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Advanced Habitation Efforts at JSC-CTSD

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The Johnson Space Center (JSC) is the NASA center for Human Spaceflight. As such, a group of engineers and space architects are working on efforts to raise the awareness of habitation requirements and habitability needs to support the US Vision for Space Exploration. Lead by a space architect, this group is working on trade studies, system level assessments, requirements validation, operational concept validation, concept development, and integrated testing. This group works within the Crew and Thermal Systems Division at JSC. The Architecture, Habitation, and Integration (AH&I) group matrixes subject matter experts such as space human factors, manufacturing, safety and mission assurance, crew support, and others as required depending the trade study, assessment, concept or testing required. The AH&I group performs much of the requirements validation by using low-fidelity mockups and rapid prototyping to evaluate solutions to issues. This paper will describe the team, processes and facilities at JSC that enable the validation of needed habitation systems for future missions to the Moon and Mars.

Introduction

The exploration of space by humans is not an easy endeavor. It takes many dedicated teams to ensure the safety and health of our brave space travelers. Many specialties comprise a complex multi-skilled team that is either planning the hardware, testing it, flying it, or repairing it. As such, a special team of engineers and space architects are on the forefront of habitation and human factors requirements development and validation. Test articles and mockups are a key tool to test these requirements.

The space environment is inhospitable to human life. Space habitats are a re-creation of the earth environment for sustaining human life. Habitats are pressurized crew volumes including laboratories, living quarters, repair, and maintenance facilities. The space environment is characterized by vacuum, orbital debris, microgravity for orbital space stations and transfer missions, partial gravity for planetary exploration missions, radiation, and planetary dust. These characteristics are major design challenges for space habitation.

Space habitats naturally attract great interest for a human-exploration program because they are sophisticated pressurized systems that contain and protect the ultimate payload -- humans. Often over looked, Humans are a complex System that is at the center of human spaceflight. Humans require habitats to live and work in space or on other planets. Habitats are complex, heavy, expensive elements around which support systems are functionally arrayed, both in transportation systems and in permanent facilities like space stations and future planetary bases. Their concept development and selection requires careful consideration.

Space habitats are systems designed to maintain a productive environment for humans living and working in space. Space habitats can be divided into three categories based on duration; short (days to weeks), medium (weeks to months), and long (months to years).

Short Duration Mission - For mission durations of a few days to couple of weeks, crews can share personal quarters by rotating shifts, as is done when the Space Shuttle carried Spacelab.

Medium Duration Mission - For mission durations up to six months, crews require their own private personal quarters for sleeping as well as private recreation (reading and communication with relatives), and will require more volume for grooming and personal hygiene.

Long Duration Mission - For mission durations of six months or more, crews essentially require all the necessary "comforts of home."

Volumetric requirements for space habitats vary based on crew size and mission duration. Historical habitat sizes are illustrated in figure 1. As shown in figure one, the longer humans want to stay in space the more total pressurized volume is required (e.g., volume per crew member). Many research articles, papers and textbooks have been written on this subject, so there is no need to restate the obvious other than to say humans need their space (or habitable volume in this case).

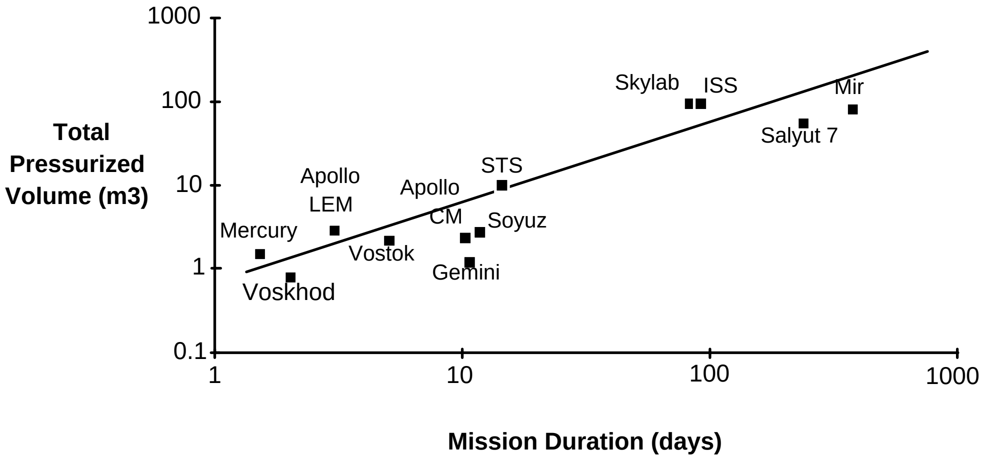

Figure 1. Historical Space Habitat Pressurized Volume.

Space habitat configurations vary according to the design program, goals, objectives, and requirements; but there is a core group of functions required in order to satisfy the basic needs of sustaining humans in space. Functions such as life support, thermal control and communications to mention a few are essential to a space habitat. Overall, a space habitat configuration combines all the subsystems required to provide and maintain a living and working environment in space. More specifically, the ability to produce power, reject excess heat, recycle water, revitalize air, maintain crew health, and meet the crew's physical and psychological needs. The habitat configuration can vary from a single open volume of a short duration spacecraft; to a medium duration habitat of a single volume with separated spaces; to the complex and sometimes multiple volumes of an outpost consisting of long duration habitats, airlocks, and laboratories.

The habitation system interfaces with external systems in all applications. The overall space system whether orbital, transfer, or surface, provides critical infrastructure support, much like structures on earth provide utility interfaces. The external system must provide a source of power, thermal control in the form of heat rejection, support structure, communications, and other external systems such as experiments, sensors for monitoring the system infrastructure, and an airlock/EVA system (figure 2).

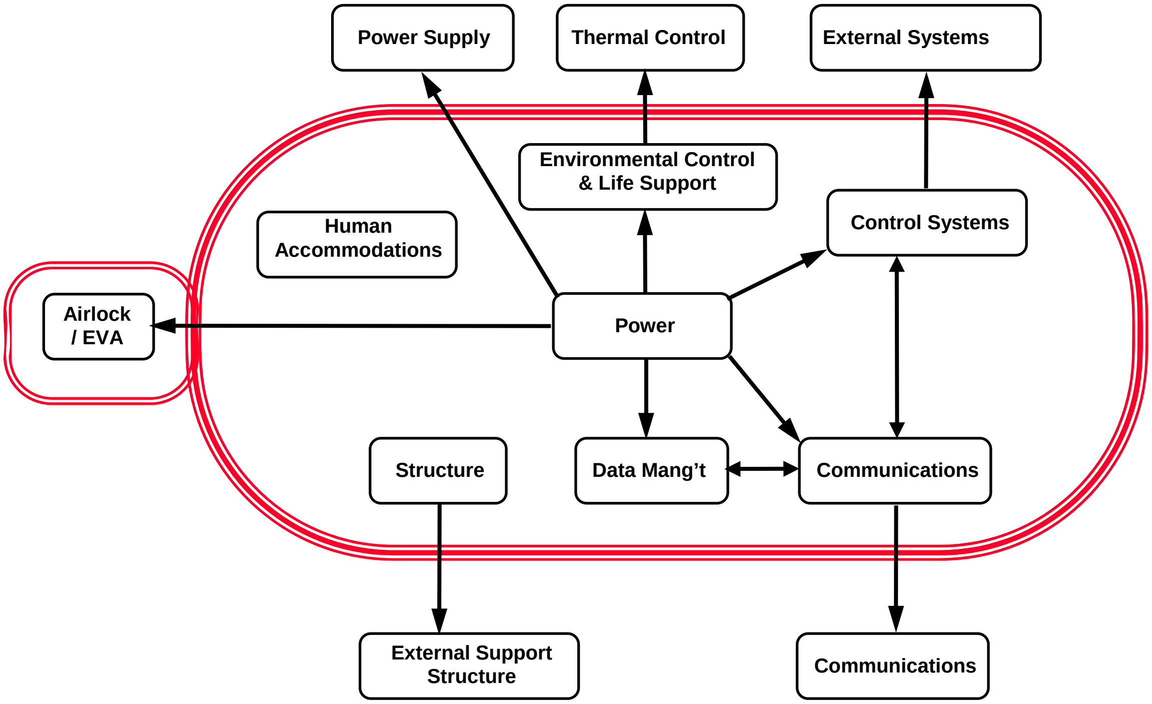

Figure 2. Habitat Elements and Interfaces.

With an understanding of space habitats, the remainder of this paper will describe the advanced habitation efforts being performed by the AH&I group in the Crew and Thermal Systems Division at JSC.

Crew and Thermal Systems Division

The Crew and Thermal Systems Division (CTSD) is responsible for most of the human systems and habitation hardware at NASA. It builds Government Furnished Equipment (GFE) hardware for the International Space Station (ISS), Shuttle, and Constellation. This hardware is for current and future EVA hardware, crew and habitation system, and Exploration Life Support technology development for the Johnson Space Center. Figure 3 shows CTSD's organizational structure to support these human exploration projects. Among the CTSD many accomplishments with technology development and flight hardware is their history and experience with habitability system.

CTSD History & Experience with Habitability

- Developing new technologies and flight systems for:
  - Environmental Control/Life Support Systems (ECLSS)
  - Active Thermal Control Systems (ATCS)
  - Extravehicular Activity (EVA) equipment
  - Intravehicular Activity (IVA) equipment
  - Space Suit Systems
- Providing test capability in both vacuum and thermal/vacuum environments, including human-rated facilities.
- Managing and implementing the design, development, testing, and qualification of systems for crewed space flight habitation, transport, science, and operations.
  - Providing engineering technical support to the Shuttle Orbiter Program Office in the areas of IVA Equipment.
  - Technical management and engineering support for the ISS Habitability Systems Hardware.
- Subsystem management for the Shuttle Flight Crew Equipment.

- System and Subsystem management for the ISS Habitability Outfitting systems and Intravehicular Equipment.
- Represent the ISS program for establishing the requirements and approving the acceptance of ECLSS, ATCS, and Habitability Outfitting systems and Intravehicular Equipment.

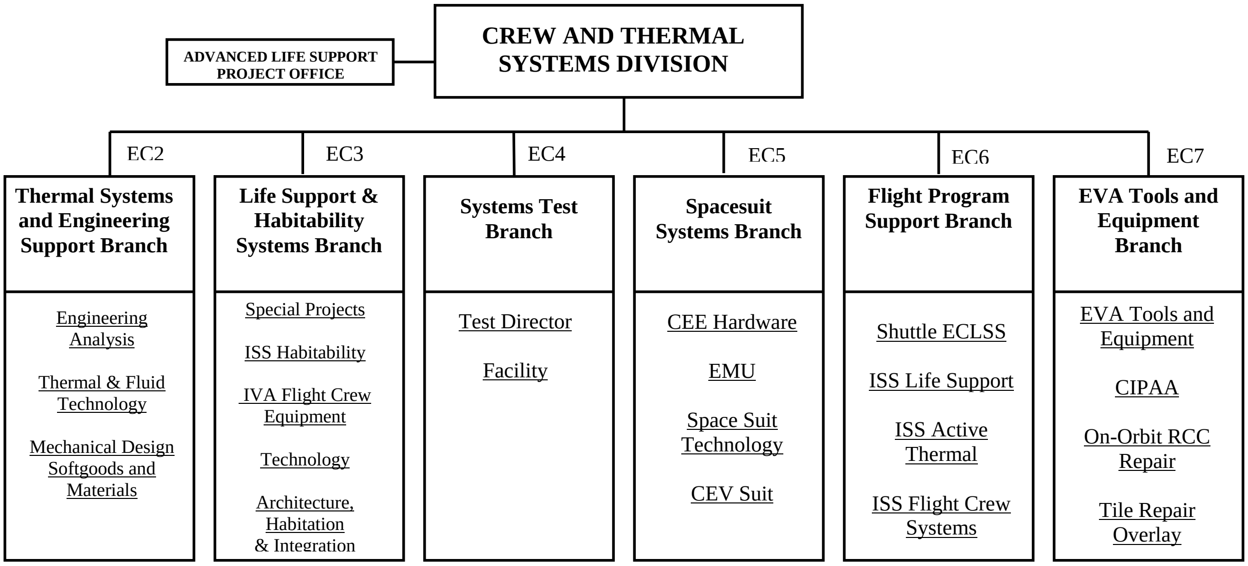

Figure 3. Crew & Thermal Systems Division Organization Chart.

The Architecture, Habitation and Integration group is a diverse group of engineers led by a space architect within the Life Support & Habitability System branch in CTSD. This group is working on architecture, habitation and integration efforts to design, validate, and verify human systems in support of the Vision for Space exploration (VSE).

Architecture, Habitation and Integration

The Architecture, Habitation, and Integration (AH&I) group matrixes subject matter experts such as space human factors, manufacturing, safety and mission assurance, crew support, and others as required pending the trade study, assessment, concept design, or testing required. This group is working on trade studies, system level assessments, requirements validation, operational concept validation, concept development, and integrated testing. The AH&I group performs much of the requirements validation by using low-fidelity mockups and rapid prototyping to evaluate solutions to issues. The following is the AH&I charter, vision, mission, purpose, goals, and objectives of this group.

<u>Charter</u>:

- AH&I's charter is to provide advanced habitability competencies to the program and project offices. This includes design knowledge and hardware engineering expertise in support of the Vision for Space Exploration. To ensure the agency has the required enabling habitation technology that will lead NASA's efforts of Human Exploration and Development of Space into the 21st century.

<u>Vision</u>:

- To develop an advanced habitability competency for JSC and the agency that is recognized as the experts for advanced habitability hardware.

<u>Mission</u>:

- The AH&I mission is to support NASA's efforts towards human space exploration by designing, developing and testing human systems for future spacecraft and planetary systems.
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<u>Purpose</u>:

- To create a CTSD core competency for advanced habitation.

- To create an integrated technology focused effort of Advanced Habitation Systems for CTSD, JSC and NASA at large.

Goals:

- To develop an advanced habitability expertise and skill base that is recognized by Constellation as the advanced habitation hardware developers.
- Develop CTSD into the lead competency for the agency for Advanced Habitation Systems hardware prototyping, development and testing.
- Ensure crosscutting system of systems integration and concepts, enabling technology, and technology flight demonstrations.
- Provide design and technology consultation to program offices, projects and mission planning activities. I.e. Crew Exploration Vehicle Lunar Lander, Lunar Habitat, Mars Spacecraft, and Mars Hab.
- Coordinate with other technologies and bioastronautics to ensure there are no technology gaps.
- Promote use of enabling advanced habitation in current and future programs & projects.
- Provide a focus for academia design and research efforts in advanced habitation.
- Promote and develop partnerships for education outreach activities.
- Provide guidance in the development of enabling advanced habitation technologies through the technology projects and University Research programs.
- Establish annual workshop devoted to advanced habitation.
- Establish partnerships with the Habitability and Human Factors Office, Advanced Projects Office (ZX), Mission Planning, ISS Habitability and Crew Accommodation Hardware groups.

Objectives:

- Obtain tasks to support the CEV, Lunar Lander, and other Constellation projects.
- Establishment of an advanced habitation group.
- Establishment of rapid prototyping of advanced habitation designs.
- Establishment of integrated testing for advanced habitation designs.

Core Competency

- Provide advanced habitation design knowledge, requirements review, technology recommendations, hardware development experience, engineering DDT&E, rapid prototyping, systems integration, space architecture, integrated testing, Validation & Verification, habitat design, space craft design, lunar base design, Mars base design, maintainability, reliability, reparability, serviceability, commonality, house-keeping

Skills

- Space Architecture, habitability, human factors, industrial design, testing, design development, risk management, knowledge of habitat structures, systems engineering & integration, requirements writing, functional flow diagramming, drafting and drawing, psychology, modeling & analysis,

Matrixed Group

- Habitability, Human Factors, Crew Office, Engineering divisions, Operations, EVA, ISS IVA GFE hardware, ISS crew accommodations, ISS Crew Quarters & Waste & Hygiene Compartment development team, medical ops, exercise equipment

Customers

- Constellation, Crew, CEV, Lunar Lander, Lunar Hab, Research & Technology developers

The Team

The AH&I team is comprised of a team of an architect and aerospace engineers. Using AH&I skills, subject matter experts, and inter-agency contacts--teams can be gathered quickly to study a design concept, perform an assessment, or execute a trade study. AH&I's organizational structure relies on the expertise of many participants to be successful (figure 4). With a strong emphasis on systems engineering and integration (SE&I) the team use establishes its foundation to how they plan, execute and document their efforts.

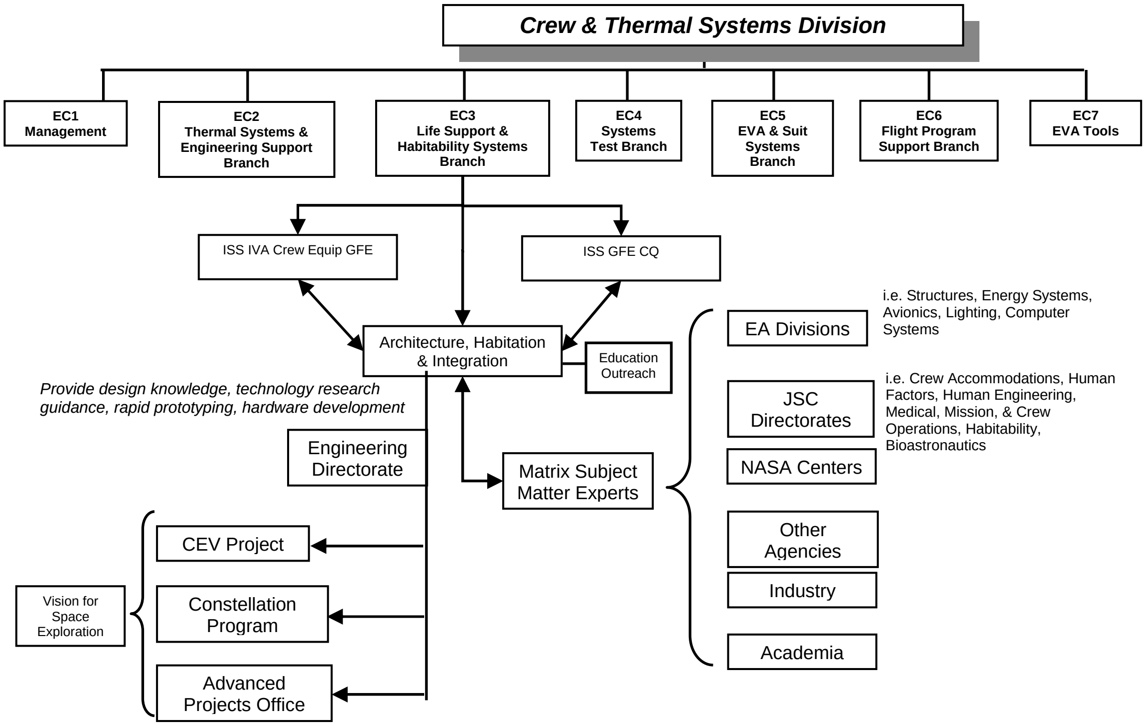


Figure 4. Architecture, Habitation & Integration Organization Chart.

Architecture & Habitation

In today's society, and in the aerospace industry, the term architecture is used in many ways. For some it means a software development strategy, to others it is a design reference mission, and yet to others it could be the overall plan of a lunar outpost. For AH&I it is the result of integrating the parts or systems into a cohesive element that is greater than they are by themselves. This may be an integrated strategy for a lunar lander to develop a lunar base, or a planetary testbed used to integrate and test technologies, operations and design concepts. Habitation is the use of these space systems by humans as livable environments during their space journeys or while they live on other planets. Many of the same design issues and principles are applied to space habitation as in architecture. AH&I strives to deliver high-quality products and services. Below are some of the products and services offered. Our customers, stakeholders and end users benefit from our design experience and knowledge of space systems. However, AH&I does not solely rely upon their own expertise, but rather the strong net of subject mater experts in related disciplines. Many other NASA organizations contribute to the success of an integrated advanced habitation team, design team, or multi-disciplined assessment (figure 5).

Products and Services

- Requirements Development, Validation & Review
- Design Knowledge & Concepts (habitats, spacecraft, interplanetary spacecraft, lunar Outposts & bases, mars bases)
- Design mockups & prototypes
- Hardware specifications
- Government Furnished Equipment & Hardware Development Leadership
- Validation & Verification Plans
- Integrated Testing
- Technology Assessments, Roadmaps, & Technology recommendations
- Habitation Subject Matter Experts

Value-Added and Benefits

- Subject matter expert for design participation
- Improved habitat design
- Better living accommodations for the crew
- Higher crew productivity
- Higher crew morale
- Improved physiological well-being of inhabitants
- Improved psychological well-being of inhabitants
- Putting the “living” back into “living and working in Space”
- Move from “tent” mentality to “house” mentality for space habitation

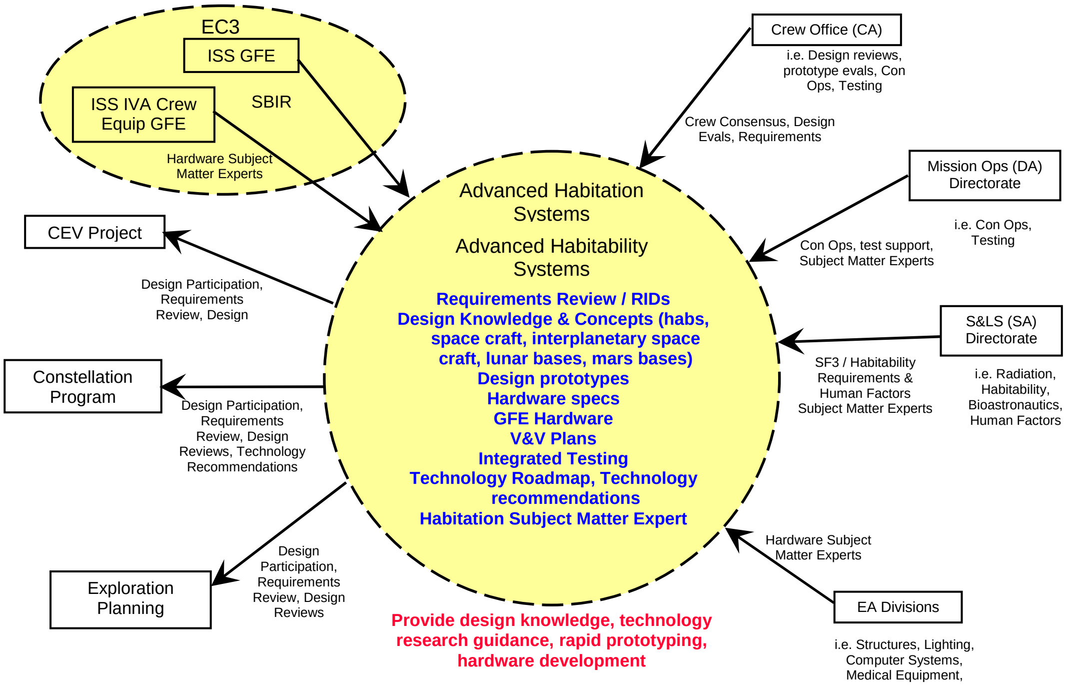


Figure 5. Architecture, Habitation & Integration Operational Chart.

The AH&I group has performed or participated in a number of trades, system assessments, studies, research, and integrated testing over past few years. Later in this paper, excerpts from some of these advanced habitation efforts will be described. However, before diving into the results of these efforts one should understand the processes and discipline of systems engineering AH&I embodies in its work.

Systems Engineering & Integration

The practice of architecture is similar to the systematic systems engineering approach to space systems design. Beginning with an understanding of the customer’s needs, to requirements development, conceptual design, design development, construction drawings, reviews & permits, building the system, and acceptance follows many of the same rigors to ensure a quality safe product is delivered to the customer’s satisfaction. The NASA Procedural Requirements (NPR 7123.1), NASA Systems Engineering Processes and Requirements, document defines the top-level systems engineering requirements for programs and projects. The purpose of NPR 7123.1document is to clearly articulate and establish the requirements on the implementing organization for performing, supporting, and evaluating systems engineering. Systems engineering is a logical systems approach performed by multidisciplinary teams to engineer and integrate systems to ensure products meet customers’ needs. Implementation of this systems approach will enhance core engineering, management, and scientific capabilities and processes to ensure safety and mission success, increase performance, and reduce cost. This systems approach is applied to all elements of a system and all hierarchical levels of a system over the complete project life cycle. From the NPR the NASA Systems Engineering Handbook is derived to provide process and product examples of the NPR implementation. Each Program and project is required to develop a System Engineering Management Plan (SEMP) that is tailored to its unique project. Systems Engineering is integral to program decision making by its systematic approach to problem solving, assessments, and technical resolution (figure 6).

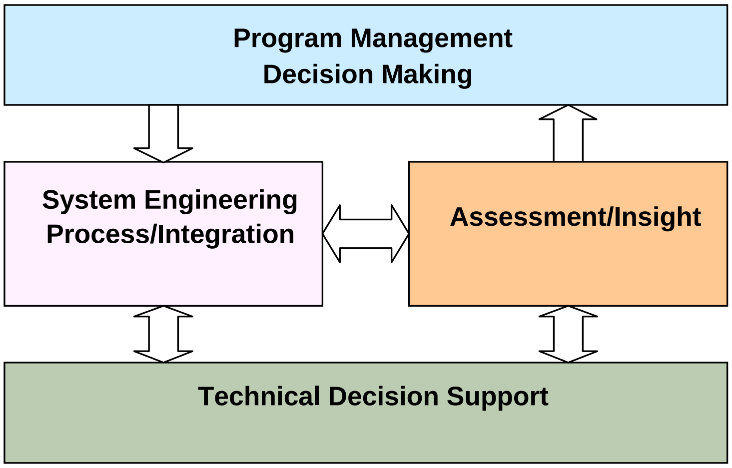


Figure 6. Systems Engineering Relationship

The purpose of a SEMP is to direct and guide the systems engineering approach for a project at all levels of the systems engineering structure. This SEMP will serve as the vehicle through which the Project Office applies an integrated system engineering approach to its development efforts. A SEMP defines the processes for implementing the systems engineering approach for a given project. Figure seven shows a typical SE process flow in the early stages of a project life-cycle. The project System Engineering (SE) team will develop, manage, and maintain these processes to assure that the project provide the products through out its life-cycle (figure 7). All practices, processes, and standards that comprise the systems approach are detailed or referenced in this SEMP. The programs, projects and tasks will translate this approach into activities specific to their work through their individual project plans.

The AH&I team applies the SE&I approach to all their tasks. Systems engineering provides the frame work to their efforts, whether it a systems assessment, integrating a test, or developing requirements. For example, AH&I uses the approach to model, test and assess when addressing or assessing technology development and integration in support of a program or project (figure 8). This approach has proven successful since it applies sound engineering principles in problem solving.

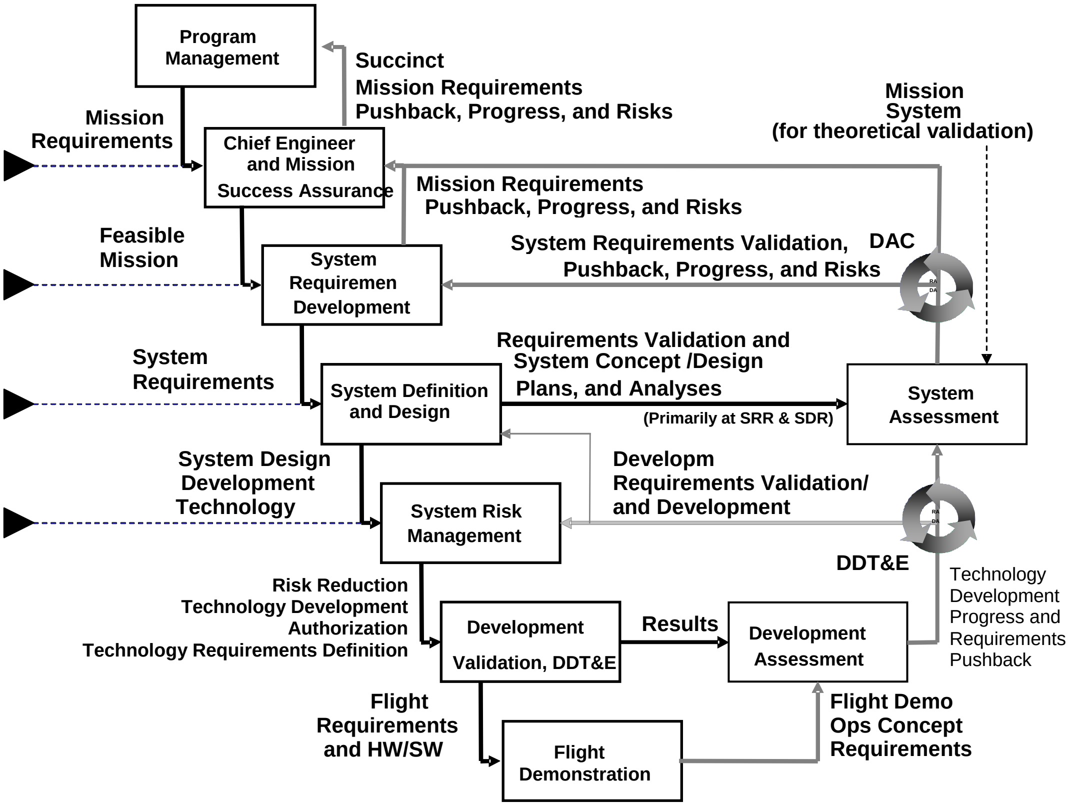


Figure 7. Systems Engineering Process.

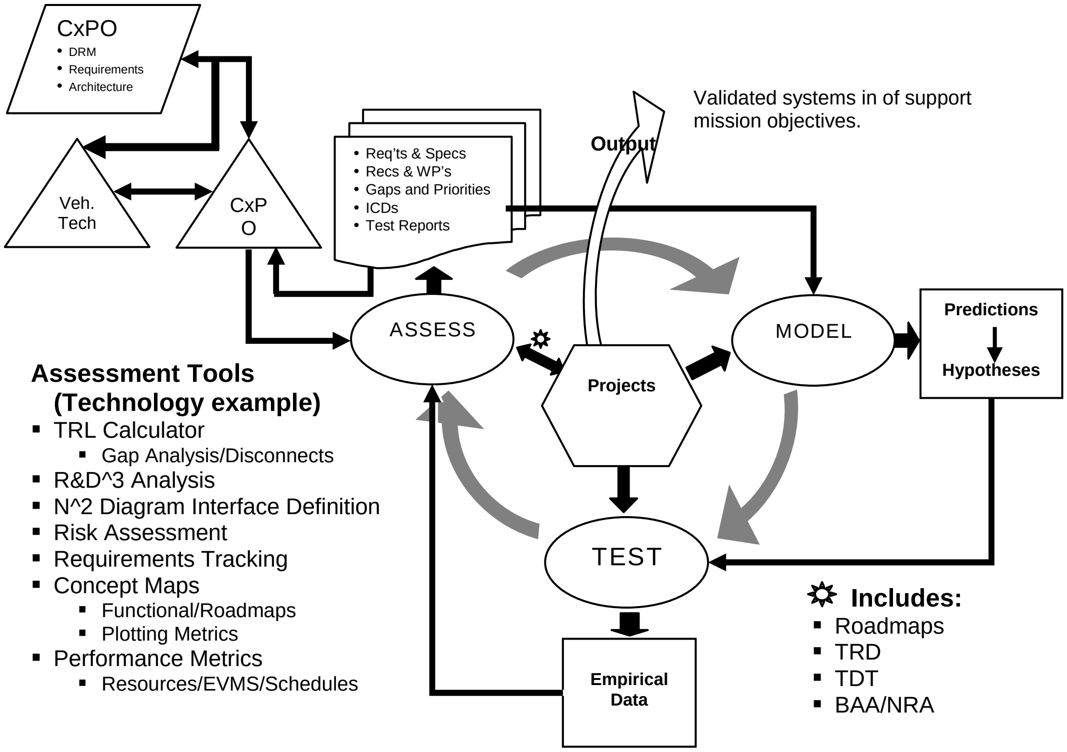


Figure 8. AH&I Integrated Assessment Cycle.

Education Outreach, Tours, and Public Interaction

As part of AH&I's mission to help NASA and the general public to understand the challenges of humans living is space is its strong Education Outreach efforts to communicate these efforts. Education Outreach to our customers, the American taxpayer, is important because it inspires young people all over the world to strive for more and be more. Efforts in AH&I has taken steps to make sure to tell the story of our past, present and future in space.

The JSC-B29 Rotunda has an important place in American space exploration endeavors. You may remember the popular movie depicting the trials of the first Apollo astronauts. If you do, you will remember the fascinating scenes of the astronauts placed in a ball-shaped container and spun around a large room to test the human limits of g-force effects. Building 29 was initially built as this g-force testing facility for the Apollo astronauts. The Human Space Flight Centrifuge Chamber tested many Mercury, Gemini and Apollo astronauts testing their endurance to gravity forces on the human body. First built in 1963 this 150 foot diameter by 35 foot high concrete and steel fortress used to spin the Gravity Test apparatus. Early human physiological testing focused on what human could with stand. Then in the 70s the Rotunda was converted into JSC's first Neutral Buoyancy Lab. This led the way in astronaut training to prepare them for the next step in human exploration of space. As NASA continued to look forward to the future the B29 Rotunda went through another transition in the 80s—this time looking to understand how human would live in isolation at a moon or Mars outpost.

An Education Outreach Module (figure 9) has been developed by AH&I to ensure quality dissemination of NASA history, projects, and testing occurring at JSC-CTSD. In 2006 AH&I hosted over 49 tours for over 980 people in the Education Outreach Module. AH&I is redesigning their web site to comply with NASA standards and to communicate continued advanced habitation efforts. The planned release of the AH&I web site is pending management approval.

Figure 9. AH&I Education Outreach Module.

Other public affairs, interviews, and education outreach events this past year include the Moon Shot Documentary; the British Broadcasting Corporation (BBC) documentary on the history and future of

Architecture, BBC Science documentary on Lunar Habitats; Swedish production of Lunar Return, and JSC internal PAO filming. All of these interviews and event help to spread the knowledge, excitement and enthusiasm for human space exploration.

Advanced Habitation Efforts

The AH&I group has performed or participated in a number of human system oriented trades, system assessments, studies, research, requirements validation, mockup developments, and integrated testing over past few years. AH&I personnel has lead numerous assessments, the JSC-led lunar lander study, performed test director duties, lead integrated testing, led the development of several program level document such as the Human Systems Research & Technology (HSRT) Systems Engineering Management Plan (SEMP), and led a multi-center systems engineering team for HSRT. The next few sections of this paper give brief descriptions of these efforts. Details papers, reports and documents are available by contacting the Johnson Space Center.

Assessments and Studies

AH&I has sponsored, performed, and assisted in numerous assessments on important issues facing human exploration efforts over the past few years. Most of the assessments were performed under the then Advanced Integration Matrix (AIM) group in CTSD. AIM performed seven assessments for the HSRT division before the reorganization of the Exploration Systems Missions Directorate (ESMD). Due to the reorganization of ESMD, AIM was also reorganized and focused towards advanced habitation efforts in CTSD. The AIM/AH&I assessments performed are listed below. These assessments are available by contacting the JSC.

- Power Systems Concepts for Human Space Exploration (JSC-62155);
- Investigation of Advanced Control Architecture Issues and Technology Gaps (JSC 62156);
- Atmospheric Monitoring Strategy for Ground Testing of Closed Ecological Life Support System (JSC-62157);
- Assessment of Dust Effects on Planetary Surface Systems to Support Exploration Requirements (JSC-62198);
- Commonality Assessment (JSC-65067);
- LSH Facility Resources for Testing at Reduced Spacecraft Atmospheric Pressures (JSC-65083);
- Communications (HSRT) Assessment Report (JSC-65338).

AH&I personnel has also lead and participated in the Constellation sponsored Lunar Lander Preparatory Study (LLPS) for the Advanced Projects Office (APO) during the spring and summer of 2006. A brief description of the project shows the how space architecture, systems engineering, mission operations, human systems, aerospace engineering, and safety and mission assurance combine to design landers, habitats, and outposts. The study was divided into two phases that looked at a diverse range of landers that meet a small set of preliminary requirements. Phase-one looked at many diverse concepts with six NASA centers each leading multi-center teams. Each team explored the edges of the design space pushing the requirements boundaries. In phase-two, the APO Review Board selected one concept for each team to study in more detail. The purpose was to study unique features that would derive desired features and requirements that Constellation would use as they look at interactions with the Crew Exploration Vehicle and forward to the future. The outputs of these design cycles will be used to develop a new lander baseline in conjunction with approved lunar strategic objectives to further refine the lunar exploration systems.

Lunar Lander Preparatory Study

The objective of the Lunar Lander Preparatory Study (LLPS) was to define innovative lunar lander approaches that meet the fixed requirement set and fall within the bounding cases for trade studies. Each lunar lander design team will use these common requirements and trade space boundaries to perform analysis and design of innovative lunar lander designs. The initial phase of the study will explore multiple design concepts, including the relationship of the lander to potential surface systems. A second phase of study will down select from initial phase concepts, refine performance and design, develop cost estimates, development schedules, and risk analyses. In this second phase, teams will also be asked to derive technology development needs and requirements for robotic precursors, including estimates of how each investment will impact the cost or risk of the human mission.

In phase one of the LLPS the AH&I lead selected a multi-center, small group of system level thinkers, designers, architects, and engineers for the tiger team. The team met daily in a “war room” to rapidly brain storm innovative ideas and work design concepts. With this approach, the core tiger team relied on subject matter experts as they needed to address specific design issues. At the end of phase one six lunar lander concepts were presented to the Constellation Program Office that examined the corners of the design space while examining unique lander features and optional operations concepts. All the landers concepts addressed the sortie and outpost missions—keeping in mind the end-state of the lunar lander objective. Some of the other six teams focused on the sortie mission only which leads to dead-end work since the lander is not able to perform the deliver of outpost infrastructure and payloads.

Using AH&I skills and knowledge of systems engineering the phase one plan laid out a process (figure (10) to quickly address customer, stakeholders, and users needs into goals, objectives and functional requirements. The tiger team defined the end-state of the lunar outpost desired in order to assess different lander brain stormed concept and down select to a handful for further refinement. At the completion of phase one, six concepts had been developed at a system level conceptually (figure 11).

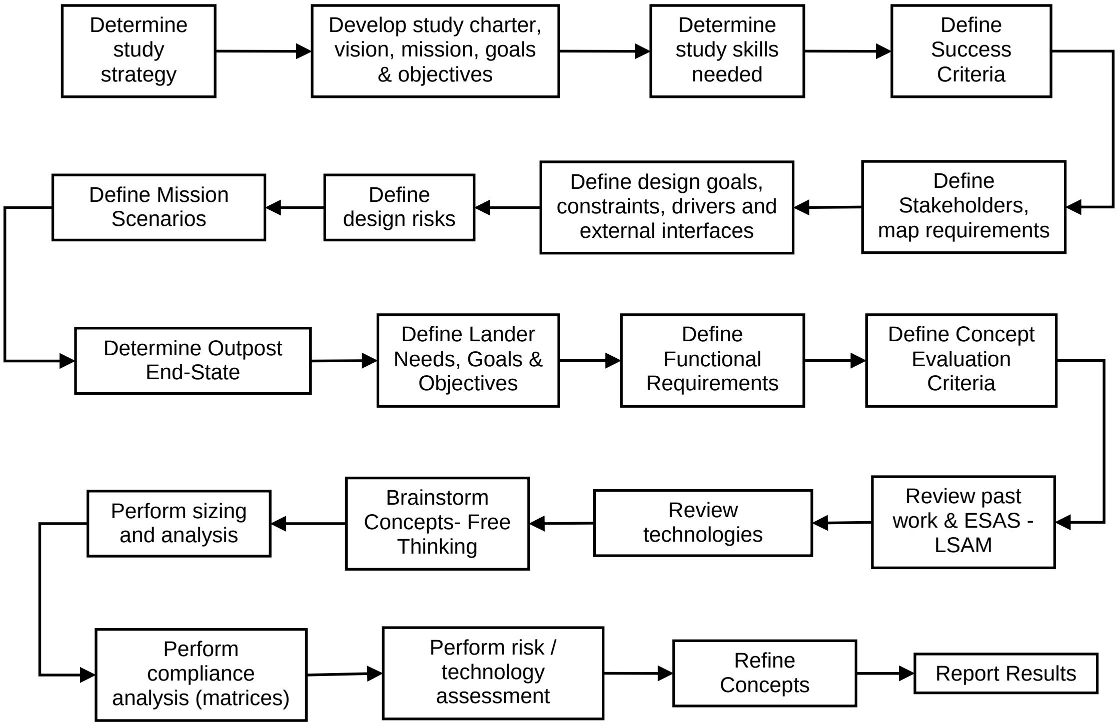


Figure 10. Lunar Lander Study-Phase 1 Design Process.

FEATURES:

- Lander concepts emerged from brainstorming & understanding Outpost End-State.
- Alterative approaches to meeting lander requirements.
- Explored lander capabilities to meet end-state use.

Concept 1: *Hab-Lander: Bring a large habitat*

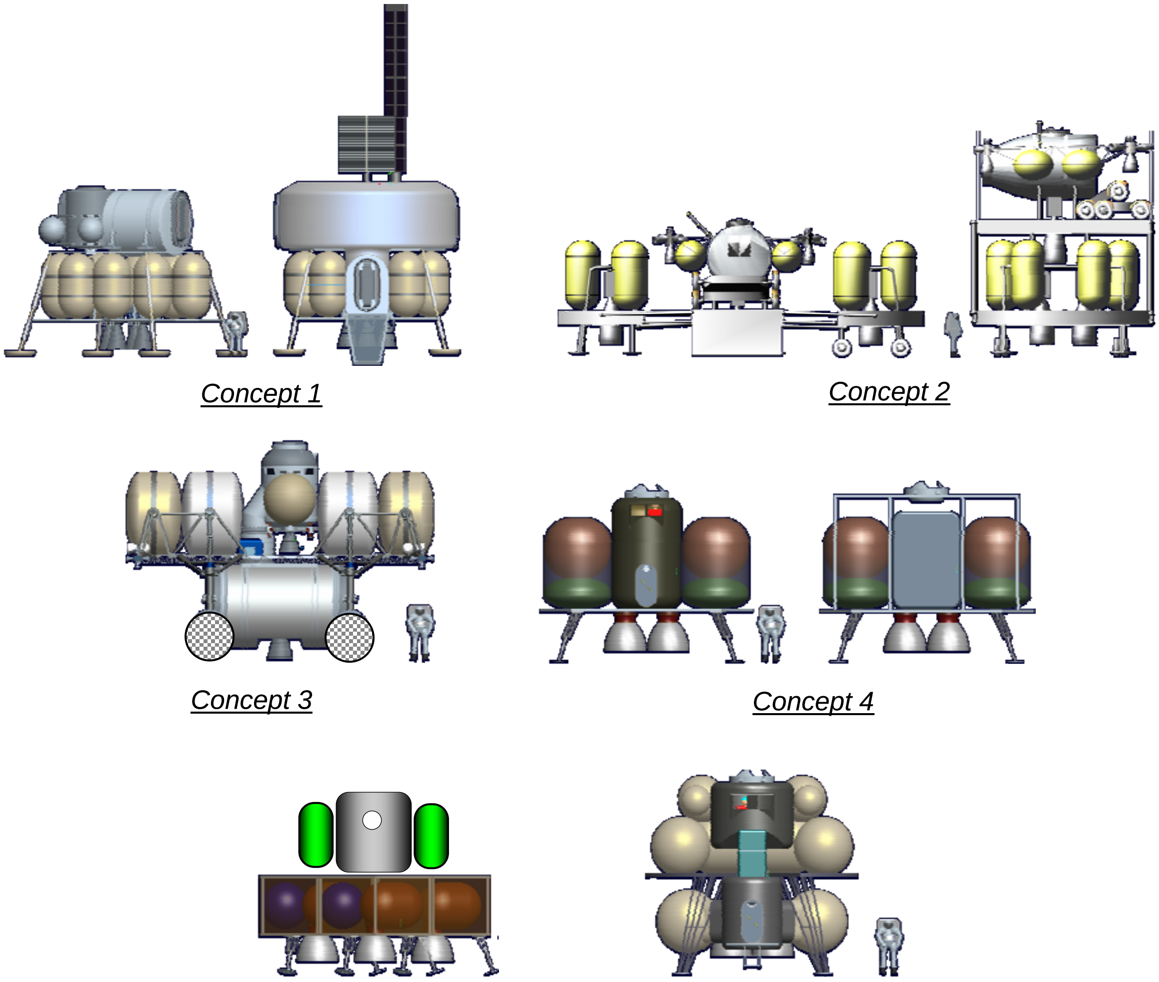
Concept 2: *Deployable LSAM Derivative: Addressed LSAM payload delivery to surface*

Concept 3: *Surface Mobile Lander: Explored mobility of a lander*

Concept 4: *Crew Taxi & Lunar Orbit Node: Explored reusable lander*

Concept 5: *Split Lunar Crew/Cargo Vehicle: Explored separation of crew and cargo function*

Concept 6: *Retrofit H2 Tanks into Habitat: Explored retrofitting H2 tanks as habitats*



Concept 1 *Concept 2*

Concept 3 *Concept 4*

Concept 5 *Concept 6*

Figure 11. Lunar Lander Phase Concepts.

The CxPO selected concept six, of the six concepts, for the JSC-led team to further explore and refine its design to better understand its features, capabilities, derived requirements, and interface requirements that may affect the Crew Exploration Vehicle. As in phase one, when AH&I personnel began planning phase two of the lunar lander study it was imperative that the expanded lander design team understand what we were tasked to do and that they all be on the same page. As such, a study charter vision, mission, purpose, goals and objectives were defined. This focused the tiger team quickly and helped to get them started. Also important was to establish the study process (figure 12) and products that were to be delivered to the customer. At the time of writing this paper the phase 2 study was not complete, therefore it can not be described in detail.

Charter:

- To develop a feasible lunar lander design and surface support systems in support of the Vision for Space Exploration. This includes a multi-discipline tiger team of designers, operators, users, and hardware engineering expertise across NASA to ensure the agency has explored innovative exploration concepts that will lead NASA's efforts of Human Exploration and Development of Space into the 21st century.

Vision:

- To develop multi-functional well integrated Lander systems that allows sustainability and flexibility for landing crew and surface infrastructure cargo to explore and establish a presence on the Moon circa 2020.

Mission:

- The mission of the this tiger team is to perform design definition of a lander concept system, the design detail, and supporting data to convey the elements functionality, volume, mass, power packaging within the defined mission constraints.

Purpose:

- To create a Lunar Lander Element that will support the Lunar Sortie and Outpost Mission Modes
- To understand the Lunar Surface Support Infrastructure to support it in an Outpost Architecture
- To deliver the Lunar Surface Outpost Payloads and their emplacement

Goals:

- Design for the Human as a System
- Crew Safety
- Maximumize commonality
- Dual functionality & Dual use systems
- Design for sustainability
- Place Crew & Equipment on Surface. Minimize surface access distance
- Subsystem commonality with CEV

Objectives:

- Develop necessary details to define requirements, cost and development schedule
- Be respectful of team members and their opinions

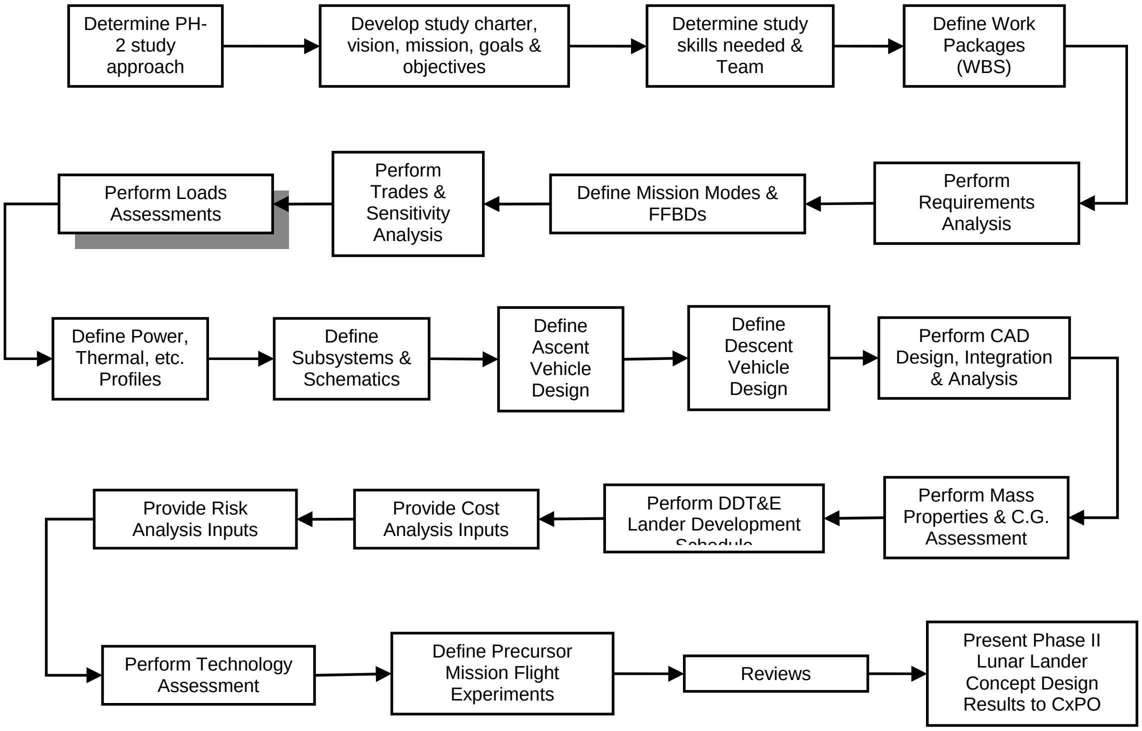


Figure 12. Lunar Lander Study-Phase 2 Design Process.

Advanced Habitation Facilities

With in the CTSD the AH&I group operates two habitation laboratories. The Advanced Integration Facility (AIF) is a multi-chambered horizontally oriented habitation lab. The other habitation lab is a vertically oriented three-story habitation lab (VHL). Each offer unique opportunities to evaluate and test habitation concepts, requirements, operational concepts, and technologies. The AIF is a mature integrated testbed that strategically offers more capability of supporting test, evaluation and validation of requirements, technologies, concept of operations, and flight systems that may require an integrated test-bed of higher fidelity. Analog Field activities are a component of this larger activity focusing on system of system interactions. The VHL is a lower fidelity mockup structure built to facilitate rapid development of designs and to quickly evaluate them.

JSC-CTSD-B29-Advanced Integration Facility-Habitation Lab

The Advanced Integration Facility, at JSC in building 29, provides a unique planetary testbed facility in a controlled environment. The AIF (then BioPlex) was first conceived in 1989 as a high-fidelity multi-chamber (bio-Plex) facility for demonstration testing of large-scale bioregenerative life support systems for long-durations with humans. Construction of this planetary testbed started in the 1990s as a human simulation and technology integration laboratory. Since its inception, this facility has started and stopped several times due to changing Agency priorities and budget constraints. Therefore, the facility has only matured its capability to ~ 60% of the fully functional planetary testbed that was planned. The focus over the past few years has been on maturing the individual chambers capabilities to be sealed and the ability to run independent tests or technology evaluations.

The facility in development is located in Building 29 at JSC and consists of four large cylindrical modules (15 ft diameter x 37 ft long) with a cylindrical airlock (12ft x 15 ft) all connected with an interconnecting tunnel (12 ft x 63 ft) included two available 15 ft diameter nodes. The original plans included installation of another airlock to enable suited EVA's (with an existing crane for weight relief / lunar-Mars gravity simulation) onto a simulated planetary surface. Testing was to get progressively longer, ranging from initial 30-day tests up to 1000-day class tests using four test subjects in the atmospherically sealed facility.

The AIF will provide a strategic investment into providing the ability for early mitigation of integration issues, risks, and technology development in support of NASA Strategic Goals and in support the Vision for Space Exploration.

Vision Statement:

- The vision of the AIM Integration Facility (AIF) is to provide the capability to support and perform integrated ground testing of research, technologies, operations concepts, mission simulations, and management integration processes in support of the “Vision for Space Exploration (VSE).”

Mission Statement:

- The AIF mission is to bring together the developers, users, stakeholders, and customers to uncover and mitigate integration risks that would impede the successful execution of the VSE goals, objectives, and milestones.
- The AIF mission is to become a core competency for the Crew and Thermal systems Division.

Goals:

- From BIO-Plex document JSC-39174: “To provide life support self-sufficiency capability for humans to carry out research and exploration productively in space for benefits on Earth and to open the door for planetary exploration”
- To support long-duration mission research and technology maturation in support of the VSE
- Perform early mitigation of research and technology integration risks.
- Perform integration testing of Human Systems research and technologies

- Provide a safe environment to perform human-in-loop testing and operations.
- To have the capability to run an integrated “closed door” (sealed) test.
- To perform “human-in-loop” testing
- Education outreach
- The testbed will be designed to simulate the look and feel of a lunar and Martian outpost
- It will be used in conjunction with the life support system and medical testing currently being planned for exploration
- This could be used for development and training on planetary surface equipment and procedures
- Provide the agency testbed capability for continued, extended human systems technology development in support of exploration objectives.
- Serve as a focal point for other disciplines to conduct research and to develop supporting technologies, techniques, and procedures pertinent to future planetary missions via cooperative and collaborative experimentation and testing
    - Human factors
    - Medical
    - Psychological
    - Training
    - Mission operations
    - Automation & robotics

Objectives:

- Support near-term (0-5 years) research and technology integration testing in support of the VSE goals, objectives, and milestones.
- Support mid-term (5-10 years) research and technology integration testing in support of the VSE goals, objectives, and milestones.
- Support long-term (10-20 years) research and technology integration testing in support of the VSE goals, objectives, and milestones.
- Establish an AIF operations control room to support research and testing
- Establish a safe environment to perform human-in-loop testing and operations.
- It will support Education Outreach by re-opening the Space Center Houston Tram tour and existing viewing area on second floor of B29. By adding web-site interactive viewing of internal Hab chambers activities and adjacent planetary yard educators and student can learn along side with architects and engineers.

During fiscal year 1998 a Construction of Facility Project was carried out to modify Building 29 for the installation of the BIO-Plex. The scope of the work covered a new electrical service, chilled water connections to the site supply and return loops, and the construction of a new foundation in the Building 29 rotunda area. The work also included electrical and water utility supply upgrades to system development areas in the east service wing of Building 29 outside the rotunda.

The AIF will be a sealed test bed for demonstrating the integrations of emerging life support technologies as well as emerging life sciences/medical technologies. The life support systems to be tested will consist of both biological and physicochemical technologies and will perform all required air revitalization, water recovery, biomass production, food processing, solid waste processing, thermal control, and integrated command and control functions.

The AIF was built to support continuous long-duration testing of bioregenerative life support systems and science and technology accommodations. In order to perform testing of this nature the multi-chamber complex shall accommodate a normal crew of four people and up to a maximum of eight people. The environment of the AIF will be maintained at an ambient pressure range (ambient pressure is defined as 14.7psig (101kPa)) and an ambient temperature range (ambient temperature is defined at 72°F (22°C)) and normal levels of oxygen (normal oxygen level is defined as 21% O_2 by volume) for humans. The following documents are available pertaining to the Advanced Integration Facility:

- Interface Definition Document—Advanced Integration Facility for Phase I (JSC 60498).
- Advanced Integration Facility Standard Operating Procedure (JSC-62300).

This multi-chamber complex (figure 13) will include the following:

- an Interconnecting Transfer Tunnel (ITT)
- an Airlock (ALK)
- a Habitation Chamber (HAB)
- a Life Support Chamber (LSC)
- a Biomass Production Chamber 1 (BPC1)
- a Biomass Production Chamber 2 (BPC2)
- a Laboratory Chamber (LAB).

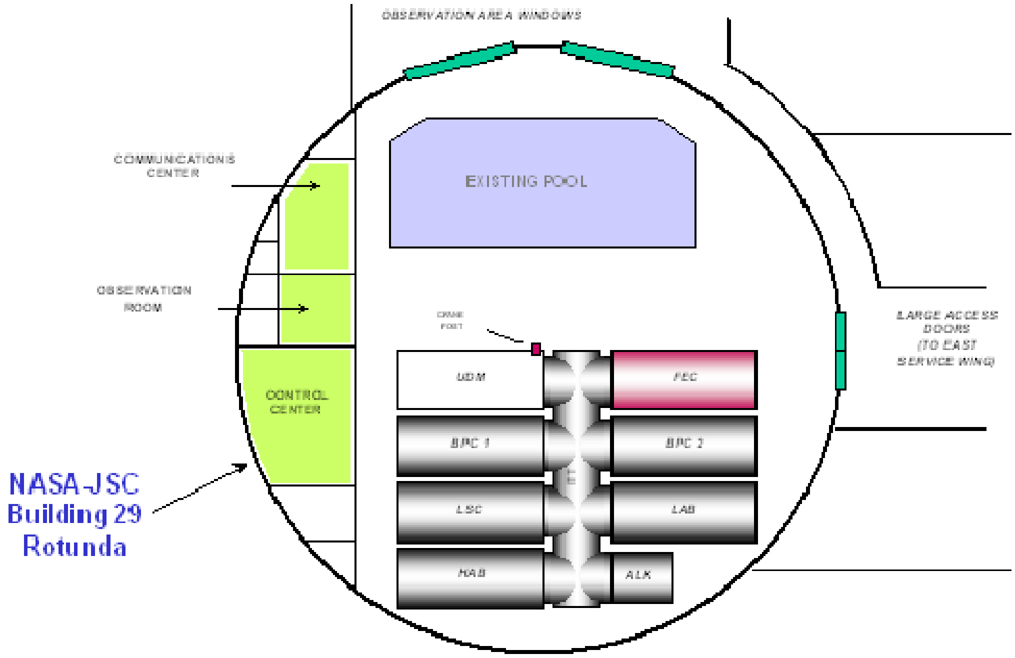


Figure 13. AIF Layout within the Building 29 Rotunda.

Integrated ground Testbeds are required to evaluate performance of designs, operations, and technologies in an "integrated environment". Integrated is a subjective term ranging from sub-system to system to mission-level integration. Integrated testing is required to identify integration issues early in the technology development process so that they can be effectively resolved during technology maturation. Integration issues within major systems and between major systems is difficult to identify without integrated testing. Test beds range from existing thermal - vacuum chambers; human-rated test facilities; and mission-level, full-scale test facilities. A full-scale, mission-level, long-duration, human-rated test bed (AIF Vision, figure 14) is needed to meet the needs of the Vision for Space Exploration.

Figure 14. AIF Vision as a Planetary Testbed within the Building 29 Rotunda

Horizontal Lunar Habitat Mockup

The habitat chamber in the AIF was ideal for the Lunar Habitat Mockups Project to evaluate habitation and design implications in a horizontally axis orientation. The Lunar Habitat Mockups Project (LHMP) designed, built and evaluated a variety of habitat configurations, and completed a number of other products to help develop a basis for validating habitat design decisions. The LHMP team decided that the asset most compatible with the project's immediate goals was the Building 29 AIF habitat module. As this was a horizontal module, the Lunar Surface Access Mission concept provided a good model from which to work. This allowed the team to construct a low-fidelity mockup very quickly, which was one of the Project's primary goals. The concepts for this habitat would be as follows:

a. An existing asset such as the ISS Habitation module would be adapted for use and placed atop a descent module.

b. The mission would be for 60-90 days for a crew of four.

c. The module would need to have a temporary capacity for up to a crew of eight for up to a week for crew transitions.

d. EVAs would be conducted every day in teams of two with the teams alternating every other day, five days a week.

e. Exercise facilities would be minimal as compared to that needed in microgravity due to the number and extent of EVAs. Exercise facilities were considered more a lifestyle accommodation rather than an absolute necessity.

f. A meeting/gathering/ward room area, private quarters, and terrestrial like personal hygiene facilities were a priority.

g. In support of EVAs an airlock/dust lock was of course essential. The airlock/dust lock would be docked to the habitation module and would not consume interior volume of the habitat itself. It was envisioned that such an airlock/dust lock could be either pre-integrated with the module or attached at some point during the mission either in route or after landing. Deciding this detail was beyond the scope of the project.

h. Facility limitations would be accommodated and work arounds for them would either be implemented, if possible, or just documented as to the intended use of a given area of the habitat. One notable example in this regard was the facility stairway that provided access to the second level of the facility. Since this volume was not actually useable it was considered devoted to systems and stowage volume.

i. System and stowage volumes for the mission concept were estimated and removed from what was available for crew accommodations.

The overall dimensions of the existing AIM cylinder determined what the major physical parameters of the horizontal mockup would be:

- An overall length of 11.28 meters (37 feet);
- A diameter of (4.6 meters) 15 feet;
- A two-story internal layout with existing floors and stairway;
- Entrance at both ends of the cylinder on the lower level.

There are four individual crew quarters on the second (upper) level, as in the original BioPlex plans for the module. The rationale for placing the crew quarters on the upper level was two-fold. First was dust mitigation to separate the sleeping quarters from the airlock. The second reason is noise mitigation with the intention that the second floor would be a quieter area.

The primary personal hygiene area, including separate shower and commode compartments, would also be located on the second (upper) level, in order to be close and convenient to the sleeping quarters. The location chosen was also to simplify the plumbing configuration that might be associated with a water-based system. Given the assumption that the habitat would only be used while on the surface of a planetary body, this would permit the use of gravity flow and eliminate or minimize certain complexities such as pumps. Furthermore, the waste and water tanks could be located directly below the hygiene fixtures, minimizing the mass associated with plumbing and greatly decreasing the likelihood of clogged pipes and other problems.

Figure 15: Galley / Wardroom of the Horizontal Habitation Mockup.

On the lower level of the habitat, a spacious and comfortable wardroom area was essential given that it would be the meeting and gathering place within the habitat where meals and videoconferences, tele-training, and planning meetings would take place. Given the anticipated durations of occupancy and the remote isolated nature of a habitat there needs to be a warm and inviting space within the habitat that has familiar “back home” features. The galley/wardroom area (figure 15) is located at the opposite end of the cylinder from the airlock in order to minimize potential dust accumulation in the wardroom. A smaller hygiene compartment, that included a small lavatory and a commode, was required on the first level near the airlock for immediately availability to returning EVA crew members without their having to completely enter the habitat.

In keeping with the philosophy, the upper level should remain a “quiet zone,” the location of the primary system functionalities are on the lower level. Therefore, their various pumps, fans, and motors would be as remote as possible from the crew quarters. This rationale also applied to placing the exercise equipment on the lower level, even though due to constraints of the facility, the team realized quickly that the volume allocated for an exercise area in the initial layout would be judged insufficient during later evaluations as indeed it was.

Habitat Autonomy Test

The purpose of the Habitat Autonomy Test (HAT) is to demonstrate integration of several subsystems required for near-term exploration habitats. This demonstration will reveal issues to be addressed while developing high-level requirements for these subsystems to operate as an integrated system and autonomously. Though short-term missions to the near side of the moon have been accomplished, lunar exploration missions are now to be used as analogs in preparation for longer duration, more complex journeys. These missions will present new challenges that will require different levels of habitat operational autonomy necessary for mission success. AH&I personnel are undertaking the basic steps to begin the understanding and integration required to operate and control the habitat’s systems. Integrated Systems Health Management (ISHM), or formerly known as Integrated Vehicle Health Management (IVHM), has been used for numerous year by the aircraft industry (Boeing 777), military aircraft (B2 Bomber), and more recently auto industry (race cars and more sophisticated automobiles). However, ISHM software and sensors have not been built, tested, verified and operated for human spaceflight use. Aspects of ISHM have been in use in the Shuttle and ISS program, but a fully integrated and operational system. The division between flight critical systems and health status data continues to be a challenge for human rating ISHM. For this reason the ground based test beds, such as the AIF, are important steps in the process of flight certification.

With this in mind, the Hab Autonomy project goals are to:

- Establish collaborative effort to built ISHM into AIF as a parallel system to our controls and data management backbone.
- Perform ISHM testing in a phased build up, starting with the smaller subsystems tests, then to the multi-chamber habitat complex.
- Gain run-time with multiple systems, technologies, the crew and Ops
- Possible path to certification for ISHM being human-rated. Test the partitioning between crit-1, crit-2, and crit-3 controls.
- Gain ISHM experience and early mitigation with future technology systems
- Become operational during the “human-in-loop” testing

The reference scenario for the test is a mission at a lunar outpost. Subsystems thought to be necessary for a lunar habitat include:

- Air revitalization
- Thermal control
- Water and wastewater handling
- Solid waste handling
- Food processing
- Lighting
- Radiation protection
- Crew countermeasures
- Integrated System Health Management (ISHM)
- Wireless Networking
- Dust control
- Crew entertainment
- Crew sleep accommodation
- Crew hygiene
- Laundry
- Extravehicular Activity (EVA)
- Lunar surface research
- Data acquisition and storage
- Communications
- Operational and Medical Protocols

Phase I of the Habitat Autonomy Test is to be conducted in the Lab West Chamber of the AH&I Advanced Integration Facility (AIF). The HAT will use both current AIF subsystems and additional subsystems developed to advanced technologies required for these surface habitats. This first phase of integrated testing of habitat systems will take place in the Lab West chamber of the AH&I testing facility. Here, several subsystems will be integrated into a common control and data acquisition system. Most of the test can be accomplished using existing test beds, facility hardware and network infrastructure. Wireless networking will be added to demonstrate how this technology can be applied to the monitoring and controlling of various subsystems with a common interface. These subsystems are:

- AH&I Controls Evaluation Test Bed, Phase II Upgrade
- Lab West Cooling and Dehumidification Subsystem
- Lab West Lighting Subsystem

Subsystems will be controlled by up to three FieldPoint banks, consisting of a network/processor module and several input/output modules. FieldPoint banks run LabView RT software configured for the subsystems interfaced with the input/output modules. These banks are networked with up to three laptop computers running LabView software, serving as the human machine interface to the other subsystems and storing data from the FieldPoint banks. This will serve as an analog for a distributed control system, unlike what has been used of previous spacecraft.

Thermal control and the dehumidification portion of air revitalization will be performed by the newly installed fan/coil air conditioning system using facility-chilled water. The integrated control system will be used to control chamber temperature and humidity by overriding this function in the fan/coil unit's (FCU) self-contained programmable logic controller via Ethernet connection. This will require software translation from object linking and embedding (OLE) for process control (OPC) to the command and data structure. Lighting will consist of three independent low voltage lighting circuits, activated and dimmed by breadboard drivers, controlled either by analog outputs from the FieldPoint modules or Zigbee wireless mesh network nodes.

Most of the value of the test will be realized while developing the test. The sheer act of determining the interfaces and integration to bring these subsystems together will help to identify the gaps that must be overcome when designing the actual subsystems for exploration missions. The actual test will serve to demonstrate how these subsystems will be controlled by a common, distributed system, showing the advantages of this architecture, while exposing any limitations.

Follow-on testing for the HAT is expected to include:

- Additional air revitalization subsystems, or simulations of that hardware
- Crew accommodation subsystems, including entertainment and hygiene
- EVA/robotics control
- Enhanced communications, including delay simulation
- An expanded role for ISHM

JSC-CTSD-B220-Vertical Lunar Habitation Laboratory

Another AH&I Habitation Laboratory is the newly acquired Vertical Axis Lunar Habitat mockup. The Lunar Habitat Mockups Project (LHMP) team designed and built the three-story vertical lunar habitat mockup (figure 16). Upon the demise of the Exploration Systems Research & Technology (ESRT) Division, this project was terminated after one year of incredible work. When this project was terminated this three-story asset was transferred to AH&I and CTSD. The mockup is a three level facility that is approximately 25 feet in diameter.

Figure 16. Exterior View of the Vertical Habitation Mockup.

Experience has shown that using mockups very early in a project's life-cycle is extremely beneficial, providing data that influences requirements for human design, volumetrics, functionality, systems hardware and operations. The overarching goal of the Project was to mature to sufficient readiness levels both the crew habitation aspects of surface habitats and the technical aspects associated with deployment strategies for the habitats. The Project developed "crew-supportive" configuration layouts for innovative habitation systems and associated deployment strategies. The mockups developed were low to medium and intended to support initial lunar. More about this project and its results can be found in the "Lunar Habitat Mockups Project" - Final Report ASPS-051: Test Articles for Early Habitat Design Trades and Surface System Requirements Definition (JSC-63348).

An ancillary benefit of this location was that the mockup would provide an additional viewing item within the building for Space Center Houston visitors as it was already on one of their regular tram tour routes. This would show case the mockup and provide one visible example of the agency's vision for exploration. This vertical habitat lab is ready to explore habitat design issues, validate requirements, perform operations simulations, and integrated testing for the Constellation Program Office.

Integrated Testing

The reason NASA performs Integrated testing is to control mission risk. Integrated testing identifies risks and mitigates them. Risks include integration risks, performance risks, durability, maintainability, and many others. Integrated testing guides the research & technology development activities and identifies deficiencies such that efforts are continuously focused on high-priority work, which is an efficient utilization of resources. Integrated testing is instrumental to the maturation of technologies. This enables availability to the Flight Programs for selection, design, build, test, and fly. Integrated testing also communicates mission objectives to individuals, managers, partners, customers, and the public.

NASA has a rich history of integrated testing that includes the programs such Mercury, Gemini, Apollo, Skylab, Shuttle, ISS, and the Lunar/Mars Life Support Test Project. Skylab implemented the Skylab Medical Experiments Altitude Test (SMEAT). SMEAT was a successful ground based testing program in that it mitigated many risk prior to the Skylab missions. The Lunar Mars Life Support Test Project (LMLSTP) was an advanced closed loop ground test project. It conducted a series for four tests. This included a 15-day biological test in 1995, Phase I; 30-day physicochemical in 1996, Phase II; 60-day ISS functional equivalents. In 1997, Phase IIA; and a 91-day combination of physicochemical & biological test in 1997, Phase III.

The exploration missions outlined by the Design Reference Missions are different from previous missions in duration & distance from Earth (abort scenarios, crew autonomy, reliability & maintainability of equipment, permanent deployment of infrastructure to the moon & Mars). Integration issues (risks) are difficult to identify. Individual technologies and systems have inherent risks. Integration of all systems & procedures on the ground will allow risks to be managed and will enable the most cost-effective way to prepare for exploration missions. Full-scale, high-fidelity, integrated testing with humans in the loop (“fly the mission on the ground”) will also enable development of improved management techniques for large, complex programs; facilitate international, academic, and industrial partnering; and facilitate education and public involvement.

Lessons learned from testing are an important part of integrated testing. Lessons learned influence how to do integrated testing, planning, build-up, conducting tests, analysis, and management. The following are examples of lessons learned from past testing.

- Humans-in-the-loop are necessary for successful integrated testing, simulators only go so far. In addition, humans are a subsystem to the overall system in which many systems require human interaction.
- Anticipated operational protocols must be verified.
- Biological systems are very resilient.
- Trace gas contaminants, such as formaldehyde, are a concern. Iodine can be a residual biocide.
- Others need integrated testing, number of collaborating experiments has increased.
- There is value in communicating with the outside world.

Other examples include commonality and software development. Lessons learned can also be gathered from external sources such as submarines, Joint Strike Fighter, and Defense Advanced Research Project Agency (DARPA).

The Objectives of AH&I integrated testing is to strategically plan for facility capability needed by future testing projects, install required infrastructure, and perform Advanced Habitation technologies integrated tests and human-in-loop testing. AH&I evaluates NASA exploration plans, previous integration issues, as well as promising technologies and methodologies, to identify the desired technology testing participants and the scope of integrated test development and coordination. AH&I will develop scalable plans and processes to design, build-up, conduct, and control integration tests of exploration mission systems. AH&I will solicit tests in several ways. This includes announcements at technical conferences and meetings and direct solicitation of program management. Tests may be proposed by individuals or organizations. AH&I will solicit tests and participants that have been previously identified through other programmatic activities or direction. AH&I will hold workshops as necessary to solicit tests and participants. Direct communication with the program elements will be utilized.

Assessment results and publications will be used for identifying candidates. The AIM assessments are documented in white papers. These white papers discuss integration issues and are a valuable asset to test identification. Publications include element or program trade studies, technical papers, and status reports. These publications provide valuable insight into technologies or processes including technical descriptions and availability. For more information pertaining to AH&I test process refer to Architecture, Habitation, and Integration Test Process JSC 65127.

The following questions should be applied to technologies that have been identified for integrated testing:

- Can the technology benefit from integrating with other technologies?

- Does this testing result in TRL advance?
- Is there a facility capable of meeting the test requirements? (test may be deferred due to facility modifications)
- Are available technologies ready to integrate?
- Which program is the technology applied? Rank according to program and need.

The AH&I personnel was the lead and test directors on three Advanced Extra Vehicle Activity (AEVA) integrated tests this past fiscal year. Each of these tests was focused on validating Constellation requirements. The test requirements and test plan are documented in (Test 1) Launch Suit Test (JSC 65104); (Test 2) the Walk Back Test (JSC 65229); and (Test 3) CEV Corridor and Hatch Test (JSC 65216). An executive summary of these test are included herein. For more information, please contact JSC.

AEVA Test #1

The purpose of the Launch Suit Test is to assist in determining the feasibility of using a planetary suit for launch. This test will collect valuable data that will assist in determining if a suit specifically designed for planetary mobility could be comfortable during certain phases of launch; this will aid in the decision of a single suit option for planetary flights. The knowledge gained from this test may impact the decision of suit use and design on the initial Crew Exploration Vehicle (CEV) flight, aid any pending CEV suit contract proposal work, as well as provide captured data for the CEV System Requirements Review (SRR).

The primary objective of the Launch Suit Test is to evaluate crew comfort in the planetary suit concepts during 1-G launch conditions in a space vehicle such as the CEV. This test will provide the AEVA and CEV teams with data to inform a decision on suit architecture and requirements for launch. In addition to evaluation of the current planetary suit concepts (Mark III and the Rear Entry ILC Dover Suit (REI-Suit)), the test will also include the Advanced Crew Escape Suit (ACES). The ACES is a design currently certified and worn in the Space Shuttle Program to protect for a cabin depressurization situation during launch and entry. Inclusion of the ACES in the test will provide a baseline for comparative purposes, and will help determine the range of motion constraints that such suit design features may have on the CEV cockpit requirements. These three suits represent fundamentally different pressure garment design practices, and thus, testing of all three will offer substantial insight into the benefits and problems each offers in this particular environment. Launch suit mobility range and visibility data requirements necessary to meet the projected CEV cockpit needs are important secondary objectives for this test. These objectives will aid the evolution of CEV cockpit task requirements and cockpit layouts.

Figure 17. AEVA Integrated Test #1: Launch Suit Test.

Specifically, four objectives were evaluated during this test (figure 17):

- Assess crewmember comfort in the ACES, Mark III, and REI-Suit in a recumbent position (with helmet).
- Determine the visibility envelope of crewmembers while in the ACES, Mark III, and REI-Suit in a recumbent position (with helmet).
- Determine the ability of crewmembers to sit and stand from a recumbent position unassisted while in the ACES, Mark III, and REI-Suit (with helmet).
- Determine the reach envelope and motion capability for the ACES, Mark III, and REI-Suit in a recumbent position (with helmet).

AEVA Test #2

The purpose of the Lunar Walk-back Test is to provide the Extravehicular Activity Office (XA) Integrated Program Team (IPT) with data, analysis and recommendations to the feasibility of a 10 kilometer (km) walk back to a surface habitat in case of a rover breakdown. The data collected in this test will help answer the initial question of whether an unaided suited crewmember can successfully translate a 10 km distance in the case of a rover breakdown. The data collected will also help determine the allowance for comfort and sufficient mobility in the suit with regards to long distance traverses. The engineering and scientific communities will analyze the data collected and specific reports will be produced by the respective organizations. The final reports will provide recommendations to the stakeholders at JSC about determining the maximum, rover-based, exploration distance from a surface habitat that can be safely traversed with a single rover.

The primary objective of the Lunar Walk-back Test is to collect baseline human performance data to assess the capabilities of an unaided suited crewmember (figure 18) to perform a 10km lunar translation. This test will use a partial gravity simulator, at 1/6 gravity level, in conjunction with the Mark III Advanced Space Suit Technology Demonstrator (MKIII) EVA suit (figure 19). The 10 km distance was proposed by the AEVA office based on the current operational concepts for planetary exploration EVA.

The secondary objectives of the study include:

1. Understand the specific biomedical and human performance limitations of the suit, compared to matched unsuited controls.

2. Gain metabolic and ground reaction force data to allow development of an EVA simulator to be used on future pre-breathe protocol verification tests.

3. Provide biomedical and human performance data for use in suit and portable life support system design (PLSS).

4. Assess the cardiovascular and resistance exercise associated with partial gravity EVA to be used in planning appropriate exploration exercise countermeasures.

Figure 18. AEVA Integrated Test #2: Walk Back Test Subject-Unsuited Walk.

Figure 19. AEVA Integrated Test #2: Walk Back Test Subject-Suited Walk.

This study determined the following physiological and biomechanical parameters:

1. Metabolic rate
2. Energy consumption per kilogram-kilometer
3. Heart rate
4. Skin temperature
5. Core temperature
6. Total body heat storage
7. Foot contact force vectors
8. Postural stability
9. Gait characteristics

These parameters were measured while a subject performs a series of short duration walking or running bouts on a treadmill under both suited and unsuited conditions, and during a suited attempt to walk 10 km. Test data was evaluated to provide the following:

1. Assessment of the gait adopted and speed to achieve walk-back

2. The metabolic cost of a crewmember translating in suited and unsuited conditions
3. The rate and distance of translation
4. Test subject discomfort and exertion while walking in the suit
5. Test subject compensation needed to accomplish walk-back.
6. Assessment of test subject's cognitive and physical ability to open a simulated hatch upon walk-back completion

The test data was in the process of being analzed and will be integrated into a final report later in 2006.

AEVA Test #3

The purpose of the CEV Corridor & Hatch Test is to assist in understanding the envelope of a suited crew member in the Low Impact Docking System (LIDS) corridor and Hatch opening. The knowledge gained from this test may impact the decision of suit use and design on the initial Crew Exploration Vehicle (CEV), aid any pending CEV suit contract proposal work, as well as provide captured data for the CEV System Requirements Review (SRR).

The primary objective of the LIDS evaluation is to validate the 32 inch internal diameter corridor using the ACES and Mark III suits. The Primary objective of the Hatch evaluation is to determine the minimum size for the CEV side hatch to accommodate crew egress/ingress for the largest possible suit, the Mark III (figure 20). A secondary objective of the Hatch evaluation is to obtain a crew consensus report on the CEV Hatch minimum size (figure 21).

Figure 20. AEVA Integrated Test #3: CEV Corridor Test.

Figure 21. AEVA Integrated Test #3: CEV Hatch Test.

For more information, see the “Phase 1: Low Impact Docking System (LIDS) and Crew Exploration Vehicle (CEV) Hatch Evaluation Detailed Engineering Test Report” (JSC 65241).

Future of Space Habitats

Humans will move from the confines of our planet Earth, and in doing so will establish new foot holds on distance places in LEO, the moon, or Mars. When human take that step space architecture and engineering will be helping to plan, prototype, build, test and prepare to make their journey habitable. Humans can endure much, but our desire is to live and work in harmony with our environment. NASA has long been a leader in research and development of new technologies for space activities. Many of which have spun off to benefit human kind and Earth. Prime examples are computers, medicine, recycling and there are many, many more.

Space and planetary habitats are pressure vessels that provide the living quarters and support systems needed by human crews engaged in space exploration. Structural and materials research and technology development is required for the very lightweight and comfortable habitats needed for the months of transport to Mars and for the months, and possibly years, which humans will spend on the surface of the Moon or Mars in carrying out exploration and development activities. Such habitat technology also has the potential for being important in opening up the possibilities for near Earth orbital platforms for commercial usage. Major technology interests are in advanced lightweight materials, in use of inflatable design techniques, and in techniques for providing protection from micro-meteoroids, orbital debris, and radiation protection.

Habitats are categorized into three classifications (table 1). Class I is a pre-integrated habitat in that it is entirely manufactured, integrated and ready to operate when delivered to space. Class II is a pre-fabricated habitat and space or surface deployed. Class III is an in-situ resource utilization (ISRU) derived habitat that its structure is manufactured using local resource available on the Moon or Mars.

Table 1. Habitat Classification

Habitat Classification	Key Characteristics
CLASS I Pre-integrated	• Earth Manufactured • Earth Constructed • Fully Outfitted and Tested prior to Launch

	• Space Delivered with Immediate Capability • Limited Volume & Mass • Limited to Launch Vehicle Payload Size Capability • Limited to Launch Vehicle Payload Mass Capability
CLASS II Pre-Fabricated – Space/Surface Assembled	• Earth Manufactured • Requires Space Assembly or Deployment • Requires Robotic and Human Time During Assembly • Partial Integration Capable for Subsystems • Requires some or all Internal Outfitting emplacement • Critical Subsystems are Earth Based and Tested prior to Launch • Requires Assembly prior to Operability • Larger Volumes Capable • Not Restricted to Launch Vehicle Size. • Not Restricted to Launch Mass
CLASS III In-Situ Derived and Constructed	• Manufactured In-Situ with Space Resources • Space Constructed • Requires Manufacturing Capability & Infrastructure • Requires Robotic and Human Time During Construction • Requires Integration of Subsystems • Requires all Internal Outfitting emplacement • Critical Subsystems are Earth Based and Tested prior to Launch • Requires Assembly to become Operability • Larger Volumes Capable • Not Restricted to Launch Vehicle Size • Not Restricted to Launch Mass

Pre-Integrated habitats are commonly an aluminum or composite structure that can be autonomously pre-deployed and operated in LEO, on the Moon, or Mars surface. They are fully integrated and have the capability for ISHM smart habitat systems for failure detection, analysis and self-repair. Pre-Fabricated habitats are constructible or deployed habitats such as an Inflatable structure that can be autonomously pre-deployed and operated on the Moon and Mars surface. They are partially integrated and flexible and also have the capability for ISHM smart habitat systems for failure detection, analysis and self-repair. ISRU-Derived habitats are based ISRU-derived structures that are manufactured using indigenous resources and constructed autonomously. It is autonomously operated and maintained utilizing artificial intelligence and ISHM. It will have capability for ISHM smart habitat systems for failure detection, analysis and self-repair. As advanced habitats evolve from current pre-integrated habitat modules to future ISRU-derived structures, so does the level of technology investment required to achieves these systems (figure 22). Pre-integrated habitats have a high level of technology maturation and thus a lower technology investment is required compared to ISRU-derived habitats.

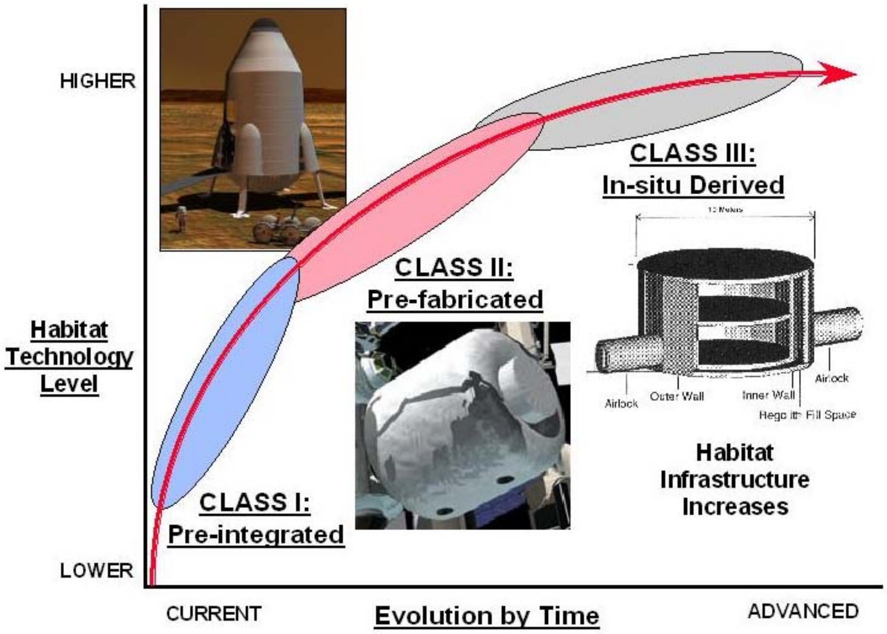


Figure 22. Advanced Habitation Evolution.

Pacing technical issues for advanced habitats include but are not limited to:

- Develop composite structures that can be deployed and operated in space and on planetary bodies for 10-20 year life time.
- Develop inflatable structures that can be packaged, deployed and operated in space and on planetary bodies for 10-20 year life time.
- Develop ISRU-derived structures, manufacturing processes and construction techniques that can be packaged, deployed and operated in space and on planetary bodies for 10-20 year life time.
- Integrate diagnostic and habitat health monitoring through out the habitat.
- Integrated self-repairing skins for habitat structures.
- Integrated design techniques that incorporate advanced systems into the habitat skin/structure and incorporates techniques to adjust resources within the habitat to automatically protect the crew based on the sensed environmental conditions.

Space and planetary habitation, pressure structures and unpressurized shelters need innovative structural solutions that combine high strength and light weight materials, along with the reliability, durability, repairability, radiation protection, packaging efficiency and life-cycle cost effectiveness. Advances in material developments and manufacturing techniques that enable the structure to “self-heal,” and the emplacement, erection, deployment or manufacturing of habitats in space or on the Moon and Mars are considered innovative technologies for the evolution of humans into space and the eventual settlement on Mars. Integration of sensors, circuitry and automated components to enable self-deployment and “smart” structures are considered necessary to allow a habitat to operate autonomously.

The objective is to create an advanced habitat that becomes a “living” structure that not only runs autonomously, but also has self-healing capability. A number of concepts, technologies and techniques have been proposed over the years that allow the delivery of deployable habitats to space and planet surfaces, or the manufacturing and construction of habitats on planet surfaces. Many new and exciting break-throughs in biotechnology have opened up exciting possibilities. The use of biotechnology combined with a fabric or matrix structure could someday produce a self-healing property analogous to our human skin.

In the future, numerous technologies will be researching methods and techniques for fully integrated inflatable “skin” and sensors/circuitry that enables “smart” structures that autonomously detect, analyze, and correct (repair) structural failure. Manufacturing methods of integrating miniaturization technology into the habitat skins, thus reducing weight and increasing self-autonomy are considered desirable. Technologies of this nature will be required far into the future to develop large planetary bases and support infrastructure such as inflatable greenhouses.

Conclusion

The evolution of space architecture and habitation is hard to predict. Through the efforts of dedicated women and men the future of space architecture looks bright. Advanced Habitation efforts throughout other NASA centers, around the country, and around the world are working on designs and research to make space travel better, more habitable, and safer for humans. History has taught us that architects and engineers have shaped our built environment; and they will continue to do so on Earth and in space. Groundbreaking design and technology work by architects and engineers in the aerospace community are laying the foundation by which many will follow for years to come. Whereas the many Architectural-Engineering teams have made incredible strides, there remains a great deal of work to be done on the ground and in space to enable humans to live and work for long durations in space.

The goal of AH&I is to provide living and working pressurized elements to support self-sufficiency for humans to carry out research and exploration productively in space for benefits on Earth, to open the door for planetary exploration, and to create self-sufficient outposts on other planetary bodies. A group at the Johnson Space Center has a dream too. That is to put the “living” into Living & Working in Space.

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