Strategic Research to Enable NASA’s Exploration Missions Conference
Cleveland, 22-24 June, 2004

Human Support Technology
Research, Development & Demonstration

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Eugene Trinh
NASA Headquarters
A Journey to Inspire, Innovate, and Discover

• The Human Support Technology research, development, and demonstration program addresses the following areas at TRL 1 through 6:
  - Advanced Power and Propulsion
  - Cryogenic fluid management
  - Closed-loop life support and Habitability
  - Extravehicular activity systems
  - Scientific data collection and analysis
  - Planetary in-situ resource utilization
Human Support Technology Program

Overview

Program Goal

- Our single purpose is to reduce the human support systems' development risks to an acceptable level
  - The risks we address are documented in the Bioastronautics Critical Path Roadmap and fall into three categories:
    - Risks to the safety and health of the crew and mission success due to the hazardous environment, autonomy, and isolation
    - Risks to the affordability of the missions by requiring excessive logistical support for the humans in terms of buffers, critical system resources, and non-regenerative supplies
    - Risks to the human support systems in terms of the ‘ilities’ (operability, reliability, maintainability, etc.)
  - Each risk is further characterized by research enabling questions (Bioastronautics Critical Path Roadmap - BCPR)

- Acceptable mitigation through development of products that answer the enabling questions is required for all of the types of risks
### AHST Risk Rating Criteria for System Performance Risks

<table>
<thead>
<tr>
<th>Rating</th>
<th>Considerable potential for improvement in efficiency in many areas, or proposed missions may be infeasible without improvements.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Considerable potential for improvement in efficiency in a few areas</td>
</tr>
<tr>
<td></td>
<td>Minimum or limited potential for improvement in efficiency.</td>
</tr>
</tbody>
</table>

### BCPR Risks relevant to HST

<table>
<thead>
<tr>
<th>RISK NUMBER</th>
<th>Theme</th>
<th>Discipline</th>
<th>Risk Category</th>
<th>ISS (1yr)</th>
<th>Moon (30d)</th>
<th>Mars (30m)</th>
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<tbody>
<tr>
<td>7</td>
<td>HHC</td>
<td>Env Health</td>
<td>Define Acceptable Limits for Trace Contaminants in Air and Water</td>
<td>G</td>
<td>Y</td>
<td>R</td>
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<tr>
<td>29</td>
<td>BH&amp;P</td>
<td>SHFE</td>
<td>Mismatch between Crew Cognitive Capabilities and Task Demands</td>
<td>G</td>
<td>G</td>
<td>R</td>
</tr>
<tr>
<td>36</td>
<td>AHST</td>
<td>AEMC</td>
<td>Monitor Air Quality</td>
<td>Y</td>
<td>R</td>
<td>R</td>
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<tr>
<td>37</td>
<td>AHST</td>
<td>AEMC</td>
<td>Monitor External Environment</td>
<td>Y</td>
<td>R</td>
<td>R</td>
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<tr>
<td>38</td>
<td>AHST</td>
<td>AEMC</td>
<td>Monitor Water Quality</td>
<td>Y</td>
<td>R</td>
<td>R</td>
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<tr>
<td>39</td>
<td>AHST</td>
<td>AEMC</td>
<td>Monitor Surfaces Food and Soil</td>
<td>Y</td>
<td>R</td>
<td>R</td>
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<tr>
<td>40</td>
<td>AHST</td>
<td>AEMC</td>
<td>Provide Integrated Autonomous Control of Life Support Systems</td>
<td>G</td>
<td>Y</td>
<td>R</td>
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<tr>
<td>41</td>
<td>AHST</td>
<td>AEVA</td>
<td>Provide Space Suits and Portable Life Support Systems</td>
<td>G</td>
<td>Y</td>
<td>R</td>
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<tr>
<td>42</td>
<td>AHST</td>
<td>AFT</td>
<td>Maintain Food Quantity and Quality</td>
<td>Y</td>
<td>G</td>
<td>R</td>
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<tr>
<td>43</td>
<td>AHST</td>
<td>ALS</td>
<td>Maintain Acceptable Atmosphere</td>
<td>G</td>
<td>Y</td>
<td>R</td>
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<tr>
<td>44</td>
<td>AHST</td>
<td>ALS</td>
<td>Maintain Thermal Balance in Habitable Areas</td>
<td>G</td>
<td>Y</td>
<td>R</td>
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<tr>
<td>45</td>
<td>AHST</td>
<td>ALS</td>
<td>Manage Waste</td>
<td>G</td>
<td>Y</td>
<td>R</td>
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<tr>
<td>46</td>
<td>AHST</td>
<td>ALS</td>
<td>Provide and Maintain Bioregenerative Life Support Systems</td>
<td>G</td>
<td>Y</td>
<td>R</td>
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<tr>
<td>47</td>
<td>AHST</td>
<td>ALS</td>
<td>Provide and Recover Potable Water</td>
<td>G</td>
<td>Y</td>
<td>R</td>
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<tr>
<td>48</td>
<td>AHST</td>
<td>SHFE</td>
<td>Inadequate Mission Resources for the Human System</td>
<td>Y</td>
<td>R</td>
<td>R</td>
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<tr>
<td>49</td>
<td>AHST</td>
<td>SHFE</td>
<td>Mismatch between Crew Physical Capabilities and Task Demands</td>
<td>G</td>
<td>Y</td>
<td>R</td>
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<tr>
<td>50</td>
<td>AHST</td>
<td>SHFE</td>
<td>Mis-assignment of Responsibilities within Multi-agent Systems</td>
<td>Y</td>
<td>Y</td>
<td>R</td>
</tr>
</tbody>
</table>
Human Support Technology Program
Research and Development Content

ADVANCED ENVIRONMENTAL MONITORING & CONTROL
EXTRA-VEHICULAR ACTIVITIES TECHNOLOGY
ADVANCED LIFE SUPPORT
ADVANCED INTEGRATION MATRIX
SPACE HUMAN FACTORS
CONTINGENCY RESPONSE TECHNOLOGIES
  - FIRE PREVENTION, DETECTION, AND SUPPRESSION
  - IN-SITU FABRICATION AND REPAIR
In Situ RESOURCE UTILIZATION for HUMAN SUPPORT
LOW-GRAVITY and EXPLORATION RESEARCH
  - ADVANCED MATERIALS RESEARCH
  - QUANTUM TECHNOLOGIES for EXPLORATION
  - MULTIPHASE FLOW TECHNOLOGIES
Advanced Life Support

- Duplicate the functions of the Earth in terms of human life support
- Without the benefit of the Earth’s large buffers --- oceans, atmosphere, and land masses
- Question is one of how small can the requisite buffers be and yet maintain extremely high reliability over long periods of time in a hostile environment
- Space-based systems must be small, therefore must exercise high degree of control
- Long-duration missions dictate regenerative systems --- minimize re-supply
### Parameters for Human Life Support Across Mission Scenarios

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Duration (Human Tended)</strong></td>
<td>7 – 14 days (Roundtrip)</td>
<td>1 – 5 days</td>
<td>1 – 18 months</td>
<td>12 – 24 months (Roundtrip)</td>
<td>1 – 45 days</td>
<td>17 – 20 months</td>
<td>1 – 7 days</td>
</tr>
<tr>
<td><strong>Air Revitalization</strong></td>
<td>Open</td>
<td>Open</td>
<td>Closed</td>
<td>Closed</td>
<td>Open</td>
<td>Closed ISRU</td>
<td>Open</td>
</tr>
<tr>
<td><strong>Water Recovery</strong></td>
<td>Collection and Storage</td>
<td>Collection and Storage</td>
<td>Closed ISRU</td>
<td>Closed</td>
<td>Collection and Storage</td>
<td>Closed ISRU</td>
<td>Collection and Storage</td>
</tr>
<tr>
<td><strong>Waste Management</strong></td>
<td>Stored</td>
<td>Stored</td>
<td>Volume Reduction</td>
<td>Volume Reduction</td>
<td>Volume Reduction</td>
<td>Volume Reduction</td>
<td>Stored</td>
</tr>
<tr>
<td><strong>Food Systems</strong></td>
<td>Conventional Stored</td>
<td>Conventional Stored</td>
<td>Conventional Stored with Fresh Food Augmentation</td>
<td>Extended Shelf Life with Fresh Food Augmentation</td>
<td>Extended Shelf Life</td>
<td>Extended Shelf Life with Fresh Food Augmentation</td>
<td>Extended Shelf Life</td>
</tr>
<tr>
<td><strong>Thermal Systems</strong></td>
<td>LP-BR</td>
<td>LP-DR</td>
<td>HP-DR</td>
<td>HP-DR</td>
<td>LP-BR</td>
<td>HP-DR</td>
<td>LP-BR</td>
</tr>
<tr>
<td><strong>System Configuration</strong></td>
<td>System A</td>
<td>System A</td>
<td>System C</td>
<td>System B</td>
<td>System A</td>
<td>System C</td>
<td>System A</td>
</tr>
</tbody>
</table>

- Closed Air is 75% by Mass
- Closed Water is 90% by Mass
- ISRU – Investigate and utilize as appropriate
- Regenerative Systems will be selected over consumable systems

**System A:** Short-duration, micro-g  
**System B:** Long-duration, micro-g  
**System C:** Long-duration, planetary surface, partial-g

**HST-Cleveland 22 June 2004 ET/RC**
Exploration Timeline


- First Uncrewed CEV Flight
- 1st Crewed CEV Flight
- 1st Human Mission to Moon
- Lunar landing outpost
- Last year for lunar landing

CEV ECLSS Tech Test System A

- 6 year prime contractor lead-time

Lunar Outpost Tech. Test System B&C

- 6 year prime contractor lead-time

Lunar Outpost Bioregenerative Test System C

- 6 year prime contractor lead-time
## Life Support Requirements

### Mass Breakdown

(Per Person-Day)

<table>
<thead>
<tr>
<th>DAILY INPUTS - NOMINAL</th>
<th>kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen</td>
<td>0.84</td>
</tr>
<tr>
<td>Food Solids</td>
<td>0.62</td>
</tr>
<tr>
<td>Water in Food</td>
<td>1.15</td>
</tr>
<tr>
<td>Food Prep Water</td>
<td>0.79</td>
</tr>
<tr>
<td>Drink</td>
<td>1.62</td>
</tr>
<tr>
<td>Hand/Face Wash Water</td>
<td>1.82</td>
</tr>
<tr>
<td>Shower Water</td>
<td>5.45</td>
</tr>
<tr>
<td>Clothes Wash Water</td>
<td>12.50</td>
</tr>
<tr>
<td>Dish Wash Water</td>
<td>5.45</td>
</tr>
<tr>
<td>Flush Water</td>
<td>0.50</td>
</tr>
</tbody>
</table>

**TOTAL** 30.74 kg

### DAILY OUTPUTS - NOMINAL

<table>
<thead>
<tr>
<th>kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Dioxide</td>
</tr>
<tr>
<td>Respiration and Perspiration Water</td>
</tr>
<tr>
<td>Urine</td>
</tr>
<tr>
<td>Feces Water</td>
</tr>
<tr>
<td>Sweat Solids</td>
</tr>
<tr>
<td>Urine Solids</td>
</tr>
<tr>
<td>Feces Solids</td>
</tr>
<tr>
<td>Hygiene Water</td>
</tr>
<tr>
<td>Clothes Wash Water</td>
</tr>
<tr>
<td>Clothes Wash</td>
</tr>
<tr>
<td>Latent Water</td>
</tr>
<tr>
<td>Other Latent Water</td>
</tr>
<tr>
<td>Dish Wash Water</td>
</tr>
<tr>
<td>Flush Water</td>
</tr>
</tbody>
</table>

**TOTAL** 30.74 kg

**5.02 - 30.74 kg per person-day**

**11.3 Metric Tons Per Person-Year**
Advanced Life Support

Commander Lousma replaces ARS LiOH canisters on middeck
S82-28921 03/31/82

Mission Pilot Ken Bowersox repairing the Regenerative Carbon Dioxide Removal System wiring.
07/09/92 STS050-20-012

Mass Savings Using a Regenerative Physicochemical Subsystem:
Shuttle Regenerable Carbon Dioxide Recovery System (RCRS)

- LiOH (Conventional CO2 Removal)
  108 Canisters, 635 kg
- RCRS (Regenerable CO2 Recovery System)
  226 kg

Length of Mission (days)

Subsystem Mass Requirement (kg)

0 100 200 300 400 500 600 700

0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Drivers for Water Purification Technologies:

**Closure**
- Recovery projected to be 80% of the recycled water. Water recovery from brine essential.

**Power**
- Current baseline is power consuming.

**Expendables**
- ISS system will require ~ 400 kg filters/year

**Variable Gravity Compatibility**
- *Fluids management issues pertinent to system performance in variable gravity*
Advanced Environmental Monitoring & Control (AEMC)

Goals and Objectives

- **Intelligent Monitoring and Control of Life Support Systems** through focused system analysis, simulation and transport modeling

- **TRL 6 Sensor Technologies for human health and process control:**
  - Internal (I), for micro and/or reduced gravity environments:
    - Sample Acquisition and Handling optimized for multiphase (i.e., gas, liquid, solid) behavior
    - Monitoring Air, Water, Surface, Food and Soil Quality
    - Monitoring Air, Water, Surface, Food and Soil Microbial Safety
  - External (E) EVA and/or on Planetary Surfaces environment hazards monitoring (e.g., reactive chemicals, erosive dust)
    - I/E Hardware/Software Diagnostic Signatures (leakage, acoustic signals) for Replacement or Repair
    - I/E Particulates and Leak detection

- **Tools for establishing Exploration Chemical/Microbial requirements**
  - Contamination acceptability limits and monitoring requirements

- **Miniaturization to reduce mission resource requirements**
  - Maintain high capabilities and sensitivities, while simplifying for robust design
Advanced Extravehicular Activity

• EVA is required for all phases/spirals of the Vision, both in-space and planetary
• Supporting the human outside the protective environment of the vehicle or habitat requires an integrated EVA System
• A new EVA suit/system will be required to support this new initiative
  – The current EVA suit is over 25 years old and is facing significant obsolescence issues
  – The current EVA suit is not compatible with the planetary environments of either the Moon or Mars and does not support the logistical requirements of long term missions
• Development of a new EVA suit/system requires technology advancements similar to those required in the development of a new space vehicle
The TΦFFy Project will conduct a robust research program to address microgravity fluid physics issues associated with Flow Boiling, Condensation, Phase Separation, and System Stability of the liquid metal-based Rankine Power Conversion Systems. The project will include concept development and normal gravity testing, reduced gravity aircraft flight campaigns and flight experiment definition and development.
In-Situ Resource Utilization Technologies for Mars Life Support

Self-Sufficiency Options for Life Support

Complete regeneration
No leaks
Total closure (100%)

Relatively relaxed closure and leakage requirements, reliance on local resources (ISRU)

Design Drivers are
- Reduced mass and power
- Increased safety and reliability

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Fire Prevention, Detection, and Suppression

- Prevention is the first line of defense against fires in any vehicle design
  - Crew Exploration Vehicle, Habitat, EVA systems
- Acceptance criteria for material flammability in reduced gravity is generally unknown
  - Current methods are thought to be conservative but …
  - Margin of safety is unknown and varies with gravity level
  - Over-design based on presumed material flammability increases system mass
- Material flammability risks must be considered in the selection of atmospheres for exploration vehicles and habitats
- False positive (nuisance) alarms on ISS require crew action and reduce confidence in fire detection and suppression (FDS) system
- Spacecraft fire suppression and response based on terrestrial experience and techniques
  - Limited incorporation of fire characteristics in reduced gravity
- Suppressant effectiveness for reduced gravity fire scenarios hasn’t been quantified

- Material flammability assessment requirements are written into vehicle specifications
- Performance of advanced detection and suppression systems is insufficient for down-select/design using relevant low- and partial-gravity data
In Situ Freeform Fabrication Technologies

Fused Deposition Modeling

ABS
PC
PPSF
Al2O3
Si3N4

Electron Beam Freeform Fab

Aluminum
Titanium
Alloys

Ti-6Al-4V

In Situ SFF Deliverables

<table>
<thead>
<tr>
<th>Project Plan Summary</th>
<th>Collaborators</th>
<th>FY '05</th>
<th>FY '06</th>
<th>FY '07</th>
<th>FY '08</th>
<th>FY '09</th>
<th>FY '10</th>
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<tbody>
<tr>
<td>Fabrication Technologies</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>A. Combustion Synthesis Parts and Tools for</td>
<td>GRC, Purdue Univ, Col School of</td>
<td>TRL 4</td>
<td>▼</td>
<td></td>
<td></td>
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<tr>
<td>B. Electron beam Freeform Fabrication</td>
<td>LaRC, JSC</td>
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<td>TRL 3</td>
<td>TRL 5</td>
<td></td>
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</tbody>
</table>

Initial Mixture

Propagating Wave

Product

Self-Propagating High-Temp Synthesis

Refractory carbides, borides, silicides, inter-metallics, composites, FG mat'ls

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How will we conduct our Business?

• Low TRL work through competitive NRAs
  - Long lead time items
• Rapid Technology Development Teams
  - Multi-disciplinary teams with clear objectives and deliverables
  - Mature technology to TRL 6
• Directed Research
  - Focused problems

There will be a healthy balance between intramural and extramural work.
Milestone Plan

- **Project Name:** Milestone Plan
- **Project Manager:** Supervisor

**Planned** | **S** | **D** | **K** | **C** | **Code** | **Milestone**
--- | --- | --- | --- | --- | --- | ---
6/1/04 |  |  |  |  | Funding Received |  
8/3/04 |  |  |  |  | Kick-off Mtg and Req Review Completed |  
12/3/04 |  |  |  |  | Air Water Separators Development Completed |  
12/3/04 |  |  |  |  | PC-based data system Development Completed |  
12/3/04 |  |  |  |  | Reagentless Calibration Development Completed |  
12/3/04 |  |  |  |  | Reagent Packaging Subsystem Completed |  
4/30/05 |  |  |  |  | Subsystem Testing and Refinement Completed |  
6/30/05 |  |  |  |  | KC-135 Subsystem Testing Completed |  
8/3/05 |  |  |  |  | Subsystem Evaluation Review Completed |  
12/3/05 |  |  |  |  | Bubble Mitigation Tech Refined & Selected |  
12/3/05 |  |  |  |  | POA Data System Development Completed |  
12/3/05 |  |  |  |  | CSPRE Methods Selected |  
12/3/05 |  |  |  |  | Reagent Shelf-life Tests Completed |  
3/2/06 |  |  |  |  | Integrated Prototype Design Completed |  
5/3/06 |  |  |  |  | Prototype Design Review Completed |  
9/30/06 |  |  |  |  | Fabricate Integrated Prototype Fabricated |  
9/30/06 |  |  |  |  | Barcode Scheme Development |  
12/31/06 |  |  |  |  | Integrated Prototype Ground Testing Completed |  
12/31/06 |  |  |  |  | Draft QA & Operating Procedures Prepared |  
3/3/07 |  |  |  |  | KC-135 Prototype Testing Completed |  
6/3/07 |  |  |  |  | Final Report and Prototype Delivered |