DEVELOPMENT OF AN INFLATABLE AIRLOCK FOR DEEP SPACE EXPLORATION

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• Introduction

• History of Inflatable Airlock Development

• Design Considerations for Inflatable Airlocks
  • Generic Airlock Considerations for Space Applications
  • Inflatable Airlock Specific Considerations

• Conclusions and Future Work
OUTLINE

• **Introduction**

• History of Inflatable Airlock Development

• Design Considerations for Inflatable Airlocks
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• Conclusions and Future Work
• Airlocks have been used for EVAs (extravehicular activities) since 1965
• Airlock designs including integrated, single, and dual-chamber, along with various volumes and hatch shapes have been used

<table>
<thead>
<tr>
<th>In Service From</th>
<th>To</th>
<th>Name</th>
<th>Type /Chamber</th>
<th>Dimensions L x D (ft)</th>
<th>Volume (ft³)</th>
<th>Mass (lbm)</th>
<th>EVA Hatch Shape</th>
<th>Opening (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1965</td>
<td>1965</td>
<td>Voskhod 2 Volga</td>
<td>Inflatable</td>
<td>8.2 x 3.9</td>
<td>88.3</td>
<td>551</td>
<td>Circular</td>
<td>26</td>
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<tr>
<td>1965</td>
<td>1966</td>
<td>Gemini Capsule</td>
<td>Integral</td>
<td>19.0 x 9.8</td>
<td>90</td>
<td>8490</td>
<td>Trapezoid</td>
<td>15 x 51 x 37</td>
</tr>
<tr>
<td>1969</td>
<td>1972</td>
<td>Apollo Ascent Module</td>
<td>Integral</td>
<td>3.5 x 7.7</td>
<td>159</td>
<td>4740</td>
<td>Square</td>
<td>32 x 32</td>
</tr>
<tr>
<td>1973</td>
<td>1974</td>
<td>Skylab Airlock</td>
<td>Single</td>
<td>12.8 x 5.4</td>
<td>322</td>
<td>16936</td>
<td>Trapezoid</td>
<td>15 x 51 x 37</td>
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<tr>
<td>1983</td>
<td>2011</td>
<td>Shuttle Airlock</td>
<td>Single</td>
<td>6.9 x 5.3</td>
<td>150</td>
<td>827</td>
<td>D-Shape</td>
<td>40</td>
</tr>
<tr>
<td>2001</td>
<td>Present</td>
<td>ISS Pirs Airlock</td>
<td>Single</td>
<td>16.1 x 8.4</td>
<td>460</td>
<td>7892</td>
<td>Circular</td>
<td>39</td>
</tr>
<tr>
<td>2001</td>
<td>Present</td>
<td>ISS Quest Airlock</td>
<td>Dual</td>
<td>18.0 x 13.1</td>
<td>1200</td>
<td>21896</td>
<td>D-Shape</td>
<td>40</td>
</tr>
</tbody>
</table>
INTRODUCTION

• Dual-chamber airlocks using an “Equipment Lock” and “Crew Lock” minimize the evacuated volume, separate the electronics and hardware, and provide redundancy in the event of a hatch failure.

• While dual-chamber airlocks are recommended, they limit the launch volume available with a metallic structure design.

• The use of an inflatable soft goods structure as a Crew Lock would provide valuable launch volume savings.

• Inflatable soft goods have been studied since the 1950’s as habitable space structures that offer large deployed volumes in a compact stowed launch package.

• They utilize high strength fabrics and internal pressure to create a stiffened vessel that can replace traditional metallic or composite shell structures.

• The soft goods shell is comparable in mass to a metallic vessel, but due to the packaged configuration, reduce the required launch volume and dynamics.

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Volga Inflatable Airlock – Voskhod 2

- Developed by USSR in 1965
- Dimensions:
  - Packed: 2.5 ft long x 3.9 ft wide
  - Expanded: 8.2 ft long x 3.9 ft wide; 88.3 ft$^3$ internal
  - Hatch: 26 in diameter
- First ever EVA was conducted from the Volga airlock on the Voskhod 2 mission by Alexei Leonov in 1965
- Designed out of necessity because Voskhod capsule could not be depressurized
- Cylindrical in shape, utilized rubber air-booms around the circumference to maintain shape
- Airlock deployed nominally to 5.8 psia, used for a single crew member, and jettisoned after use

HISTORY OF INFLATABLE AIRLOCK DEVELOPMENT
HISTORY OF INFLATABLE AIRLOCK DEVELOPMENT

Volga Inflatable Airlock – Voskhod 2

Image Source: [3]

Airbooms
No Thermal Protection Cover

With Thermal Protection Cover
D-21 – Goodyear Inflatable Airlock

- Built by Goodyear Aerospace Corporation in the 1960’s
- Dimensions:
  - Packed: 2.5 ft long x 4 ft wide
  - Expanded: 5.4 ft long x 5 ft wide; 78 ft³ internal
  - Hatch: 34 in diameter
- Developed with Air Force and designed to fly on Skylab with a single crew member, but was dropped from mission suite
- Design pressure of 3.5 psia, made of nylon/foam/foil bladder, stainless steel/Taslan yarn, filament-wound structural layer, and polyurethane foam for MMOD (micrometeoroid and orbital debris) and thermal protection
- Extensive ground testing demonstrated structural capability and cold temperature deployment test proved the need for additional thermal protection layers and fire resistant materials
HISTORY OF INFLATABLE AIRLOCK DEVELOPMENT

D-21 – Goodyear Inflatable Airlock

Image Source: [6]

9/18/2018  D. Litteken, NASA/JSC/ES2 | AIAA SPACE 2018
Whittaker Inflatable Airlock

- Developed by Whittaker Corporation in 1965
- Dimensions:
  - Expanded: 7 ft long x 4 ft wide; 87 ft\(^3\) internal
  - Hatch: 30 in diameter
- Developed under a research grant with NASA
- Design pressure of 10 psia, made of a thick vinyl bladder, isotensoid filamentary restraint layer in a knitted material, polyester foam for MMOD and an outer thermal coating for temperature control, sized for a single crew member
- Multiple design iterations were evaluated, including an inner airlock and packaging trials that identified the benefit of rigid (metallic) hoop bands in the structural shell to induce fold lines and resist loads
HISTORY OF INFLATABLE AIRLOCK DEVELOPMENT

Whittaker Inflatable Airlock

Image Source: [10]
Advanced Inflatable Airlock (AIA)


• Dimensions:
  • Expanded: 8 ft long x 7 ft wide; 226 ft$^3$ internal
  • Hatch: 40 in diameter

• Built upon TransHAB technology for soft airlock to fit any platform or vehicle needing EVA capability with two crew members

• Design pressure of 14.7 psia, made of a nylon bladder, Vectran restraint layer, Nextel MMOD layer, MLI (multi-layer insulation) thermal blanket and Beta cloth outer layer

• Work focused on restraint layer, a single wide-angle braided Vectran tube, and a deployment/retraction system using linear actuators, air-beams, and pneumatic muscles
HISTORY OF INFLATABLE AIRLOCK DEVELOPMENT

Advanced Inflatable Airlock (AIA)

Image Source: [14]
Dual-Chamber Hybrid Inflatable Suitlock (DCIS)

• Developed by NASA JSC and JPL in 2011

• Dimensions:
  • Expanded: 24.2 ft long x 9.2 ft wide; 470.1 ft$^3$ internal
  • Hatch: Surface door-type hatch

• Developed for the Lunar Surface Systems project under the Constellation Program

• Design pressure of 8.2 psia, made of three metallic bulkheads separated by fabric tunnels, creates a dual-chamber airlock that can be collapsed and moved on demand

• Operational testing was completed in a simulated surface mission with focus on suitport integration, dust mitigation, and a porch used for easier surface ingress/egress
HISTORY OF INFLATABLE AIRLOCK DEVELOPMENT

Dual-Chamber Hybrid Inflatable Suitlock (DCIS)

Image Source: [15]
Minimalistic Advanced Soft Hatch (MASH)

• Developed by NASA LaRC in 2014-2016

• Dimensions:
  • Expanded: 14.7 ft long x 6.5 ft wide; 356 ft³ internal
  • Hatch: Integrated linear hatch

• Goal to significantly reduce weight of airlock hatch by integrating a soft hatch into a soft goods airlock structure

• Design pressure of 15.2 psia using a non-axisymmetric shape with lobed areas that provide low hoop stress zones, made of urethane coated nylon bladder, Vectran fabric and cordage restraint layer, designed for two crew members

• Structural testing completed on the non-axisymmetric shape and linear seal integration showed proof of concept for soft hatch in a unique design
HISTORY OF INFLATABLE AIRLOCK DEVELOPMENT

Minimalistic Advanced Soft Hatch (MASH)

Image Source: [18]
Lightweight Inflatable Structural Airlock (LISA)

- Developed by Thin Red Line Aerospace and Computational Fluid Dynamics Research Company in 2016-2018
- Dimensions:
  - Expanded: 5.9 ft long x 9.8 ft wide; 327 ft$^3$ internal
  - Hatch: Integrated linear hatch
- Developed under an SBIR with NASA
- Design pressure of 15.2 psia, utilizing a Ultra High Performance Vessel and proprietary linear seal, made of a urethane coated nylon bladder, Kevlar fabric and Vectran cordage, designed for two crew members
- Structural testing with an integrated linear seal was completed, advancing the state of the art and showing additional feasibility for a soft hatch airlock
Lightweight Inflatable Structural Airlock (LISA)
Lightweight External Inflatable Airlock (LEIA)

- Developed by NASA JSC in 2017-2019
- Dimensions:
  - Expanded: 13 ft long x 10.5 ft wide; 565 ft³ internal
  - Hatch: 40 in diameter
- Design pressure of 14.7 psia, sized for two crew members, with focus on internal sub-structure and crew interfaces
- Iterated on two concepts for internal structure including an inflatable truss (made of Kevlar fabric) and an erectable truss (made of carbon fiber tubes)
- Conducted full scale mobility testing with micro-gravity simulation, developed soft handrails, and completed structural burst testing of an inflatable truss design
HISTORY OF INFLATABLE AIRLOCK DEVELOPMENT

Lightweight External Inflatable Airlock (LEIA)

Image Source: NASA
HISTORY OF INFLATABLE AIRLOCK DEVELOPMENT

Other Concepts and Patents

1. NASA patent (1968) – single hatch with moveable airlock
2. NASA patent (1976) – flexible, deployable tunnel
4. Lockheed Martin Portable Air Lock (PAL) (1963) – airlock concept shown in local newspaper
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**GENERIC AIRLOCK CONSIDERATIONS**

- **Dual vs Single Chamber Design**
  - ISS airlock uses a dual-chamber design
  - Dual-chamber designs provide redundancy in the event of a failure, eliminate the need for hardware and electronics to be vacuum compatible, and minimize gas loss during a depress/repress cycle
  - EVA community assumes future airlocks provide at least a secondary ingress capability as a backup option in the event of a failure

- **EV Hatch**
  - Sized for crew members and payloads to pass through
  - Typically EV hatches are pressure-assisted and inward opening
  - Mounted on side of Crew Lock on ISS because of mobility issues with a suited crew member
    - They can only use their hands/arms in front of their chest, so hatch placement and operation should be accommodating to these constraints
  - Exploration guidelines designate a hatch should have $\geq 39$ in diameter opening
GENERIC AIRLOCK CONSIDERATIONS

• Internal Volume
  • Need volume for suit don/doff, suit maintenance, suit servicing equipment, logistics, tools, and payloads, which are typically housed in an Equipment Lock, but could be part of an integrated habitat or utility module
  • The Crew Lock is often the smallest volume and only requires room for two suited crew members to be able to translate and operate the hatch

• Suit Interfaces
  • Suits must be able to interface with the airlock to recharge consumables and be repaired/maintained
  • Most of the servicing equipment is located in the Equipment Lock with a suit umbilical interface in the Crew Lock

• Handrails/Tethers
  • Crew members translate through the airlock and onto the exterior of the spacecraft using handrails, handholds, and tether attach points
  • Rigid translation aids are required for all expected translation paths, these are typically composed of metallic tubing that is designed for crew member tether and translation loads
  • ISS translation aids use a specific cross-sectional shape that is designed to interface with the suit gloves and prevent inadvertent damage
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INFLATABLE AIRLOCK CONSIDERATIONS

• Dual vs Single Chamber Design
  - Inflatables achieve full structural capability once pressurized, so an inflatable Equipment Lock is not recommended because of the rigid equipment needed
  - An inflatable Crew Lock, however, offers EVA capability in a small launch package
  - Additionally, a dual-chamber design provides redundancy in the airlock

• Deployment/Folding
  - Soft goods airlock should be packaged as small as possible on the ground, while not damaging the fabric layer
  - Deployment method should provide initial expansion in a controlled and predictable manner using internal pressure and an internal/external deployment mechanism

• Environmental Protection
  - Airlock must protect against the space environment, like a metallic airlock, but special considerations should be made for low temperature effects on polymer materials, radiation exposure to fabrics, and dust degradation on a surface airlock
INFLATABLE AIRLOCK CONSIDERATIONS

• EV Hatch
  • Soft hatches are still a low TRL and continue to be pursued by NASA and industry
  • Integrating a traditional, rigid hatch into a soft goods airlock provides the most heritage and flight history for EVA ingress/egress

• Mobility/Handrails
  • Crew members will require handholds, foot restraints, and tether attach points to move around the vehicle in micro-gravity
  • Handholds could be made from soft goods and be foldable/expandable as long as they provide the required stiffness and rotational control
  • Railing and attach points will also be required on surface missions to assist in crew mobility

• Internal Secondary Structure
  • When the airlock is depressurized, a secondary structure is needed to maintain the module’s stiffness and provide a framework for crew handholds and tethers
  • This structure can be integrated into the fabric layers and be used on both the inside and the outside of the soft goods airlock
### INFLATABLE AIRLOCK CONSIDERATIONS

<table>
<thead>
<tr>
<th>Consideration</th>
<th>In-Space LEO/Interplanetary Vehicle</th>
<th>Moon/Mars Surface Surface Outpost/Mobile Vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gravity</strong></td>
<td>Micro-gravity</td>
<td>Reduced gravity</td>
</tr>
<tr>
<td><strong>Thermal</strong></td>
<td>LEO: Cyclic, day/night; Interplanetary: Constant extreme cold</td>
<td>Location dependent, Constant shadows, Long/regular day/night cycles; Mars: Atmosphere and seasons; Moon: Abrupt day/night transitions</td>
</tr>
<tr>
<td><strong>Radiation</strong></td>
<td>LEO: Low risk; Interplanetary: Higher risk with GCR and SPE</td>
<td>Higher risk with more common EVAs, longer distance from SPE shelters, long term GCR</td>
</tr>
<tr>
<td><strong>Atmosphere</strong></td>
<td>None, clean, hard vacuum</td>
<td>Low to zero; Abrasive, magnetic, fine dust; Mars: High speed, low pressure wind</td>
</tr>
<tr>
<td><strong>MMOD</strong></td>
<td>LEO: High risk (orbital debris); Interplanetary: Lower risk (micrometeoroids)</td>
<td>Medium to low risk (long exposure)</td>
</tr>
<tr>
<td><strong>Crew Restraint</strong></td>
<td>Handholds, handrails, foot restraints; Tether attachments required</td>
<td>Handrails, Rigid floor, Fewer mobility restraints</td>
</tr>
<tr>
<td><strong>Crew Movement</strong></td>
<td>Cable and clip tether, Maneuvering unit</td>
<td>Self-powered, Walk, Hop, Climbing</td>
</tr>
</tbody>
</table>
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<tr>
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<th>In-Space LEO/Interplanetary Vehicle</th>
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</tr>
</thead>
<tbody>
<tr>
<td>EVA Suits</td>
<td>Limited range of motion, Fewer requirements than surface suits</td>
<td>Lightweight, Higher mobility, Robust to environment/dust, Need more maintenance</td>
</tr>
<tr>
<td>Consumables</td>
<td>Possibility of venting air on each EVA, Primary vessel can provide contingency air and egress volume</td>
<td>Must recycle/recapture air, Mobile: Additional contingencies needed due to risk</td>
</tr>
<tr>
<td>Extra Equipment</td>
<td>EVA tools, Repair units, Upgrade supplies</td>
<td>Outpost: EVA surface tools; Mobile: Equipment may need to be accessed through external hatch</td>
</tr>
<tr>
<td>EVA Frequency</td>
<td>Infrequent, Typically for repairs</td>
<td>Common, Potentially daily, Surface exploration</td>
</tr>
<tr>
<td>Hatch</td>
<td>Circular or heritage D-shape with ≥ 39 in diameter opening</td>
<td>Taller and larger hatch for easier access and more common entrance/exit in gravity</td>
</tr>
<tr>
<td>Volume</td>
<td>Min. volume/mass for consumables, Based on two EVA suited crew members</td>
<td>Min. volume/mass needed for planetary missions, Based on at least two EVA suited crew members</td>
</tr>
<tr>
<td>Pressure</td>
<td>Mission dependent, Typically 14.7 psia habitat pressure</td>
<td>Mission dependent, Potentially 8.2 psia suitport and exploration pressure</td>
</tr>
</tbody>
</table>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>Deployment</strong></td>
<td>One time deployment with secondary or habitat consumables</td>
<td>Deployment with outpost consumables and retractability for modularity and mobile use</td>
</tr>
<tr>
<td><strong>Depressurized Stability</strong></td>
<td>Needs lightweight deployable or erectable internal and external structure including handrails and attachment points</td>
<td>Needs lightweight deployable or erectable internal and external structure including handrails, equipment stowage and floors</td>
</tr>
<tr>
<td><strong>Redundancy</strong></td>
<td>Dual or single chamber with multiple seal lines, Needs contingency for failed hatch</td>
<td>Outpost: Multiple elements and contingency airlocks available; Mobile: Dual hatches</td>
</tr>
<tr>
<td><strong>Maintainability</strong></td>
<td>Vehicle relatively easy to access in micro-g during EVA with translation aids, Long term missions should carry replacement hardware and design for repairs</td>
<td>Habitats harder to access with gravity, Long term missions should carry replacement hardware and design for repairs, Dusty surface environments require maintenance of seals and electronics</td>
</tr>
<tr>
<td><strong>Modularity</strong></td>
<td>Mission dependent, Not required</td>
<td>Mission dependent, Likely reusable/common elements for repair and replace in space, Design for multi-use on Moon and Mars</td>
</tr>
</tbody>
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CONCLUSIONS AND FUTURE WORK

• A rigid Equipment Lock with an inflatable Crew Lock is the most feasible near-term integration approach for a Gateway airlock

• An inflatable Crew Lock provides several advantages over a metallic structure:
  • Reduced launch volume can offer increased habitat volume
  • Dual-chamber airlock offers contingency with little additional volume
  • Secondary inflatable can be used to capture and reuse gas
  • Soft goods materials have excellent impact resistance for MMOD protection
  • Ability to deploy and retract and can be modular for multiple uses

• Developmental work continues at NASA to further develop:
  • IVA/EVA outfitting and soft handholds
  • Lightweight hatch developments
  • Air circulation and ventilation integration
  • Rigid hatch to soft goods seals
  • Cold temperature materials testing
  • Long term creep materials testing
QUESTIONS?

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