced gravity testing are documented and initial work is indicated for a reduced gravity test plan.**

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1. INTRODUCTION

The Common Habitat Architecture is a human spaceflight study involving the use of an SLS Liquid Oxygen tank as the primary structure for a long-duration habitat [1], shown in Figure 1, capable of supporting a crew size of eight for missions up to 1200 days in various gravity environments across the inner solar system.

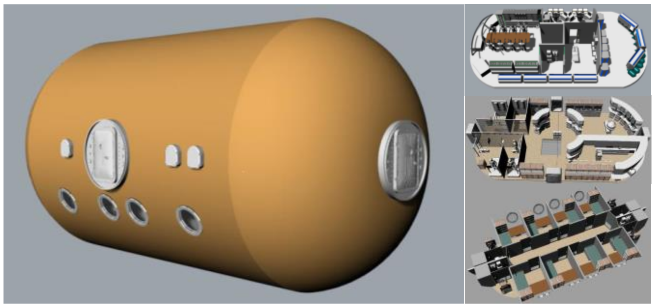

Figure 1. Common Habitat

This is a similar approach to that taken in the 1970s with the Skylab space station from the Saturn S-IVB liquid hydrogen propellant tank. The primary difference is that Skylab was designed exclusively for microgravity, while the Common Habitat operates in multiple gravities. This architecture study is not part of the Artemis program but is being explored as a potential next step after Artemis and potentially the first or second human Mars landing. The Common Habitat has a horizontal orientation divided into three decks, an upper deck, mid deck, and lower deck

2. Operating Environments

When crew are living and working in a human exploration mission, it cannot be overstated how important it is for the crew to have a means to remain stationary. This is easy to accomplish in a standard office or home setting on Earth and it can therefore be overlooked by designers. But when conducting operations, whether performing a science experiment, providing medical care, performing maintenance activities, or any number of other activities, it is necessary to provide aids to ensure crew member stability.

An example on the International Space Station (ISS) is shown in Figure 2, where three crew members are gathered around a laptop. The specific activity is not evident from the picture, but any number of activities such as procedure reviews or execution, failure diagnoses, conferences with Mission Control, training, recreation, or many other crew tasks could result in a need to maintain position around a fixed location. The crew will use any number of hand holds, foot holds, other fixtures on the wall, ceiling, or floor to float in position.

Figure 2. ISS Crew Maintaining Position in Microgravity

This can be contrasted with Figure 3, where crew are living and working in the Human Exploration Research Analog (HERA), a habitat mockup at NASA Johnson Space Center (JSC) used for 45-day crew habitation studies. The three HERA crew featured in the image are similarly gathered around a computer display. But obviously, in Earth gravity, their postures are constrained by gravity. Two are seated in chairs and one is standing.

In order for the Common Habitat Architecture to fulfill its goal of a common habitation system that can be used throughout its intended operating domain, it must be able to accommodate the crew with the same internal architecture in every gravitational environment in which it finds itself.

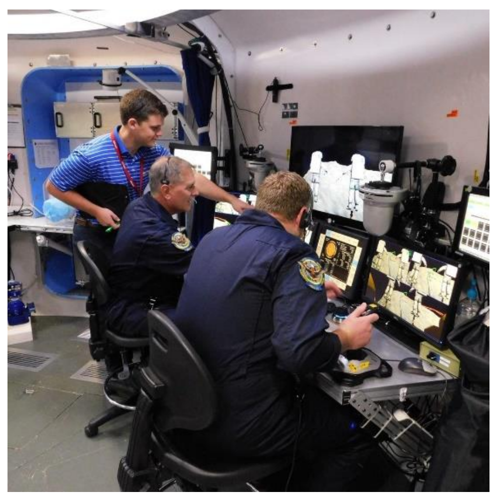

Figure 3. Analog Habitat Crew Maintaining Position in Gravity

The Common Habitat Architecture is concerned with crew stationary accommodation in multiple environments: the continuous microgravity experienced in orbits of planets and moons and in trajectories between them; 1/6 gravity experienced on the surface of the Moon; 3/8 gravity experienced on the surface of Mars; very low fractional gravities experienced on Near Earth Asteroids (NEAs) and Martian moons; alternations between microgravity and various fractional gravities experienced in rotating artificial gravity spacecraft; high fractional gravities experienced in the atmosphere of Venus; and one gravity experienced in trainers on Earth.

Key areas in the Common Habitat where stationary accommodation (e.g., seating or microgravity equivalent) are needed include the crew quarters, galley, medical care facility, command and control center, science laboratories, and the Repair, Maintenance, and Fabrication facility.

3. Limitations of Prior Restraints and Mobility Aids

Most of NASA's spaceflight experience with restraints and mobility aids has been focused on microgravity spaceflight.

Skylab Floor System

NASA's first space station, Skylab, experimented with a restraint system intended to enable the crew to walk in the habitat, much like they would on in a gravity field on Earth. Portions of Skylab were outfitted with a triangular floor grid pattern, shown in Figure 4. Crew could wear special shoes with triangular cleats that they could use to wedge into this grid by rotating the shoe slightly. [2] While in general the shoes were successful, crew comments indicated that it took undesirably long periods of time to lock the shoes into the grid and to release them. [2] The crew also noted a benefit of the shoes that the could be used almost anywhere. [2]

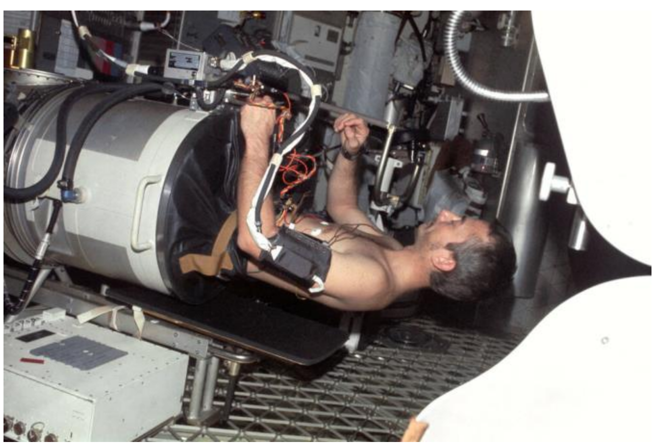

Figure 4. Skylab Floor Grid Pattern

ISS Foot Restraints

On the ISS, crews have become familiar with handrails and foot restraints, using them for daily activity. Handrails are visible in Figure 5, and foot restraints in Figure 6.

Figure 5. ISS Handrails on Floor and Walls

The use of handrails and foot restraints uses muscles and triggers forces and reactions associated with several key parts of the body. Translation or relocation via handrails involves primary movement with the fingers, hands, arms, and shoulders. Secondary movement is achieved with toes, feet, legs, stomach, and back. [3] Station keeping is primarily achieved via toes, feet (tops), legs (shin), stomach, and back. Fingers, hands, arms, and shoulders are secondary. [3]

Some concerns have emerged regarding the handrails and foot restraints aboard the ISS. The Flight Crew Integration (FCI) Operational Habitability (OpsHab) team maintains the FCI ISS Crew Comments Database (CCDB), which contains crewmember comments from the ISS Post Flight Debriefs. CCDB data reports generated from the CCDB do not represent or replace an official crew office position or consensus. The content of the CCDB reflects individual crew opinions and are not to be interpreted as Astronaut Office position or consensus.

Figure 6. ISS Foot Restraint Near Hatch

By definition, handrails and foot restraints are limited to specific placement within the habitable environment and cannot literally be everywhere a crew member might venture.

Some ISS crew have felt that the handrails were not always in the places where they wanted them.

Possible injuries ISS crews could experience associated with both handrails and foot restraints, including back pain, shin splints, stress fractures, tendinosis or tendinitis, and compartment syndrome. Several crew members have noted in debriefs that when moving about the space station, when attempting to catch a handrail, especially if moving quickly, they can get their foot or wrist in an awkward position that places them at risk of a fracture. Some crew believe it is inevitable that eventually such an injury will occur.

Reduction of crew injury risk is of increasing importance as missions travel farther from Earth. A broken wrist or ankle within the latter few months of a transit to Mars could result in an inability to conduct surface operations and a loss of mission objectives. Such an injury towards the end of the return to Earth could result in an inability to safely egress Orion following splashdown, which in a worst case could lead to loss of crew. Until now, the previously mentioned handrails and foot restraints have been accepted as the only alternative.

Crew also commented a variety of usability concerns associated with extended use of the handrails, including handrails not necessarily in the desired orientation, comfort of using the handrails, callouses, red marks, soreness, and other discomfort even to the point of blistering and bleeding.

Additionally, given the common design philosophy of the Common Habitat architecture (identically manufactured and outfitted habitats in both microgravity and gravity), handrails and foot restraints are fundamentally unsafe. These restraints and mobility aids become trip hazards in the presence of gravity and would therefore be unacceptable for use in a Moon or Mars base camp.

4. DERIVATION OF MULTI-GRAVITY CREW SEAT CONCEPT

JSC Hackathon

A challenge was issued to members of the JSC community at a hackathon event held in 2019, for a seat that could also operate in microgravity. The winning concept was essentially an office chair that used the arm rests as thigh restraints in microgravity as shown in Figure 7. This became the springboard for future MGCS concepts.

Figure 7. 2019 JSC Hackathon Concept

The 2019 concept was later modified by a Pathways Intern to add to the microgravity conversion the ability to pitch up the seat pan, approximating the neutral body posture, and added foot restraints, shown in Figure 8.

Figure 8. Updates to 2019 Concept

Crowdsourcing Contenders 2020

A NASA crowdsourcing campaign executed through the GrabCAD platform in 2020 solicited ideas for a common restraint and mobility aid system for multiple gravity environments. This system would replace traditional handrails and foot restraints, exchanging it for a gravity-independent system that will restrain crew members in microgravity, while being unobtrusive in gravity; that will enable astronauts to translate between decks on the Moon or Mars, but not be a passageway obstruction in microgravity.

The project results directly led to further intern solutions for the Vertical Translation System and Gecko Mobility Aids, but the only seating concept among the finalists [4], shown in Figure 9, did not contribute significantly to crew seating.

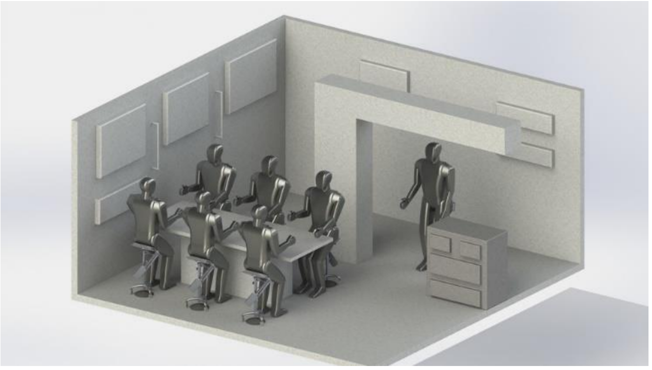

Figure 9. Crowdsourcing Contenders Restraint Chair

However, Space Grant interns from the Rhode Island School of Design (RISD) escalated the concept to a mature configuration starting in the summer of 2021.

5. MGCS KEY REQUIREMENTS

A set of key requirements were established to drive design of the MGCS:

1. The seat shall have at least two operational configurations: One is a crew restraint suitable for use in microgravity (e.g., on a Mars Transit Hab). One is a crew restraint suitable for use in the presence of gravity (e.g., in a lunar surface or Mars surface habitat).

2. The seat shall be suitable for use on Earth (e.g., in a crew trainer).

3. The seat shall be usable with the above configurations at a science lab station, at a vehicle systems monitoring / teleoperations workstation, at a desk in a crew quarters private workstation, at a wardroom for crew meals or group recreation/movie viewing and/or crew meetings, in a maintenance workstation (soldering, usage of hand tools, power tools, etc.), by a medical caregiver within a medical facility, or other habitat locations. Optional uses may involve additional configurations. Some uses may require different sitting heights (e.g., chair vs. stool).

4. The seat shall not inhibit nominal upper body movement for the performance of tasks.

5. The seat shall provide ease of ingress and egress.

6. The design of the seat shall be visually inviting.

7. The seat shall be capable of 360-degree swivel.

8. The seat back shall be capable of recline.

9. The seat shall be capable of adjustment to address anthropometric body differences.

10. A crew member shall be able to conduct up to 8 hours of continuous work in the seat/restraint without seat-related discomfort or fatigue in duty/operations-related locations.

11. The seat shall be capable of attachment to either fixed or mobile interfaces with the spacecraft deck.

The following additional requirements are not binding for the initial prototypes but were to be kept in mind as aspirational for the eventual flight unit.

1. The seat shall be capable of autonomously converting between its configurations, triggered by the presence or absence of gravity, such as during spin up or spin down of an artificial gravity spacecraft.

2. The seat should be capable of converting between configurations without the assistance of motors or electrical power.

3. The seat shall not have any separable fasteners (e.g., no loose screws that could float/roll away).

4. The seat shall launch disassembled with components that fit inside standards CTBs.

5. Initial seat in-space crew assembly shall not generate small particles (e.g., shavings)

6. Initial seat in-space crew assembly shall not require more than at most three hand tools.

7. Initial seat in-space crew assembly ideally should not require the use of any tools.

8. Initial seat in-space crew assembly shall require no more than 15 minutes.

6. INITIAL DESIGNS AND SCALE MODELS

Terrestrial Seating Concept Exploration

Work began with a review of terrestrial seating concepts, exploring trends of innovation, comfort, and mobility. Several chairs were identified as points of inspiration. Their design intentions were considered, such as chair postures that strengthen the back, enhance weight distribution, not restricting blood flow, reducing stress points on the body, supporting posture changes, and user-friendly adjustment controls.

Additional ergonomics research explored mechanisms in office chairs, examining how different vendors achieved tilts and articulations. Gas struts and alternative mechanisms were also explored.

Neutral Body Research

Research conducted into the neutral body posture (the position the human body wants to assume at rest in microgravity) revealed that there is significant variation between different people. [5] The neutral body posture measured during the Skylab program, shown in Figure 10, has been widely cited in literature.

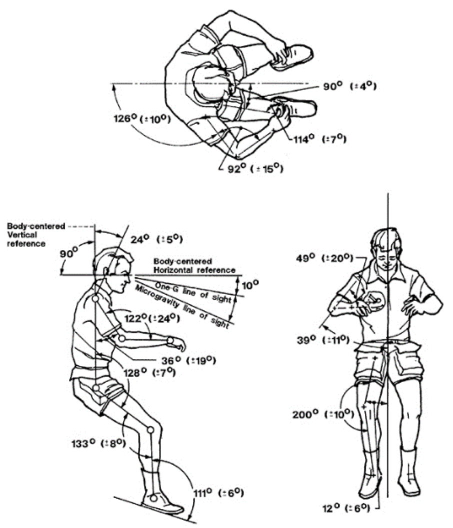

Figure 10. Neutral Body Posture as Measured on Skylab

However, the posture was measured during the STS-57 (Spacehab-1) mission with significant variation between the six crew, as shown in Figure 11. It was measured again aboard the ISS with nine crew members and again produced different results. Figure 12 shows body scans of three of the nine crew.

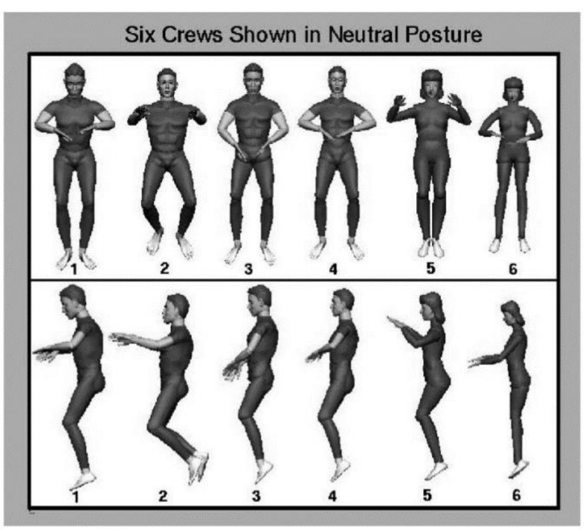

Figure 11. Neutral Body Posture as Measured During STS-57

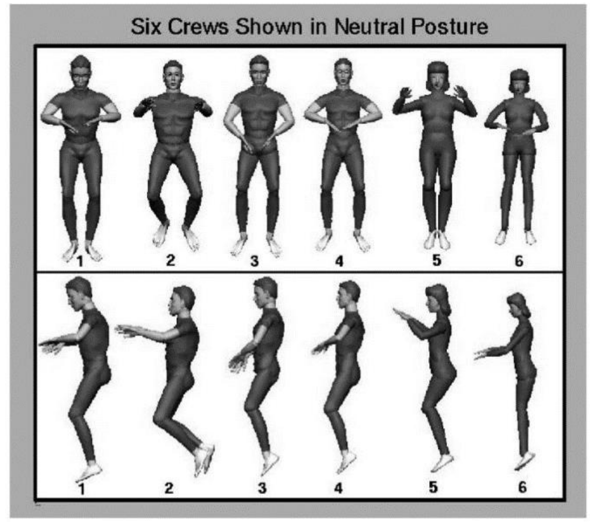

Figure 12. Neutral Body Posture as Measured on ISS

CAD Model Development

With this background established, the design of an initial CAD configuration began. After some design trades, the pitch articulation of the seat pan was retained. The foot restraint was removed from the concept as unnecessary and redundant to the restraint of the thighs. Figure 13 shows the seat pan pitch adjustment. Notice that the seat pedestal also telescopes upwards to allow clearance for the changing position of the legs.

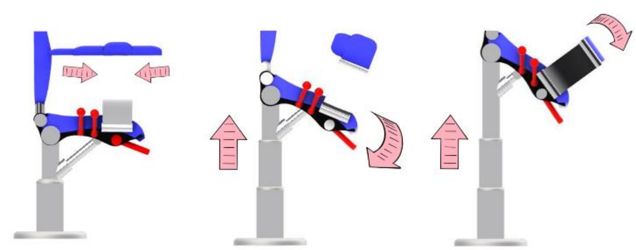

Figure 13. Seat Pan Pitch Adjustment

The general concept of using the arm rests as thigh restraints was also retained, but with significant modification. An arm rest appropriately sized to act as an arm rest is too long to perform the thigh restraint function as intended. As a result, the arm rests are telescoping. To convert, the arm rests telescope inward, then the arm rests rotate inward until they compress downward against the thighs, as illustrated in Figure 14.

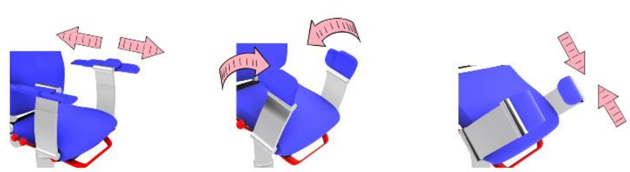

Figure 14. Arm Rest to Thigh Restraint

It was realized that the arm rest restrained the lower body as a thigh restraint but might still leave the upper body in a position where it might want to float away from the chair. To address restraint of the upper body, a converting headrest was added to the chair. The headrest was designed to be capable of converting from a headrest in gravitational environments to a shoulder restraint in microgravity environments. The headrest first splits apart, rotating 180 degrees outward to line each half up with the shoulders and clear the head. The headrest then telescopes to become roughly a third longer. It finally rotates downward to grip against the shoulders. This process is illustrated in Figure 15.

Figure 15. Headrest to Shoulder Restraint

The three transformations: seat pan pitch, arm rest transformation to thigh restraint, and headrest transformation to shoulder restraint form the basis of the MGCS. The initial concept is intended as spring loaded, where mechanisms related to gravity are designed to either spring open when the force of gravity is removed AND mechanisms design to restrain are designed to lightly clamp shut, such that an astronaut could easily place themselves within, but could also remove themselves from without too much trouble.

The conversion process is represented in Figure 16, with gravity mode on the left, transition in the middle, and microgravity mode on the right.

Figure 16. MGCS Gravity Mode Conversion

A CAD render of a crew member in the MGCS in gravity mode (left) and microgravity mode (right) is shown in .

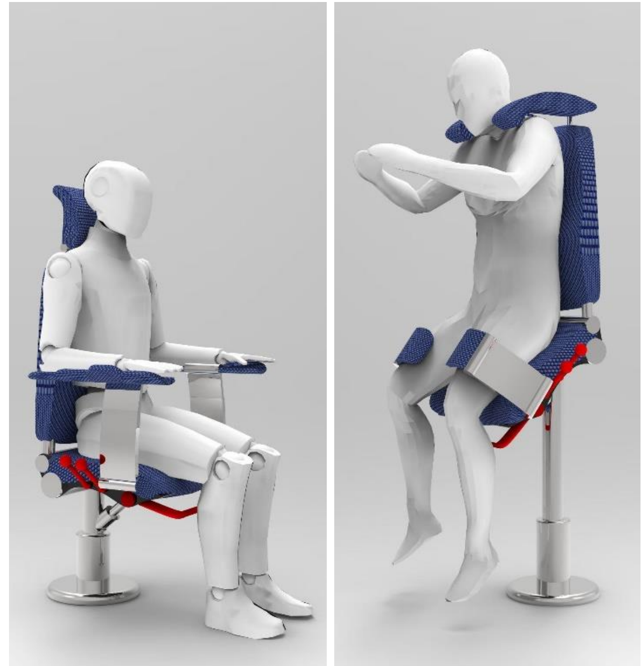

Figure 17. Crew in Gravity vs. Microgravity Mode

A second design iteration attempted to push from the notional nature of the initial CAD models to a system that could actually be fabricated and that would be capable of transitioning between gravity and microgravity modes. This resulted in several changes.

The initial spring-loaded concept was deemed too complex for any potentially available manufacturing methods for the intern. Pistons and servos were instead selected, as shown in Figure 18, considering that the early prototypes do not need to be held to flight vehicle requirements.

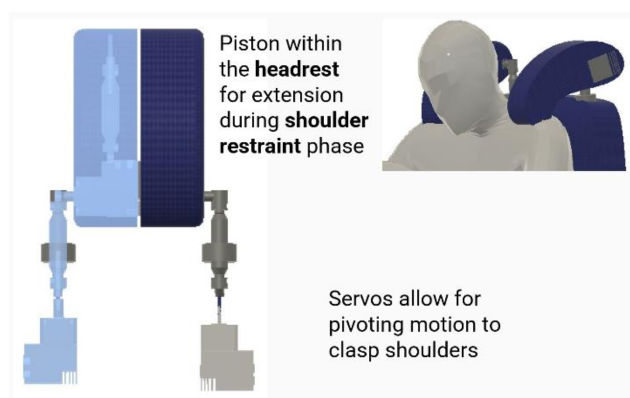

Figure 18. Piston and Servo Modifications to Headrest

The arm rest was simplified as shown in Figure 19 to a non-telescoping, compromise length that was deemed short enough to allow for use as a thigh restraint but still functional as an arm rest. A servo motor would serve to rotate the arm rest a little more than 180 degrees such that it would rest outward as an arm rest and rotate inward to grip the thighs. The arm rest pylons would telescope vertically to allow the proper positioning for different size crew members.

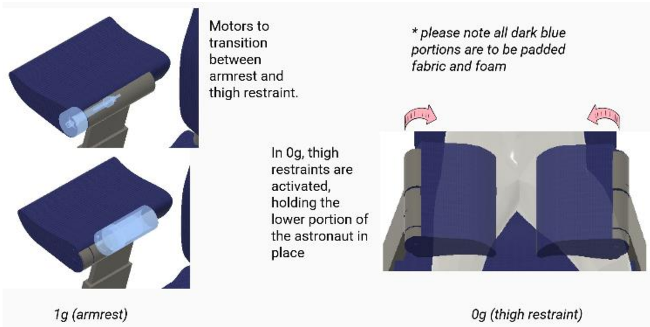

Figure 19. Arm Rest Servo

The seat pan pitch angle is controlled by a linear actuator, shown in Figure 20. This does require manual adjustment to the seat back to keep it vertical as the seat pan pitches up.

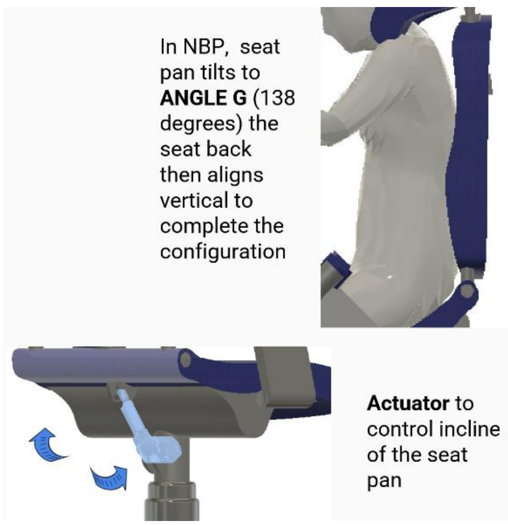

Figure 20. Seat Pan Actuator

Scale Model Demonstrations

A simplified CAD model of this updated configuration was then created, and 3D printed for a scale model demonstration. The process of developing a printable model forced some simplifications in the design. Most significantly, the arm rest conversion could not be implemented in a scale model – the 3D printed material was too thin. Consequently, the arm rest was modified to a variation on the original version, with the forward half of the arm rest rotating inward. Also, the seat base does not telescope, placing the gravity mode at a higher seated position. Several iterations were needed to overcome fragility issues associated with the small sizes of the 3D printed parts, with the final model shown in Figure 21, Figure 22, and Figure 23, with a wooden mannequin used for illustration.

Figure 21. Scale Model Gravity Mode

Figure 22. Scale Model Transition

Figure 23. Scale Model Microgravity Mode

7. PROTOTYPE DEVELOPMENT

Funding Limitations

The next step was to build a full-scale prototype to further demonstrate the viability of the MGCS prototype. It had been hoped to obtain a source of funding to do so, but no such funding was available. Consequently, a Pathways Intern was tasked to construct a prototype with no funding, using only materials that could be obtained at no cost. The prototype was constructed entirely from 3D printed parts and scrap materials, such as office chairs from JSC's Excess Warehouse (where NASA property to be disposed is sent), as well as surplus metal plates, PVC pipes, bolts, screws, and fabric from JSC's fabrication shops. As was to be expected, this approach forced modifications to be made to the MGCS design. The automated reconfiguration was not attempted and even manual reconfiguration was limited in scope.

Headrest Construction and Conversion

The headrest was 3D printed, as shown in Figure 24. A metal rod is used to hold the two halves together in gravity mode, so they do not swing open when a crew member leans against the headrest.

Figure 24. Full Scale Headrest in Gravity Mode

To convert to microgravity mode, the rod is pulled out of the headrest, and the halves are rotated outwards until they are positioned behind the seated crew member's shoulder blades. They are then rotated forwards about the elbow connectors, as shown in the partially assembled unit in Figure 25, to restrain the crew member's shoulders.

Figure 25. Microgravity Mode Shoulder Restraints

To begin construction of the headrest, the seat back of an office chair was detached from the rest of the chair as shown in Figure 25. The plastic backing of this office chair was removed, and an aluminum bracket was bolted to the spine of the chair, as shown in Figure 26. A set of PVC pipes were drilled with quarter-inch holes every inch along the pipes and were bolted to the aluminum bracket. A second set of PVC pipes with a smaller diameter were also drilled with quarter-inch holes every inch along the pipes to create a telescoping mechanism between the wider pipe and the narrower pipe, which would allow for the headrest's height to be adjusted to fit the crew member. The telescoping pipes are secured at a selected height using a pip pin.

Figure 26. Seat back with Telescoping PVC Pipe Fixtures

The reclining feature on the original office chair that was used for this prototype was found to be damaged (perhaps the reason why the chair had originally been excessed), causing the headrest to lean back when a crew member sat in the chair. To partially remedy this issue, two holes were drilled into the seat back and two zip ties were threaded through these holes and around the PVC pipes to secure the system in place.

A CAD model of the overall shape of each half of the headrest was created in CREO Parametric. Approximate measurements were taken for how long the headrest would need to be to comfortably support the back of the crew member's head, as well as appropriately restrain their shoulders when converted.

Due to 3D-printer print envelope constraints of 6"x6"x6", an entire headrest half could not be printed at once. As a result, from the initial CAD model, three separate CAD files were created for each half of the headrest as shown in Figure 27, Figure 28, and Figure 29. These three parts fit together, with the top piece having a male end, the middle piece having a female and male end, and the bottom piece having a female end.

Figure 27. Top Piece of Right Half of Headrest in CREO Parametric

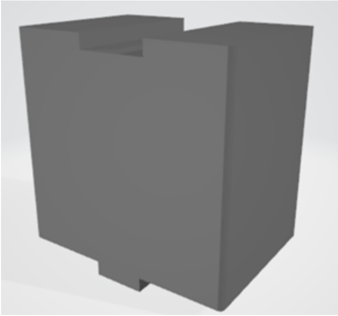

Figure 28. Middle Piece of Right Half of Headrest in CREO Parametric

Figure 29. Bottom Piece of Right Half Headrest in CREO Parametric

These three parts were 3D-printed and adhered together with wood glue, as well as a layer of duct tape for an additional measure of security. The assembled right half of the headrest is shown in Figure 30. This version of the headrest does not telescope but is instead fixed at the length needed to serve as a shoulder restraint.

Figure 30. Assembled Right Half of Headrest

A hole was added to the top piece of each headrest half to fit the steel rod holding the two halves together in gravity mode, as shown in Figure 24.

Additionally, a second larger hole was added to each bottom piece. Two small pieces of PVC pipe were inserted through the holes, as shown in Figure 29. The inner end of these PVC pipes was connected to the telescoping PVC pipes on the seat back using a pair of 3D-printed elbow connectors, which can rotate freely in the horizontal direction. The headrests are able to rotate about the smaller pieces of PVC pipe going through them to convert between headrest and shoulder restraints configurations.

Arm Rest Construction and Conversion

The armrests face straight ahead to operate nominally in gravity mode. To convert to microgravity mode, the user would simply turn the armrests inwards and adjust the height to effectively restrain their thighs.

To construct the armrests, the seat cushion with attached armrests was detached from the chair base structure, as well as the seat back of the chair. The plastic covers on top of the tracks that the armrests slid forward on were removed. A set of small aluminum plates were cut, drilled, and bolted to existing holes on this piece. Similarly, the plastic covers on the base of the armrests themselves were removed, and a larger set of aluminum plates that extended out from beneath the armrest were cut, drilled, and bolted to the bases, as seen in Figure 31.

Figure 31. Aluminum Plate Bolted to Base of Armrest

The armrest was flipped upside down to cushion the thighs when the restraints are being used in microgravity mode. The two aluminum plates were then connected using a shoulder bolt, which acts as a point for the armrest to pivot about when changing modes. This can be seen in Figure 32.

Figure 32. Aluminum Plates Connected with Shoulder Bolt

Finally, the aluminum plates were covered in padding and fabric using hot glue, so that the armrests would feel more comfortable, and the user would not injure themselves. The final prototyping of the armrest can be seen in Figure 33.

Figure 33. Padding Covering Armrest

Seat Back Construction

The constructed seat back with headrest shown in Figure 25 was bolted upright to the existing base of the office chair. The bolted area is shown in Figure 34.

Figure 34. Seat back Bolting Area

This area is located at the end of the spine originally connecting the seat back to the base of the chair. This mounting ensures that when the MGCS is converted between gravity and microgravity modes, the seat back stays vertical. Once the chair is converted to microgravity mode, headrest position can be raised further to ensure the MGCS is still adjusted to the crew member's height.

Seat Base Construction

The original office chair pedestal, along with the height adjusting lever, visible in Figure 36, were kept as-is for the base to ensure the MGCS remained height adjustable. The seat pan was unfastened and removed. Additionally, the wheels on the base of the chair were removed to prevent the MGCS from rolling away when a crew member attempts to sit in it in microgravity mode. After removing the wheels, five pins were exposed and extruded from the base of the chair. To level the base, these pins were covered by five equally sized blocks of 80/20 aluminum, as shown in Figure 35. A hole was drilled out in each block that was slightly smaller than the pins, and the blocks were hammered until the top surface of each block was flush with the base of the chair, ensuring they would stay in place.

Figure 35. 80/20 Blocks Replacing Wheels on Chair Base

Seat Pan Construction and Conversion

In gravity mode, the seat pan acts as a terrestrial seat and remains level with the ground (horizontal), as shown in Figure 36. Two pip pins (one on each side of the MGCS) are used to secure the seat pan at three different levels: flat, 1, and 2. Both levels 1 and 2 are for microgravity mode, with a greater seat pan incline for level 2. The inclined seat pan can be seen in Figure 37.

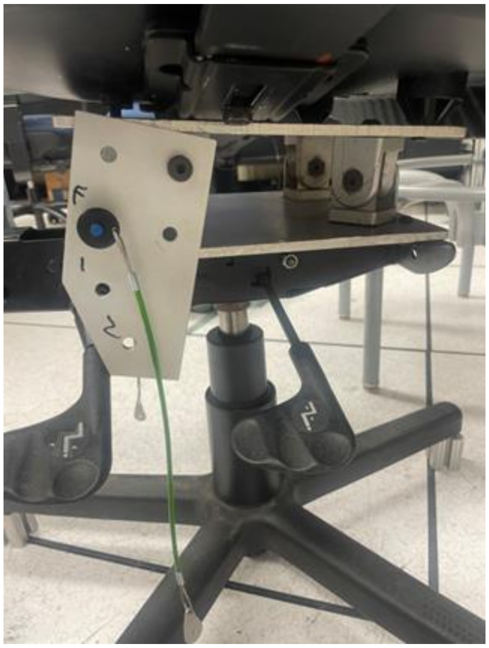

Figure 36. Seat Pan Gravity Mode Configuration

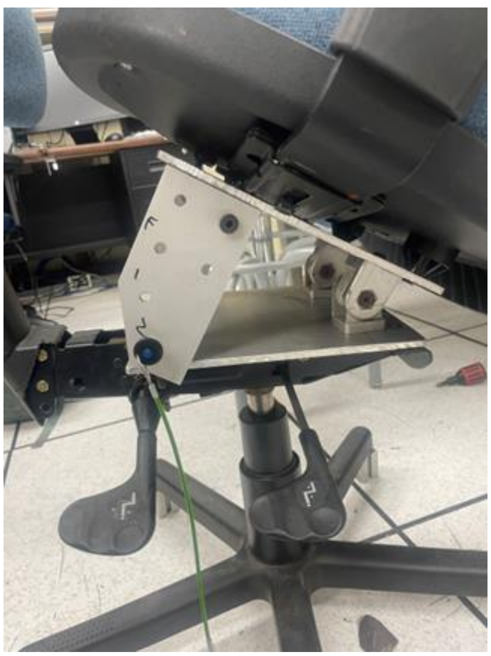

Figure 37. Seat Pan Microgravity Mode Configuration

To convert from gravity mode to microgravity mode, the pip pins on both sides of the MGCS must first be removed. Next, the back of the seat pan should be lifted so that the seat is tilted downwards. The attached bracket holes shown in Figure 37 should be aligned with the pin holes behind them on either side of the MGCS, and the pin pins should be secured at the desired position.

The seat pan underwent several design changes throughout the process of construction. After several design iterations, a final solution was developed that utilized a set of thick, aluminum plates to connect the seat pan to seat base and provide the seat pan pitch adjustment.

The top plate was drilled to align with the holes on the base of the office chair's seat cushion, and the bottom plate was drilled to match the existing holes on the base of the chair.

Four round blocks with pre-drilled holes, as well as two trapezoidal brackets with pre-drilled holes were selected from scrap materials in one of JSC's fabrication shops. These saved a significant amount of time during the fabrication process. As seen in Figure 38, two of the round blocks were bolted to the bottom plate, which would later be bolted to the existing holes in the office chair's base. These two round blocks function as the pivot points using a shoulder bolt going through the bracket on either side, as seen in Figure 39.

Figure 38. Final Design of Tilting Mechanism for Seat Pan: Rear View

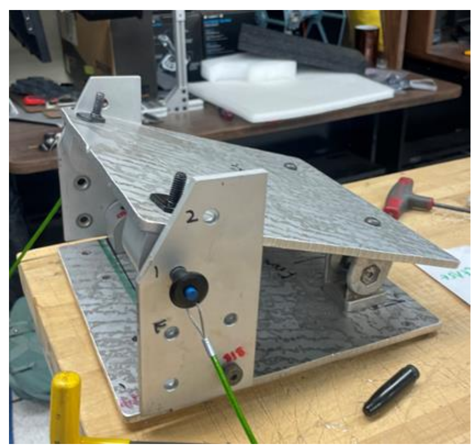

Figure 39. Final Design of Tilting Mechanism for Seat Pan: Side View

The remaining two round blocks are bolted to the top tilting plate shown in Figure 38 and Figure 39. These blocks are used to hold the pip pins on the inner sides of the brackets at each of the three different inclination levels. Finally, two swivel blocks are bolted towards the front of the bottom plate. These swivel blocks help support the tilting and movement of the front end of the seat pan.

Figure 40. Final Design of Tilting Mechanism Bolted to Shock and Base Structure of Chair

This final tilting mechanism was bolted to the base structure of the chair, shown in Figure 40. The seat structure with attached armrests was then bolted to the top plate. The assembled MGCS is shown in gravity and microgravity modes in Figure 41.

Figure 41. Assembled MGCS in Gravity and Microgravity Modes

8. Human-in-the-Loop Evaluations

The current prototype will require some refinement, or there must be construction of a funded, higher fidelity model, prior to conducting human-in-the-loop (HITL) evaluations. These evaluations are the next step in assessing the viability of the MGCS concept.

The first HITL evaluations should be in normal Earth gravity. This should include a 1g usability evaluation and a microgravity simulation. The 1g usability evaluation should focus on use in a nominal seated configuration as would be experienced by crew during training activities. This may involve performance of activities such as science experiments, repair, maintenance, or fabrication activities, systems monitoring, meal consumption, or private recreation. The activities must be of sufficient duration to confirm that the MGCS is sufficiently acceptable for daily activities in areas of usability, comfort, and ease of ingress and egress.

The microgravity simulation should serve as a dry run for reduced gravity evaluations of the MGCS. This would not involve a repeat of the 1g test activities because the only way to currently perform a reduced gravity test (short of actual spaceflights) is on the reduced gravity aircraft, where periods of reduced gravity are limited to 15-20 second periods. Ingress and egress can be tested, as can a short comfort test, one that would primarily identify any acute sources of discomfort in the microgravity mode.

Following 1g evaluations, evaluations should be performed in reduced gravity: 1/6g, 3/8g, and 0g.

9. Conclusions and Forward Work

The MGCS began out of a recognition that crew will need a place to sit down in gravity environments, but in the Common Habitat Architecture, this solution must also serve as a microgravity accommodation. Through a combination of crowdsourcing and intern tours, the concept was refined and finally given physical form.

The fabrication exercise had the benefit of serving as a learning experience for the involved Pathways Intern, but more importantly it created a tangible demonstration of the Multi-Gravity Crew Seat concept. The MGCS was initially conceived just prior to the COVID lockdown and most of the CAD design work and all of the scale modeling was performed virtually from Rhode Island with the involved RISD intern unable to present his work in person onsite in Houston. Having a full-scale unit present at JSC is helpful to communicate the potential of the MGCS more clearly.

During the demonstration of the mockup, it became evident that there are unanticipated terrestrial applications. It had previously been assumed that the microgravity mode would be unusable in normal gravity because the person would be too unstable. However, it was learned that with foot bracing the reduced gravity mode could be used as a leaning stool. While this has not yet been explored, it is possible that the MGCS could be used terrestrially at a standing desk or in any application where a stool would otherwise be used.

That being said, the current full-scale mockup is limited by the restriction to assemble it with surplus and discarded materials available at JSC. Compromises in its functionality had to be made simply because of the inability to purchase parts. A more functional unit that builds on the predecessor CAD modeling and is also compatible with requirements for reduced gravity aircraft should be assembled.

In concert with, or perhaps prior to, the fabrication of a more functional mockup, test plans should be written for both the 1g and reduced gravity HITL test campaign.

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BIOGRAPHY

Robert Howard *is the Habitability Domain Lead in the Habitability and Human Factors Branch and co-lead of the Center for Design and Space Architecture at Johnson Space Center in Houston, TX. He leads teams of architects, industrial designers, engineers, and usability experts to develop and evaluate concepts for spacecraft cabin and cockpit configurations. He has served on design teams for several NASA spacecraft programs, projects, and study teams including the Orion Multi-Purpose Crew Vehicle, Orion Capsule Parachute Assembly System, Altair Lunar Lander, Lunar Electric Rover / Multi-Mission Space Exploration Vehicle / Pressurized Rover, Lunar Terrain Vehicle, Deep Space Habitat, Waypoint Spacecraft, Exploration Augmentation Module, Asteroid Retrieval Utilization Mission, Mars Ascent Vehicle, Deep Space Gateway, Surface Habitat, Transit Habitat, Lunar Terrain Vehicle, and other human spaceflight studies mission studies. He received a B.S. in General Science from Morehouse College, a Bachelor of Aerospace Engineering from Georgia Tech, a Master of Science in Industrial Engineering with a focus in Human Factors from North Carolina A&T State University, and a Ph.D. in Aerospace Engineering with a focus in Spacecraft Engineering from the University of Tennessee Space Institute. He also holds a certificate in Human Systems Integration from the Naval Postgraduate School and is a graduate of the NASA Space Systems Engineering Development Program.*

Sebastian Boal *holds a B.F.A. in Industrial and Product Design from the Rhode Island School of Design (RISD). During his time at RISD, He was a User Research and Product Intern for the MIT Media Lab and a NASA Industrial Design Intern. As co Project Manager for TEST-RAD, he established a cross-functional engineering and design team which was awarded $80,000 by NASA to compete in the Big Idea Challenge. As RISD Rover Club President, he led the team to restart operations in 2020 and expanded the team to participate in multiple challenges: Micro G Next, Big Idea Challenge (partnered with Brown Space Engineering), NASA SUITS, and H.E.R.C. In addition, he studied computation and art, and developed a variety of artistic computer supported works. Sebastian currently is a UX Designer at Capital One, continuing the trend of innovating new ideas. Many of his former soft skills carried over, such as design thinking and human centered design, and he is developing skills of UI, UX, CX, Interaction Design, Design Strategy, and more.*

Vennela Gottiparthy *is a senior studying Aerospace Engineering with a minor in Vocal Music Performance at North Carolina State University. Vennela is a Pathways intern at NASA's Johnson Space Center, where she completed four internships. Her work included aerothermal analysis of entry capsules using Computational Fluid Dynamics; CAD hardware design and drafting of materials for hardware and spacesuit tests in vacuum chambers; training materials for flight controllers and hardware maintenance and install procedures for astronauts on the ISS; and a prototype of the Multi-Gravity Crew Seat while working with JSC's Center for Design and Space Architecture. Previously, Vennela also interned with NAVAIR, where she supported Rolls Royce Pegasus engine maintenance, repair, and disassembly for the AV8 Harrier*

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