Water Walls: Highly Reliable, Massively Redundant Life Support Architectures

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Motivation

- The cost of human space flight today is prohibitive.
- Cost is a major impediment to the frequency and duration of future exploration missions.
- What is needed is to reduce the cost of human spaceflight by an order of magnitude.
- We need a new approach to sustaining humans in space.
Habitat Water Walls Architecture

- Our approach integrates life support, thermal, structural, and radiation protection functions into the walls of the spacecraft.

- We achieve a mass savings by combining the mass and function of all subsystems within the mass allocation of a radiation protection water wall.
The Need for Radiation Protection Calculated for an ISS Aluminum Module

![Graph showing cumulative dose (mSv) over days for different radiation types (GCR, SPE, Trapped ions, Total) and the dose limit.](image-url)
Water Walls Applied to a TransHab-type Inflatable Module
Radiation Protection

Providing “parasitic” radiation protection is prohibitively massive and expensive.

- For a 240 day deep space mission with 150 mSv career dose limit and an ISS derived cylindrical habitat 130,000 Kg will be required.
- For the same mission where solar radiation protection is all that is required a 20 cm thick water wall in an ISS sized element will require more than 25,000 Kgs of water.

But do we need to provide this water from Earth?

- A 6 person crew producing 15 l/person-day of wastewater with a 80% recovery ratio will produce 6500 Kg/year of wastewater.
- It would require 4 years of operation to accumulate enough water to provide a solar water wall for a single ISS element.
### Equivalent System Mass and Metric Values for a Range of Missions and Technologies

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>Near-Term Exploration Mission:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crew Exploration Vehicle</td>
<td>19,973</td>
<td>13,553</td>
<td>1.47</td>
</tr>
<tr>
<td>Lunar Surface Access Module</td>
<td>3,316</td>
<td>2,258</td>
<td>1.47</td>
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<tr>
<td>Lunar Outpost</td>
<td>2,323</td>
<td>1,982</td>
<td>1.17</td>
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<td><strong>Independent Exploration Mission:</strong></td>
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<tr>
<td>Mars Transit Vehicle</td>
<td>14,334</td>
<td>9,313</td>
<td>1.54</td>
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<tr>
<td>Mars Descent / Ascent Lander</td>
<td></td>
<td></td>
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<tr>
<td>Surface Habitat Lander</td>
<td>52,996</td>
<td>29,208</td>
<td>1.81</td>
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<tr>
<td><strong>Mars Transit Vehicle</strong></td>
<td>16,643</td>
<td>10,890</td>
<td>1.53</td>
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<tr>
<td><strong>Mars Descent / Ascent Lander</strong></td>
<td>4,894</td>
<td>3,039</td>
<td>1.61</td>
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<tr>
<td><strong>Surface Habitat Lander</strong></td>
<td>31,459</td>
<td>15,279</td>
<td>2.06</td>
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Reliability for Long Duration Missions

<table>
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<tr>
<th>Mars Mission</th>
<th>Transit Days</th>
<th>Mission Days</th>
<th>Surface Days</th>
<th>Stay Time Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conjunction</td>
<td>400 (Min)</td>
<td>500 (Max)</td>
<td>500 (Min)</td>
<td>600 (Max)</td>
</tr>
<tr>
<td>Opposition</td>
<td>570 (Min)</td>
<td>700 (Max)</td>
<td>30 (Min)</td>
<td>90 (Max)</td>
</tr>
<tr>
<td>Flyby</td>
<td>500 (Min)</td>
<td>650 (Max)</td>
<td></td>
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</table>

Experience from operation of the life support system on Mir and ISS has demonstrated significant reliability issues for conventional systems.

The Water Walls concept uses a more passive approach than the mechanical systems used on ISS.
Reliability – A More Passive Approach to Life Support is Better than all Mechanical

Nature uses no compressors, evaporators, lithium hydroxide canisters, oxygen candles, or urine processors to revitalize our atmosphere, clean our water, process our wastes, and grow our food.

Conventional NASA approach is to use electro-mechanical systems which tend to be failure prone.

In comparison, Nature’s passive systems do not depend upon machines and provide sufficient redundancies so that failure is not a problem.

The Water Wall concept takes an analogous approach that is biologically and chemically passive and massively redundant.
Water Walls Modular Construction
Water Walls
Initial Functional Flow Diagram
Water Walls Process Block Integration Diagram
### TABLE 1. Water Walls Life Support Functions and Systemic Redundancies

<table>
<thead>
<tr>
<th>WW Primary Functions (Based on Inputs and Outputs)</th>
<th>Algae Growth Bag</th>
<th>Blackwater/ Solids Bag</th>
<th>PEM Fuel Cell</th>
<th>Urine/ H20 Bag</th>
<th>Humidity &amp; Thermal Bag</th>
</tr>
</thead>
<tbody>
<tr>
<td>O2 Revitalization</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>CO2 Removal</td>
<td>X</td>
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<tr>
<td>Denitrification/Liberation of N2</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Clean Water Production</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Urine &amp; Graywater Processing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
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<tr>
<td>Semi-Volatile Removal</td>
<td>X</td>
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<td></td>
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<tr>
<td>Blackwater Processing</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humidity &amp; Thermal Control</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Nutritional Supplement Production</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Electrical Power Production</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
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</table>
Development Approach

1. Fabricate and test functions, processes and units at the bench scale.
2. Scale up to a sub-scale functional prototype such as a Forward Osmosis bag.
3. Test Functional Prototypes in a controlled (e.g. closed chamber) and field environments.
4. Microgravity Flight Testing on ISS, and
5. Integrated System Test in the Bigelow Inflatable Module.
Core Air Revitalization Process: CO₂ Sequestration & O₂ Production

Testing using OptiCells™ Cyanobacteria and *Synechococcus*

- Cyanobacteria 53.6 mg CO₂ fixed L⁻¹ hr⁻¹,
- *Synechococcus* 250 mg CO₂ fixed L⁻¹ hr⁻¹.

Future tests will use green alga *Chlorella*, and the edible cyanobacterium *Spirulina*. As well as determining O₂ production.

Algae/cyanobacteria needs to offset 1Kg CO₂/person-day
Forward Osmosis: A Natural Process -- X-Pack™ forward osmosis bag
Example of Water Walls Research: Reduction in flux as a function of the number of times a bag has been reused.

Data was taken after 4 hours of operation for each data point. Error bars are 11%.
STS 135 Forward Osmosis Bag Flight Test
2013 New Design for Forward Osmosis Cargo Transfer Bag (CTB) that Accommodates Flight Demonstrations of Functional Cell Elements
Cargo Transfer Bag Placement in an ISS Module for Functional Process Use and Radiation Shielding
FO – CTB Field Tests at Desert-RATS

D-RATS 2011

D-RATS 2012
Results of D-Rats Field Tests Measured Recycling Ability for Hygiene Water

<table>
<thead>
<tr>
<th>Product at Feed at</th>
<th>Feed at</th>
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<tbody>
<tr>
<td>Start</td>
<td>End, 5 h</td>
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<tr>
<td>Na</td>
<td>12737.0</td>
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<tr>
<td>NH4</td>
<td>nd</td>
</tr>
<tr>
<td>K</td>
<td>nd</td>
</tr>
<tr>
<td>Mg</td>
<td>nd</td>
</tr>
<tr>
<td>Ca</td>
<td>nd</td>
</tr>
<tr>
<td>Cl</td>
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<td>PO4</td>
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<tr>
<td>SO4</td>
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<td>TOC</td>
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<tr>
<td>TIC</td>
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<tr>
<td>TN</td>
<td>&lt;0.5</td>
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<tr>
<td>pH</td>
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<tr>
<td>Cond.</td>
<td>54.4 mS</td>
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</table>
In the News: Inspiration Mars Fly-By 2018

**New Scientist** – 26 FEB 2013 - Taber McCallum told *New Scientist* that solid and liquid human waste products would get put into bags and used as a radiation shield...“which is an idea already under consideration by the agency's Innovative Advanced Concepts programme, ... called Water Walls, which combines life-support and waste-processing systems with radiation shielding. “

VIRAL all the way to the **Colbert Report**, etc....
Water Walls-Related Projects When We Proposed to NIAC

**Funded**

Humidity Control
JPL & Ames Air Team
Gamechanging Darrell Jan
TRL-4

Volatile Organic Destruction
NASA Ames+ UC Santa Cruz
NASA STTR & Ames Center
Innovation Fund
Bin Chen
TRL-3

**Proposed**

Complementary Funding

Forward Osmosis Cargo Transfer Bag
Logistics to Living
Advanced Exploration Systems
Sherwin Gormly
Michael Flynn, ARC
Scott Howe, JPL
Joe Chambliss, JSC
TRL-4

**Past Funding**

Forward Osmosis Bag
Flight Experiment for Simulated Urine
Exploration (Joshi)
Sherwin Gormly
Dan Schultz, KSC
Monica Solar, KSC
TRL-7
Current Water Walls-Related Technology Development

**Funded**

- Water Walls Architecture
  - 2012 NIAC to NASA Ames
  - Michael Flynn + Astrotecture™
  - Marc Cohen
  - Renée Matossian

- Humidity Control
  - JPL & Ames
  - Air Team Gamechanging
  - Darrell Jan
  - Michael Flynn
  - TRL-4

- Volatile Organic Destruction
  - NASA Ames + UC Santa Cruz
  - NASA STTR & Ames Center Innovation Fund
  - Bin Chen
  - TRL-3

- CO₂ Sequestration/O₂ Production
  - NASA Ames
  - Director’s Matching Grant to Sherwin Gormly
  - Rocco Mancinelli
  - BAERI
  - TRL-3

- Forward Osmosis Secondary Treatment (FOST)
  - Urine/Graywater Processing
  - Gamechanging
  - Michael Flynn
  - TRL-4

- Microbial Organic Fuel Cell
  - 2012 NASA Synthetic Biology
  - John Hogan
  - Michael Flynn
  - TRL-3

**Proposed**

**Complementary Funding**

- Forward Osmosis Cargo Transfer Bag
  - Logistics to Living
  - Advanced Exploration Systems
  - Sherwin Gormly
  - Michael Flynn, ARC
  - Scott Howe, JPL
  - Joe Chambliss, JSC
  - TRL-3

- Past Funding

  - Forward Osmosis Bag Flight Experiment for Simulated Urine
    - Exploration (Joshi)
    - Sherwin Gormly
    - Dan Schultz, KSC
    - Monica Solor, KSC
    - TRL-7
Current and Proposed Water Walls-Related Technology Development

Funded

- Water Walls Architecture
  2012 NIAC to NASA Ames
  Michael Flynn + Astrotecture™
  Marc Cohen
  Renée Matossian

- Humidity Control
  JPL & Ames
  Air Team
  Gamechangers
  Darrell Jan
  TRL-4

Proposed

- Nitrogen Economy/Module Sizing
  Astrotecture™ + BAERI
  NASA SBIR Proposal
  Rocco Mancinelli
  Marc Cohen
  Renée Matossian
  TRL-2

- CO₂ Sequestration/O₂ Production
  NASA Ames
  Director's Matching Grant to Sherwin Gormly
  BAERI
  Rocco Mancinelli
  TRL-3

- 3D Food Printing from Algae & Spirulina
  Astrotecture™
  2013 NIAC Step A
  Michelle Terfelsky
  Marc Cohen
  Rocco Mancinelli
  TRL-2

Complementary Funding

- Forward Osmosis Cargo Transfer Bag
  Logistics to Living
  Advanced Exploration Systems
  Sherwin Gormly
  Michael Flynn, ARC
  Scott Howe, JPL
  Joe Chambliss, JSC
  TRL-3

- Past Funding

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  Dan Schultz, KSC
  Monica Solor, KSC
  TRL-7

- Microbial Organic Fuel Cell
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  John Hogan
  Michael Flynn
  TRL-3

- Secondary Effluent Treatment proposal to the Calif. Energy Commission
  Environmental/Energy R&D
  Astrotecture™
  Sherwin Gormly
  Marc Cohen
  Rocco Mancinelli
  TRL-2

- Volatile Organic Destruction
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