Carnegie Mellon University

SPACE ARCHITECTURE

Kriss J. Kennedy
Architect
• 2.3.16 Space Studio CMU: Mars and Architecture Beyond the Atmosphere
  – A traditional architecture studio focusing on a "post-pioneering" settlement (a first step research station with an emphasis on material, resources, closed-loop systems, as well as programmatic network and spatial considerations) for the surface of Mars or for Earth-Mars transit.

• Kriss Kennedy
  – History of Human Spaceflight/Space Stations and TransHab
Three (3) degrees in Architecture

Worked on over 42 designs and projects

Written over 40 publications, papers, or chapters in books
published in numerous magazines, periodicals & books

Has two patents and numerous NASA Technology Brief Awards

Recognized by his architect peers as one of the new upcoming architects in Texas as published in the millennium issue January 2000 Texas Architect magazine.

First space architect awarded the prestigious Rotary National Award for Space Achievement in March 2000

Registered licensed architect in the State of Texas
Space Studio CMU: Mars and Architecture Beyond the Atmosphere

History of Human Spaceflight/Space Stations and TransHab
Space Architecture...

...theory and practice of designing and building inhabited environments in outer space...

...design of living and working environments in space related facilities, habitats, surface outposts and bases, and vehicles...
Human Spaceflight Evolution

- Russia: Yuri Gagarin, the first person in space, and the first person to orbit the Earth, 1961
- Alan Shepard, the first American in space, 1961
- John Glenn, the first American to orbit the Earth, 1962
- Valentina Tereshkova, the first woman in space, 1963
- Neil Armstrong, the first person to set foot on the surface of the Moon, 1969
Human Spaceflight

### Suborbital human spaceflight

<table>
<thead>
<tr>
<th>Name</th>
<th>Years</th>
<th>Flights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercury</td>
<td>1961</td>
<td>2</td>
</tr>
<tr>
<td>X-15</td>
<td>1963</td>
<td>2</td>
</tr>
<tr>
<td>Soyuz 18a</td>
<td>1975</td>
<td>1</td>
</tr>
<tr>
<td>SpaceShipOne</td>
<td>2004</td>
<td>3</td>
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</table>

### Orbital human spaceflight

<table>
<thead>
<tr>
<th>Name</th>
<th>Years</th>
<th>Flights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vostok</td>
<td>1961—63</td>
<td>6</td>
</tr>
<tr>
<td>Mercury</td>
<td>1962—63</td>
<td>4</td>
</tr>
<tr>
<td>Voskhod</td>
<td>1964</td>
<td>2</td>
</tr>
<tr>
<td>Gemini</td>
<td>1965—66</td>
<td>10</td>
</tr>
<tr>
<td>Soyuz</td>
<td>1967—present</td>
<td>126 as of December 2015</td>
</tr>
<tr>
<td>Apollo</td>
<td>1968—69</td>
<td>2</td>
</tr>
<tr>
<td>Skylab</td>
<td>1973</td>
<td>3</td>
</tr>
<tr>
<td>Apollo-Soyuz</td>
<td>1975</td>
<td>1</td>
</tr>
<tr>
<td>Space Shuttle</td>
<td>1981—2011</td>
<td>135</td>
</tr>
<tr>
<td>Shenzhou</td>
<td>2003—present</td>
<td>5</td>
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</table>

### Lunar human spaceflight

<table>
<thead>
<tr>
<th>Name</th>
<th>Years</th>
<th>Flights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apollo</td>
<td>1968—72</td>
<td>9</td>
</tr>
</tbody>
</table>
History of Space Stations

- Soviet/Russia: Salyut 1-7: 15 years from 1971 to ~1990
  - Salyut 1, the first station in the program, became the world's first crewed space station
- USA: Skylab 1973 - 1979
- Soviet/Russia: Mir 1986 - 2001
- USA: Shuttle/SpaceLab 1981 - 2011
- USA/RSA/ESA/JAXA: ISS 1998 (assembly began) - current
  - Continually human occupied and operated for 15+ yrs (2000)
- China: Tiangong-1 2011 - current.
  - Testbed for a larger station in ~2023
International Space Station
Continually human occupied and operated for 15+ yrs

ISS Configuration

As of late May 2015
## Space Environmental Factors

<table>
<thead>
<tr>
<th>Consideration</th>
<th>Earth Orbital</th>
<th>Lunar/Mars Transfer</th>
<th>Lunar/Mars Surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Vacuum</td>
<td>Pressurized enclosure</td>
<td>Pressurized enclosure</td>
<td>Pressurized enclosure</td>
</tr>
<tr>
<td>2. Debris</td>
<td>Requires Shielding</td>
<td>None</td>
<td>Launch and Landing</td>
</tr>
<tr>
<td>3. Gravity</td>
<td>Microgravity</td>
<td>Microgravity Induced gravity</td>
<td>Partial (less than 1 earth g) changes interior architecture</td>
</tr>
<tr>
<td>4. Radiation</td>
<td>Protected by Van Allen Belts South Atlantic Anomaly potential problem</td>
<td>Lunar transfer protection probably not required Mars transfer protection required</td>
<td>Lunar protection required Mars: TBD protection required</td>
</tr>
<tr>
<td>5. Dust</td>
<td>None</td>
<td>None</td>
<td>Lunar dust is a design challenge Mars dust a potential issue</td>
</tr>
</tbody>
</table>

- **Vacuum**: Pressurized enclosure
- **Debris**: Requires shielding
- **Gravity**: Microgravity
- **Radiation**: Protected by Van Allen Belts South Atlantic Anomaly potential problem
- **Dust**: None
Human Exploration Destination Systems
*a sustained human presence*

**Lunar Missions**
lunar orbit, lunar surface
- Landing systems
- Nuclear power
- In-situ resource utilization
- Surface Habitation
- Autonomous Operations
- Surface Rover
- Surface EVA mobility

**Deep Space**
LaGrange Points, NEOs and beyond
- Crew support for 30-60 + days (habitat)
- Radiation protection (habitat)
- Life support (habitat)
- Deep space propulsion
- Cryogenic fluid management
- Supportability & maintenance
- Autonomous Hab Operations

**Mars Missions**
Lunar missions plus:
- Mars entry & landing systems
- Advanced propulsion
- Partial-gravity countermeasures

**Remote Earth Destinations**
Antarctica, Deep-Water
- Analogs
- Operations Concept Validation
- Science & Mission Ops
- Autonomous Hab Operations
- Hardware/Software Demos
- Closed-loop life support
- Inflatable Hab Demos
- Environmental monitoring
- Supportability & Maintenance

**Near-Earth Space**
HEO, lunar orbit, Libration Points
- Heavy lift launch
- Autonomous Hab Operations
- Inflatable Hab Module
- Closed-loop life support
- Crew support for - 20 days
- Deep-space propulsion
- Radiation protection

**Low-Earth Orbit**
Commercialization
- Zero-g research platform
- Autonomous Hab Operations
- Inflatable Hab Module
- Closed-loop life support
- Environmental monitoring
- Supportability & Maintenance concepts

**Interplanetary Transportation**
LEO to Destinations
- Heavy lift launch
- Autonomous Hab Operations
- Inflatable Module
- Closed-loop life support
- Crew support for long-duration flights
- Deep-space propulsion
- Radiation protection
Surface Exploration Development Phases

- Surface Exploration Sorties
- Base Planning
- Surface Research Outpost
- Initial Outpost
- Resource Production & Utilization
- Surface Base
- Industrialization / Exploitation
- Sustained Human Presence
Space Habitat Classifications

CLASS I: Pre-integrated
CLASS II: Pre-fabricated
CLASS III: In-situ Derived

Habitat Technology Level:
- Higher
- Lower

CURRENT: Habitat Infrastructure Increases
Evolution by Time: Advanced
Orbital Habitats

SKYLAB

US HAB
Airlocks & Nodes

Planetary Airlock

ISS Airlock

Planetary Node
Human Exploration Systems

Elements
- Crew Return Vehicle
- Deep Space Habitat (DSH)
- Space Exploration Vehicle
- Propulsion Stage
- EVA Capabilities
- Power Generation & Storage
- Deep Space Communications

Exploration Habitat Systems
- Environmental Protection
- Life Support
- Power Management & Distribution
- Thermal Control
- Crew & Medical Systems
- Laboratory Systems (Geo & Life Science)
- Logistics, Repair & Manufacturing
Crew Operations - IVA
Sustain crew on lunar surface for mission. These functions are necessary to insure the safety of the crew. It also includes providing the functions necessary to sustain the crew from a health and well being perspective.

Crew Operations – Supporting EVA
Enable Redundant EVA Function & Enhanced EVA Capability. These functions are necessary to provide the crew with additional means to conduct routine EVAs. The extent provided is driven by the mission duration and the number of EVAs required to conduct that mission.

Mission Operations
Enable Enhanced Mission Operations Capability. These functions are those that enable the lunar surface crew to conduct surface operations in concert with the Earth based mission control. For longer surface stays it should also establish autonomy from the Earth based "mission control" enabling command and control with other surface assets such as rovers, landers, etc.

Science Operations
Enable IVA Bio/Life Science & GeoScience Capability. These functions are necessary to conduct the science involved with the mission. It can include sample collection, sample analyses, sample prioritization and storage, and any sample return required. It also is meant to include any specific "environmental" requirements specific to Life Science or GeoScience

Logistics & Maintenance Operations - IVA & EVA
Enable Maintenance, Resupply, & Spares Cache. These functions are those that allows for maintaining the surface assets during recognized maintenance intervals. It also includes those functions necessary to resupply the habitat(s) with consumables (both pressurized and unpressurized) to support the crew for the mission. Lastly, it also includes the functions necessary to deliver and store the necessary spares related to the maintenance as well as unexpected failures.
Habitation Functional Elements and Operations

- **Crew Operations** (enable sustainability of 4 crew on lunar surface for 7-180 days)
- **EVA Operations** (enable redundant EVA function & enhanced EVA capability)
- **Mission Operations** (enable enhanced mission operations capability)
- **Science Operations** (enable enhanced IVA bio & geo science capability)
- **Logistics Operations** (enable resupply & spares cache)

- Structure and Environmental Protection
- Power Management and Distribution
- Life Support
- Thermal Control
- Lunar Surface Science and Technology Demonstrations
- Communications
- EVA Support
- Crew Accommodations
Inflatable Structures Overview

• Materials:
  – Kevlar
  – Vectran
  – new tensile fabric materials

• Construction:
  – “basket weave” w/ Clevis Pins
  – wound spun fibers on a mandrel like a tube sock
  – Bladder Seal: Marman Clamp

• Assembly:
  – Pure Inflatable
  – Hybrid (hard and soft materials)
  – Packaging
  – Deployment
  – Internal Assembly
  – Outfitting
  – Checkout and initial ops. Verify human occupancy ready

• Interfaces:
  – Fabrics to hard end caps or bulkhead termination
  – Airlock, other modules, Common Berthing Mechanism (ISS derived)
  – Structural Nodes
  – Surface: Foundation or support

• Design:
  – Pressure Vessel shapes
    • Sphere, cylinder, torus, hybrids

• Architecture:
  – External Protection
  – Internal Layout
  – Utilities Distribution
Inflatable Lunar Habitat

DESIGNED 1989
Inflatable Lunar Habitat

DESIGNED 1992
Inflatable Structures in Space
TransHab (Inflatable Space Habitat)

- U.S. Patent granted

DESIGNED 1997
NASA TransHab Concept

- TransHab was a light weight inflatable habitation module for space applications
- Original 1997 concept for light weight habitat module for human mission transit to Mars
- Proposed to the International Space Station (ISS) Program as a replacement for a Hab Module
ISS TransHab  Full Scale Shell Development Unit (SDU-3)

First Inflation: November 17, 1998
ISS TransHab

Hatch Door

Inflatable Shell

Central Structural Core

20” Window (2)

Integrated Water Tank

Soft Stowage Array

Wardroom Table

Level 4: Pressurized Tunnel

Level 3: Crew Health Care

Level 2: Crew Quarters and Mechanical Room

Level 1: Galley and Wardroom
Mars Surface Hab/Combo Lander

DESIGNED

2000
Mid-Expandable Habitat Concept

DESIGNED 2008
Lunar Architecture
Habitat Concepts
DESIGNED
2007/09
Providing the knowledge, the hardware, and the materials to support human life beyond our world
DRIVE – DESIRE – DETERMINATION
Moon, Mars, Beyond...
Space Architecture
...shaping the future
Be inspired...
...inspire others
BACKUP
Earth Analog Testing
Deep Space Habitat

DESIGNED
2010
RAPID PROTOTYPING

Habitat Demonstration Unit

STARTED 2009
Habitat Demonstration Unit

Rapid Prototyping
Habitat Demonstration Unit
2010 Fit Check w/ Rover
Deep Space Habitat Inflatable Loft added
Exploration Habitat Academic Innovation Challenge

Started 2010