Crewed and Uncrewed Semi-autonomous Habitat for the Exploration of Deep Space (CU SHEDS)

Midterm Status Review

Date: 03/18/2021

Rydell Stottlemyer, Colin Claytor, Kaitlyn Olson, Conner McLeod, Sam Schrup, Alex Liem, Marta Stepanyuk, Aaron Stirk, Neil Banerjee
Agenda

• Introduction
• Project Overview
• Team Organization
• Semester Progress
  • Overall
  • Conceptual Design Progress
  • Mockup Progress
  • Human Factors Progress
• Risk Management
Project Overview
Project Overview

- Develop a conceptual design of a deep space habitat
  - Accommodate 4 astronauts for long-duration missions
  - Vehicle remains operational without astronauts present
- Modify our existing mockup to serve as a one of the modules of the deep space habitat
- Perform human factors testing to evaluate the effectiveness of the design
## Project Phases

<table>
<thead>
<tr>
<th>Phase 1</th>
<th>Phase 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Design a deep space habitat</strong></td>
<td><strong>Mockup modification</strong></td>
</tr>
<tr>
<td>• Mass and volume estimates</td>
<td>• Airlock / robotics / logistics module</td>
</tr>
<tr>
<td>• CAD model</td>
<td>• Culminates with Mockup Safety Review</td>
</tr>
<tr>
<td>• Trade studies to determine optimal technologies</td>
<td><strong>Human factors testing</strong></td>
</tr>
<tr>
<td>• Culminates with PDR</td>
<td>• Evaluate the adequacy of the mockup design</td>
</tr>
<tr>
<td></td>
<td>• Culminates with Final Project Report</td>
</tr>
</tbody>
</table>

**COMPLETE**
Customer Info

HOME – Habitats Optimized for Missions of Exploration

• CU HOME team members:
  • Dr. Allison Anderson
  • Dr. Torin Clark
  • Dr. David Klaus
  • Dr. James Nabity

• Point of Contact – Dr. Allison Anderson

• Funded by NASA
Team Organization
Phase 1 Organization Chart

Senior Manager
- Rick Hieb

Project Advisor/Senior Engineer
- Col. James Voss

Project Management
- Rydell Stottlemyer
- Colin Claytor

POC: Dr. Allie Anderson

HOME

Senior Manager

Financial Manager
- Marta Stepanyuk

ECLSS
- Samuel Schrup
- Kaitlyn Olson
- Marta Stepanyuk
- Rydell Stottlemyer

SYSTEMS ENGINEER
- Kaitlyn Olson
- Neil Banerjee

Structures & Mechanisms
- Aaron Stirk
- Alex Liem
- Samuel Schrup

Technical Director
- Conner McLeod

Thermal, Power, & Propulsion
- Colin Claytor
- Alex Liem

EVA, CA, & Communication
- Marta Stepanyuk
- Conner McLeod
- Aaron Stirk

Safety
- Neil Banerjee
Overall Progress
### Spring 2021 Tasks and Deliverables

<table>
<thead>
<tr>
<th>Task</th>
<th>Description</th>
<th>Scheduled Completion Date</th>
<th>Actual Completion Date</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIOASTRO-1</td>
<td>Conduct a Kickoff Meeting with BIOASTRO management and the BIOASTRO HOME Team researchers to refine work to be completed in support of the Deep Space Habitat and mock-up design. Agree on scope of work to be performed.</td>
<td>1/26/2021</td>
<td>1/26/2021</td>
<td>✓ Complete</td>
</tr>
<tr>
<td>BIOASTRO-2</td>
<td>Conduct Technical Interchange Meetings (TIM) with BIOASTRO HOME Team researchers to verify the concept for the HOME mock-up to support future research needs and human factors evaluations.</td>
<td>1/28/2021</td>
<td>1st TIM on 1/28/2021</td>
<td>✓ Complete</td>
</tr>
<tr>
<td>BIOASTRO-3</td>
<td>Complete systems engineering documents in support of the Deep Space Habitat design.</td>
<td>2/25/2021</td>
<td>2/21/2021</td>
<td>✓ Complete</td>
</tr>
<tr>
<td>BIOASTRO-4</td>
<td>Complete design of a Deep Space Habitat.</td>
<td>3/11/2021</td>
<td>3/11/2021</td>
<td>✓ Complete</td>
</tr>
<tr>
<td>BIOASTRO-5</td>
<td>Complete work to repurpose the existing TALOS mock-up.</td>
<td>3/29/2021</td>
<td></td>
<td>On Track</td>
</tr>
<tr>
<td>BIOASTRO-6</td>
<td>Complete limited human factors evaluations of the HOME mock-up.</td>
<td>4/22/2021</td>
<td></td>
<td>On Track</td>
</tr>
<tr>
<td>BIOASTRO-7</td>
<td>Prepare and conduct additional meetings and reviews of program progress, readiness, and status.</td>
<td>4/27/2021</td>
<td></td>
<td>On Track</td>
</tr>
</tbody>
</table>
Hours Worked (Jan. 16 – March 12)

**Average Team Hours/Week:**
22.4

**Total Hours Worked:**
1618.7

**Total Est. Cost with Full Time Employees (at $35/hr):**
$56,653

**Cost for Graduate Project:**
$4,000
<table>
<thead>
<tr>
<th>Category</th>
<th>Estimated Cost</th>
<th>Current Spending</th>
<th>Remaining</th>
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</thead>
<tbody>
<tr>
<td>Mock-Up Construction</td>
<td>$3,033.18</td>
<td>$368.75</td>
<td>$2,664.43</td>
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<tr>
<td>Administrative Costs</td>
<td>$385.00</td>
<td>$271.66</td>
<td>$113.34</td>
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<tr>
<td>Human Factors Testing</td>
<td>$100.00</td>
<td>$0</td>
<td>$100.00</td>
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<tr>
<td>COVID-19 Safety</td>
<td>$275.50</td>
<td>$6.87</td>
<td>$268.63</td>
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<tr>
<td>Project Subtotal</td>
<td>$3,793.68</td>
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<tr>
<td>5.44% Margin</td>
<td>$206.32</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>$4,000.00</strong></td>
<td><strong>$647.28</strong></td>
<td><strong>$3,146.40</strong></td>
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</table>
Conceptual Design Progress
Conceptual Design Status Update

• Completed systems engineering deliverables in support of the conceptual Deep Space Habitat design
  • System Requirements Review – COMPLETED
  • Concept Definition Review – COMPLETED
  • Preliminary Design Review – COMPLETED
    • Master Equipment List with mass, volume, and power estimates
    • Conceptual DSH CAD model
    • Compliance with HOME Deep Space Habitat System Requirements

• Work Remaining
  • Delta Concept Definition Review Document – IN PROGRESS
Overall Layout
Full Subsystem Layout
Laboratory Module

Includes ECLSS, Avionics, Power, Communications, Crew Accommodations, and Robotics
Airlock, Robotics, and Logistics (ARL) Module

Includes ECLSS, Crew Accommodations, Robotics, and EVA
Power Propulsion Element (PPE)

Includes Communications, Power, Propulsion, Thermal, and Avionics/ADCS
Subsystem Breakdown
Structures and Mechanisms
Structures and Mechanisms Summary

• Five-layer Whipple Shield for MMOD protection
• Primary Structure of Al 2219-T87 Isogrid Shell
• Secondary Structure of Extruded Al 6061
• One observation window with 20 in diameter
• Radiation Protection: High-Density Polyethylene paneling and water
• Docking: Three IDSS Docking Ports
• Multi-Layered Insulation (MLI)
ECLSS
ECLSS Summary – Atmospheric Maintenance

• Focus on regenerability and flight heritage
• CO2 Removal and Reduction: four bed molecular sieve, Sabatier reactor
• Oxygen Provision: Oxygen Generator Assembly, oxygen storage tanks
• Inert Gas Provision: Nitrogen storage tanks
• Gas regulation: pressure regulator, distribution lines, pressure control assembly
• Environmental Monitoring: Major Constituent Analyzer (MCA), Volatile Organic Analyzer
• Particulate and microbe control: Trace Contaminant Control System, HEPA filters
• Humidity Control: Condensing Heat Exchanger, water separator
• Temperature control: Condensing Heat Exchanger, temperature control and check valve
ECLSS Summary – Water and Waste

• Focus on regenerability and flexibility
• Water Processor: two sorbent beds, volatile removal assembly, and final ion exchange bed
• Water storage: Bladders
• Water distribution: potable bus, wastewater bus
• Waste collection: Universal waste management system
• Waste Processing: Urine Processor (Vapor compression and distillation subassembly), Brine Processor (Ionomer Water Processor)
• Waste storage: UWMS Containers (bags for fecal waste, urine canisters), hand compactor
• Waste disposal: Waste Storage bags slowly transferred to resupply vehicle
Water Bladder Locations

Dehydrated Food Storage

Sabatier Reactor

Oxygen Generator

Contingency LiOH

Universal Waste Management System

UWMS Canisters

Contingency Oxygen Tanks
ECLSS Summary – Food, Crew Services & Thermal Management

• Food provision: dehydrated food
• Food storage: CTBs, designated storage area, resupply vehicle
• Food prep: Water dispenser provides adjustable temperature water for food and beverage hydration
• Vacuum: wet/dry vac for crew usage
• Heat removal: condensing heat exchanger, dual water loop, cold plates
Data and Hazard Mitigation

- ECLSS Monitoring: Publish-subscribe architecture
- Data and communication: Redundant Ethernet Wi-Fi system

- Fire Detection: Four fire detectors located in racks, ducting, and module 1
- Personal breathing apparatus
- Three Fire extinguishers
- Contingency CO2 removal: LiOH
- Contingency Oxygen: Pressurized O2
Communications
Communications Summary

• Earth to Habitat: via MAXAR PPE (x and ka bands)

• Inter-Habitat: Intercomm and speakers

• EVA Capabilities: Space-to-Space Station Radio (SSER)
Crew Accommodations
Crew Accommodations Summary

• Exercise: Cycle Ergometer, Resistive Overload Combined with Kinetic Yo-Yo (ROCKY)
• Hygiene: Personal Hygiene Kits
• Sleep: Four Private Sleeping Quarters (sleeping bags, restraints, eye covers)
• Leisure and entertainment: Personal storage area
• Medical supplies: Level IV Medical Care Kit, Crew Restraint Medical System, Medical Waste Disposal
• Food prep and storage: Pullout table, Velcro attached dinner trays, Basic Utensils, Scissors
• Trash disposal: trash bags, disposed of during resupply missions
• Internal handholds and foot restraints
Crew Accommodations in Laboratory Module

- Crew Restraint Medical System
- Medical Care Kit
- Medical Waste Container
- Handholds
- Crew Storage (Leisure/Entertainment)
- (Personal) (Clothing)
- Personal Hygiene Kit
- Sleeping Quarters
Crew Accommodations in Laboratory Module

Pullout Table

CA CTBs
Robotics
Robotics Summary

• External Robotic Arm similar to CANADARM
  • Grapple fixture
  • Can reach both ends of the habitat

• Internal UR5e Robotic Arm
  • Mounted on internal rail system
  • Can reach all racks
EVA
EVA Summary

- Airlock Module
- EVA Assistance:
  - Lighting
  - Handholds/Footholds and Railings
  - Umbilical Interface Assembly (UIA)
- EVA equipment storage volume for tools and work belts
- EVA suit storage volume
Avionics and ADCS
Avionics and Data Handling

• Main processor: BAE Systems RAD5545 (2x)
• Total storage capacity of 9.6 TB
• Misc. GNC hardware:
  • Star trackers, sun sensors, IMUs, and a rendezvous and docking sensor
  • Ball Aerospace CT-2020 (x3), New Space NFSS-411 (x3), Honeywell MIMU (x6), and Optronik RVS 3000 (x2)
ADCS Summary

• Four Control Moment Gyroscopes for attitude control
• Reaction Control Thrusters for coarse attitude adjustment and desaturation capabilities
Power
Power Summary

• Mainly on PPE
• Solar Panels
• Lithium-ion batteries store electricity and are interfaced to Battery Charge/Discharge Units
• The robotic arm will include its own lithium-ion battery as a backup
Power Subsystem Layout (PPE)

- Solar Wing
- Static Solar Panel
- Battery
- Battery Charge/Discharge Unit
Thermal
Thermal Summary

- Dual-sided radiator vane and an ammonia-water dual loop act as active thermal control
- Radiators are collapsible and rotatable with Z-93 coating
- MLI for passive thermal control
Propulsion
Propulsion Summary

- PPE
- Thrusters: Hall-Effect Thrusters with Xenon as their fuel
Volume, Mass, and Power Estimates
Volume Estimates

Total Internal Volume $[m^3]$

- Structures, 3.65
- Robotics, 0.11
- EVA, 1.82
- Avionics, 1.50
- Power, 0.01
- Comms, 0.06

ECLSS, 8.15
CA, 3.89

Total Volume (Volume Estimate + Consumable Volume) $[m^3]$

- ECLSS 8.15
- CA 3.89
- Structures 3.65
- Robotics 0.11
- EVA 1.82
- Avionics 1.5
- Thermal 0
- Prop 0
- Power 0.01
- Comms 0.06
- TOTAL 19.19
Habitable Volume Breakdown

Internal Volume Breakdown [m^3 and %]

- Habitable Volume: 103.14 (84%)
- Subsystems: 19.19 (16%)

Legend:
- Blue: Habitable Volume
- Orange: Subsystems
### Mass Estimates

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Internal Mass [kg]</th>
<th>External Mass [kg]</th>
<th>Subsystem Total [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECLSS</td>
<td>4139</td>
<td>0</td>
<td>4139</td>
</tr>
<tr>
<td>CA</td>
<td>385</td>
<td>0</td>
<td>385</td>
</tr>
<tr>
<td>Structures</td>
<td>5865</td>
<td>0</td>
<td>5865</td>
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<tr>
<td>Robotics</td>
<td>136</td>
<td>286</td>
<td>422</td>
</tr>
<tr>
<td>EVA</td>
<td>669</td>
<td>0</td>
<td>669</td>
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<tr>
<td>Avionics</td>
<td>300</td>
<td>0</td>
<td>300</td>
</tr>
<tr>
<td>Thermal</td>
<td>269</td>
<td>9946</td>
<td>10215</td>
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<tr>
<td>Prop</td>
<td>0</td>
<td>11012</td>
<td>11012</td>
</tr>
<tr>
<td>Power</td>
<td>6</td>
<td>4200</td>
<td>4206</td>
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<tr>
<td>Comms</td>
<td>42</td>
<td>0</td>
<td>42</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td><strong>11,811</strong></td>
<td><strong>25,444</strong></td>
<td><strong>37,254</strong></td>
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</tbody>
</table>

**DSH Mass:** 12,096 kg = 13.3 US tons < 22 US ton requirement
## Power Estimates

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>ECLSS</td>
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<td>0</td>
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<tr>
<td>CA</td>
<td>340</td>
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</tr>
<tr>
<td>Structures</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Robotics</td>
<td>371</td>
<td>3681</td>
<td>4052</td>
</tr>
<tr>
<td>EVA</td>
<td>120</td>
<td>0</td>
<td>120</td>
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<tr>
<td>Avionics</td>
<td>170</td>
<td>0</td>
<td>170</td>
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<td>Thermal</td>
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<td>2200</td>
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<tr>
<td>Prop</td>
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<td>54400</td>
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<tr>
<td>Power</td>
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<td>-85400</td>
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<tr>
<td>Comms</td>
<td>144</td>
<td>0</td>
<td>144</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td><strong>5130</strong></td>
<td><strong>-25119</strong></td>
<td><strong>-19989</strong></td>
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</tbody>
</table>

** Negative values denote power generation, positive value denote power use
Conceptual Design
Schedule and Integration
Conceptual Design Integration

• Integration of the ARL Module performed by Spring 2021 CU BIOASTRO Graduate Project Team
  • Work with Mockup and Human Factors subteams

• Future Integration of the Laboratory Module performed by Fall 2021 CU BIOASTRO Graduate Project Team
  • Provide integration recommendations and lessons learned documentation to the Fall 2021 CU BIOASTRO Graduate Project Team by the Final Review
Mockup Overview & Modification Tasks

- Modify the Fall 2020 TALOS team HLS crew cabin mockup into a combined airlock, robotics, and logistics module based on the CU SHEDS paper design and the Spring 2021 Statement of Work

- Preparation & Relocation – COMPLETED
- Docking Port & EVA Hatch – IN PROGRESS
- Observation Window – IN PROGRESS
- Crew/EVA Accommodations – IN PROGRESS
- Robotics Workstation – IN PROGRESS
- General Refurbishment – IN PROGRESS
- Final Integration, Test Prep, & “Better/Nicer” Tasks – NOT YET STARTED

- Overall Sub-Team Status: ON SCHEDULE
Preparation and Relocation

• Removal of all unnecessary hardware
• Shortening of the mockup platform
• Removal of the porch
• Addition of access stairs
• Relocation of the mockup to accommodate future work
Docking Port & EVA Hatch

• Non-functional facsimiles of an EVA hatch and “ceiling” docking port
• Floor docking port is not being included
• These will be posters that will be printed to the appropriate size and shape using either ITLL services or a commercial printer
• This is the one task that may have a lead time
Observation Window

• 20-inch diameter circular window
• Located next to the robotics workstation
• Affects the overall “skeletal” structure of the mockup
• CAD model being created to perform simulations
Observation Window

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Observation Window

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Observation Window

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- Affects the overall “skeletal” structure of the mockup
- CAD model being created to perform simulations
Observation Window
Crew & EVA Accommodations

• Crew Accommodations:
  • Build cabinet to secure 5 CTBs
  • Develop exercise equipment stowage methods
  • Collect CTB CA items
  • Insert handholds
  • Insert footholds

• EVA Accommodations:
  • Quick inspection and clean-up of xEMU suits
  • Attach depressurization panel to wall
  • Build suit stowage system
Robotics Workstation

• Reuse the pilot station controls from the Fall 2020 TALOS team mockup including:
  • Translational hand controller
  • Rotational hand controller
  • Dual monitors
  • Non-functional switch panels

• Monitors will be placed in their "landscape" configuration one on top of another
General Refurbishment

• Replace damaged wall sections
• Inspect and tighten all screws in the main structure
• Patch holes in floor
• Cover holes in wall causing excessive light bleed
Final Integration, Test Prep, & “Better/Nicer”

• Clean up workspace and mockup interior in preparation for internal and beta testing

• Ensure Human Factors Sub-Team has everything they need exactly as they need it

• “Better/Nicer” Tasks:
  • Improve ventilation system
  • Improve door mechanism
  • Repair and upgrade functional CTBs
  • 3D-Print new bezels for monitors
Current State of the Mockup
Mockup Layout

- EVA Hatch
- VISE Panel
- Observation Window
- Suit Storage
- Entrance door
- CTB & xPLSS Cabinet
- CTB Storage
- XPLSS Slots
Mockup Schedule

Mock Up
Clear Items from Under the Mock Up
Remove All Items from Inside the Mo...
Temporarily Remove Interior Electron...
Remove Windows and Walls Around...
Remove Damaged Wall Segments N...
Move Mock Up/Platform Assembly
Construct New Staircase Assembly
Design and Build Observation Window
Create Docking Port/EVA Hatch
Build Crew Accommodations
Build EVA Accommodations
Add in Wall Sections that Need Repla...
Reattach Modified Robotics Station/
Final Integration, Pre-Test Preparation...
Mock Up Safety Review
Human Factors
Current Progress/Accomplishments

• Conducted Human Factors briefing led by Dr. Sanchez
• Looked over previous semesters’ documentation to guide our own
• Wrote Human Factors Test Plan first draft
  • Test plan
  • Test procedures
  • Pre-test forms
  • Post-test questionnaires
  • Test monitor evaluation form
  • Safety plan
• Currently implementing edits and interfacing with Mockup Team
• Plan for revisions in place
Testing Goals and Evaluations

• Per the Statement of Work, we will evaluate:
  • Robotics workstation control and display reach and visibility
  • Crew accommodations acceptability (handholds, foot restraints, exercise equipment, EVA support equipment, storage)
  • Suitability for use as an airlock
  • Interior volume adequacy for expected use
  • Operational tasks (WCS usage, exercise)
Procedure Overview (very high level)

• Robotics Workstation (Issue diagnosis)
  • Display visibility
  • Translational, rotational controller reach
  • Switch panel reach and visibility

• Exercise (Daily Routine)
  • Retrieve exercise clothes from CTB (not donned)
  • Deploy, use, and stow ROCKY

• xEMU Inspection and Maintenance Task (EVA Preparation)
  • Retrieve maintenance tools and spare part from CTB
  • Open suit back and perform minor maintenance task (e.g. battery swap)
  • Close suit
  • Stow xEMU tools and spent part in CTB
Test Subject Population and Planning

• Reduced population size due to COVID-19
• Test participants drawn from following groups, (+1 team member):
  • Senior management and external advisors to the graduate project
  • CU Boulder Bioastronautics faculty
  • Members of the graduate project
  • Employees of BioServe Space Technologies
  • Dr. Sanchez and Michael Zero

• Preliminary list of safety measures:
  • Test subjects will wear masks during the entirety of the test
  • Test subjects will be screened immediately before a test using questionnaires and body temperature measurement
  • The mock-up will be wiped down with disinfectant after every use
Data Collection Methodology

• Post-Test Questionnaire (6-Point Likert Scale Questions + General Comments)
• Post-Test Interview/Discussion
• Demographic Questionnaire
  • Prior applicable experience
  • Anthropometric data
  • Placed last due to recent initiative in human subject research + BOLD Center
Data Analysis Methodology

• Specific tests used based on briefing and feedback from Dr. Sanchez
• Demographic questionnaire used to determine weighting factor on each subject
  • Prior spaceflight or piloting experience?
  • How close/involved was test subject to project?
• Likert Questionnaires
  • Measures of central tendency, consensus, and data visualization
  • Comparison between groups
  • Effect size of demographics on scores (experience, anthropometrics)
• Post-test Interview/discussion information:
  • Common points compiled and presented at the end of the semester
  • Findings documented for subsequent semesters
Human Factors Testing Schedule

Today
Programmatic Risk Assessment
Risk Matrix prior to Mitigation

Consequence

- Severe
- Major
- Moderate
- Minor
- Negligible

Likelihood

- Extr. Low
- Low
- Medium
- High
- Extr. High

Implement new processes or change baseline
Aggressively manage; consider alternative processes
Track and monitor

Significant Risks:
1: Project Halted due to COVID-19
2: Individual team member illness
3: Restricted Access to High Bay
4: Human Factors Testing Delay
5: Inefficiency in team communication
6: Budget Overshoot
7: Construction Schedule Slip
8: Manufacturing Delays
9: Expanding Scope
Selected Risk Mitigation Strategies

1-4: Delays and Risks due to COVID-19
  • Begin semester working from home, practice good hygiene
  • Explicit protocols in place for the team
  • Seek special access to high bay, coordinate with other users
  • Human factors testing restricted to approved members of CU AERO

6: Team Communication/Dynamics
  • Significant carryover from previous semester, using MS Teams

7, 8: Schedule Slips (Construction, Manufacturing)
  • Start construction early, use/augment existing stock material
  • Keep open communication with machine shop early on, formulate list of reliable external resources
  • All-hands work sessions (“Workapalooza”)

9: Expanding Scope
  • Fair negotiation of expectations and constant contact with project leadership
Significant Risks:
1: Project Halted due to COVID-19
2: Individual team member illness
3: Restricted Access to High Bay
4: Human Factors Testing Delay
5: Inefficiency in team communication
6: Budget Overshoot
7: Construction Schedule Slip
8: Manufacturing Delays
9: Expanding Scope

Risk Matrix following Mitigation:

- **Severe**
  - Consequence: 9
- **Major**
  - Consequence: 1, 3, 4, 6
  - Likelihood: 2
- **Moderate**
  - Consequence: 5, 7, 8
- **Minor**
  - Consequence: Extr. Low, Low, Medium, High
- **Negligible**
  - Consequence: Extr. High

**Likelihood**:
- Low
- Medium
- High
- Extr. Low
- Extr. High

**Consequence**:
- Low
- Medium
- High
- Extr. Low
- Extr. High

**Risk Assessment**:
- **Severe**: Implement new processes or change baseline
- **Major**: Aggressively manage; consider alternative processes
- **Moderate**: Track and monitor

**Negligible**
Backup Views
Backup Views
Backup Views
Backup Views
Avionics

- **ADCS processor: BAE Systems RAD5545**
  - Quad core
  - Radiation hardened
  - SpaceWire I/O
  - Vision Processing Unit serves as backup

- **Storage: Mercury Systems TRRUST-Stor VPX RT 2\textsuperscript{nd} Generation Radiation-Tolerant Large Geometry SLC NAND SpaceDrive**
  - 10 total units onboard
  - Total storage capacity of 9.6 TB

- **Misc. GNC hardware:**
  - Star trackers, sun sensors, IMUs, and a rendezvous and docking sensor
  - Ball Aerospace CT-2020 (x3), New Space NFSS-411 (x3), Honeywell MIMU (x6), and Optronik RVS 3000 (x2)
Attitude Control Trade Study

• Control solutions:
  • Controls Moment Gyroscopes
  • Reaction wheels
  • Bias-momentum wheels

• Control criteria:
  • Fine control capability
  • Desaturation frequency
  • Maintenance capability
  • Mass
  • Latent system stability
Attitude Control Summary

• Selected Control Moment Gyroscopes to provide fine control of the habitat due to their fine control capability, proven capability at reorienting large spacecraft, reduced desaturation needs, and high latent stability

• Reaction Control Thrusters are to be used as the coarse attitude adjustment solution for the habitat as well as the control moment gyroscope desaturation mechanism
  • Will ensure habitat can exit orientations for which control moment gyroscopes cannot correct its attitude
Power Trade Study

• Proposed solutions
  • Static solar panels
  • Rotating solar wings
  • Radioisotope thermoelectric generators
  • Nuclear fission reactor
  • Fuel Cells

• Criteria:
  • Power production
  • Mass
  • Operational life
  • Adaptability to mission demands
Power Summary

• Selected solar wings as primary power generation method, with static solar panels as secondary power generation method

• Low mass, long operational life, versatility in application led to these concepts being selected
Thermal Trade Studies

• Configuration options:
  • Single or Double-sided panel

• Criteria:
  • Heat dissipation capability
  • Versatility to changing thermal loads
  • Complexity

• Working fluid options:
  • Ammonia-water dual loop or propylene glycol-water dual loop

• Criteria:
  • Flight heritage
  • Heat transfer effectiveness
  • Team familiarity
Thermal Summary

• Ultimately decided on a dual sided radiator vane and an ammonia-water loop for the active thermal control system
• To allow for varying thermal loads, the radiators will be collapsible and rotatable
  • Partially collapsing the radiator will limit its view factor, causing it to retain more heat
  • Rotating the radiator relative to the sun will cause it to absorb some thermal energy.
• Decided to use Z-93 coating for its flight heritage
• Will use MLI for passive thermal control
• Still need to allocate space in PPE for Ammonia pump and tank
Propulsion Trade Study

• Proposed solutions:
  • Hall Effect thrusters
  • Bipropellant thrusters
  • Nuclear thermal thrusters

• Criteria:
  • Efficiency
  • Mass
  • Power consumption
  • Mission applicability
Propulsion Summary

• Decided upon Hall Effect thrusters
• Efficient, reasonable mass, and well suited to mission