Human Support Technology Research to Enable Exploration

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Go anywhere, anytime

Sustainable Planetary Surfaces
Going Beyond and Staying

Accessible Planetary Surface
Going for Visits

Earth's Neighborhood
Getting Set by Doing

Earth and LEO
Getting Ready

- Traveling out to ~1.5 AU, and beyond
- Traveling out to 1.5 AU
- Staying for 1-3 years
- Staying for indefinite periods
- Enabling sustainable scientific research
- Enabling tactical investigations
- Visiting and working on another planet

- Traveling up to 1.5 million km
- Staying for 50-100 days
- Enabling huge optical systems
- Living in deep space
- Living and working on another planet

- Space Station experience
- Solar System learning
- Technology advancements
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
Advanced Life Support

- Enabling technology for human exploration and development of space
- Long-duration missions dictate regenerative systems —— minimize re-supply
- Minimize mass, volume, power, thermal requirements
- Such systems will be replete with physicochemical and biological components
• Mission objectives drive the functional requirements of Advanced Life Support technology development.
• Systems Engineering enables R&TD efforts to meet the functional requirements the best way possible.
  - Identification and evaluation of feasible designs
  - Performance of technology/configuration trade studies
  - Optimization of operational strategies
  - Provide guidance for future R&TD efforts
Progressive Capabilities

Earth’s Neighborhood Capability
- Current launch systems
  Payload: 40mt
- In-space propulsion, Isp>1000 sec, high thrust
- Power systems, >200 w/kg
- Integrated Human/robotic capabilities
- Crew countermeasures for 100 days
- Closure of water/air systems
- Materials, factor of 9
- IVHM - Integrated Vehicle Health Monitoring

Accessible Planetary Surface Capability
- ETO $/kg (under review)
  Payload: ~100mt
- In-space propulsion, Isp>3000 sec, high thrust
- Power systems, >500 w/kg
- Robotic aggregation/assembly
- Crew countermeasures for 1-3 years
- Complete closure of air/water; options for food
- Materials, factor of 20
- Micro-/Nano- avionics

Sustainable Planetary Surface Capability
- ETO $/kg (under review)
  Payload: 100+mt
- In-space propulsion, Isp>3000 sec, high thrust
- Sustainable power systems
- Intelligent systems, orbital and planetary
- Crew countermeasures for indefinite duration
- Closure of life support, including food
- ISRU for consumables & spares
- Materials, factor of 40
- Automated reasoning and smart sensing
\* = Incorporation of food regeneration in ALS
Advanced Life Support

Partially closed Life Support System
Resupply Mass - 12,000 kg/person-year

Water 89%

Oxygen 2.5%
Food (dry) 2.2%
Crew Supplies 2.1%
Gases lost to space 2.1%
Systems Maintenance 2.1%
Water Processing

• Goal is to develop a processing system that is capable of generating potable water.
• Current baseline recycles only a fraction of the water at the cost of expendables and power.
• Future technologies (VPCAR, biological processors) have to be optimized for microgravity compatibility.
National Aeronautics and Space Administration

Air Revitalization Systems

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

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
Why Advanced CO\textsubscript{2} Removal Technologies?

- The ISS CO\textsubscript{2} removal subsystem has the highest power penalty of any ISS life support subsystem (~3200 W-hr/kg CO\textsubscript{2}). Current technology has a thermodynamic efficiency of about 3%.

- Current CO\textsubscript{2} removal & reduction technology in closed-loop mode (with Sabatier/oxygen recovery) will require ~5400 W-hr/kg CO\textsubscript{2}.

- Life scientists are calling for lower CO\textsubscript{2} levels on International Space Station.  
  - ISS requirement is 7000 ppm, compared to ~400 ppm Earth-normal  
  - Achieving lower concentrations translates directly into more energy consumption.  
  - Power will be an extremely critical resource for a Mars transit vehicle.  
  - The Mars Reference Mission would use a solar-powered transit vehicle with total estimated available power of 30 kW; 12 kW for ECLS

- Develop CO\textsubscript{2} removal technology that consumes 10x less power than current Space Station technology for same performance.  
  (or maintains substantially lower concentrations of CO\textsubscript{2} for no increase in power)
• Low pressure, low temperature process (potential for low power operation).
• Complex solids pumping or handling techniques are not required.
• The technique should not produce \( \text{CO}_2, \text{NO}_x, \text{SO}_x \), or any other undesirable oxidation byproducts (gases generated are primarily water vapor).
• The final product is a stable dried material with 1 to 3% \( \text{H}_2\text{O} \).
• The approach is fully regenerable, meaning that the process requires no consumables, only energy.
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

ISRU Technologies for Mars Life Support
Atmospheric Resources of Mars

Mars atmosphere composition
- Pressure: ~1% of Earth’s
- Temperature: 180 – 290 K (equatorial)
- Dusty, windy

Mars Pathfinder, 1997
N\textsubscript{2} Consumables / Make-up for Mars Life Support

- **Transit Leakage Losses:**
  - 0.1 kg/day leakage,
  - 260 days = 26 kg N\textsubscript{2}

- **Surface Leakage Losses:**
  - 0.1 kg/day leakage,
  - 619 days = 62 kg N\textsubscript{2}

- **Surface/Airlock Losses:**
  - 1 kg/cycle, 2 cycles/day,
  - 619 days = 1200 kg N\textsubscript{2}

- **Total Mission N\textsubscript{2} Losses:**
  - ~1.3 tonnes N\textsubscript{2} lost
  - (2x safety factor = 2.6 tonnes)

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*Figure 3-4 Fast-transit mission profile*

Integrated Test beds

Why do we need integrated test beds?

- Allows for validating a subsystem in a relevant environment
- Subsystems get exposed to off-nominal loads which allows for testing the limits that the system can effectively tolerate
- Effect of the test article on the optimal functioning of other subsystems
- Subsystems get exposed to real streams which cannot be simulated in laboratory studies
SUMMARY

- Human exploration missions are very complex and risky – duration and distance from Earth
- Integration issues are difficult to identify
- Individual technologies & systems have inherent risk
- Integration of all systems & procedures on the ground will allow risk to be more effectively managed
- Integrated procedures can be developed and validated

- Definition of “missions” provides focus for R&D
- INTEGRITY is a cost-effective way to prepare for future human exploration missions beyond low earth orbit
- INTEGRITY will facilitate:
  - Development of improved management techniques, including cost & risk estimation
  - International, Commercial, Academic partnering
  - Education & Public involvement
  - Re-invigorate NASA workforce
    - Recruiting tool

**Visitors’ viewing area**
Phase I: 15-day, 1-Person Test
March 1995

Phase II: 30-day, 4-Person Test - June 1996
Phase IIA ISS: 60-day, 4-Person Test - January 1997
Phase III: 90-day, 4-Person Test - September 19, 1997
Monitoring & Controlling the environment

- Air
- Water
- Plant chambers
- Food and Food Preparation surfaces
- Gradual buildup of toxic species
- Hazardous events
- Chemical
- Biological

Control

Sensors
Actuators

Air processor
Water processor
Gradual buildup of harmful chemical or microbials

Hazardous event such as fire or leakage

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<th>DETECTION LIMIT</th>
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<tr>
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<td>Freon 12</td>
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* microgravity combustion not shown
Ground-based Commercial technology

- High mass
- High power requirement
- High operator skill
- High capability
- May require gravity

- Lower mass
- Lower power requirement
- Low operator skill
- Low capability
- May require gravity

**Breakthroughs needed to achieve high capability and low mass/power plus autonomy**
Optimizing Size vs Capability
**AEMC Vision: Hierarchical monitoring/control**

- **Analysis Instrument**: eg GCIMS, GCMS, FTIR
  - Analyzes for almost everything
  - Complex, expensive (although low mass)
  - Probably only one on board
  - “Fill-in” covers the few things that the Analysis Instrument doesn’t cover (eg, formaldehyde, O2, CO2…)
    - eg TDL, SERS
- **Sensor is simpler, cheaper, more robust**
  - May be fixed or portable
  - Much more capable than off the shelf
  - eg Enose, Bioarray
Some Top level Issues for Wastes Processing

- **Gas-liquid Separation**
  All P/C, Bio water treatment systems
  Humidity control systems

- **Solid-liquid Interactions**
  Settling problems in Bio and P/C systems
  Optimal functioning of P/C systems

- **Thermal Control**
  Heat Rejection
  Heat Transport
Water Recovery Systems
Flight Verification Topics

- Thermal properties of thin fluid films
- Two phase flow in open chambers
- Splashing in liquid/gas boundaries
- Centrifugal separations, what occurs during start and stop events
- Pumping of saturated fluids
- Surface tension directed flow stability
Water Recovery Systems Flight Verification Topics (Cont.)

- Reaction kinetics in packed beds, effects of channeling and condensation
- Stability of packed beds during launch
- Deterioration of packed beds during operation
- Lubrication of rotating gears
Issues for Plant Growth Systems

- Delivery of adequate water and oxygen to rooting systems
- Recovery and recycling of transpired water from plant systems (typically can expect ~5 L m\(^2\)/day)
- Liquid / gas phase separation issues for both water delivery and retrieval systems
- Maintain adequate air flow around leaves and "soil" surface to offset lack of thermal stirring
Some Top level Issues that Prevail

• Particles issues in air filtration systems
  Fine particles in air treatment systems (CDRA)
  Settling issues ad clogging (Bends in systems)
  Gravity effects

• Sensors and Monitoring Systems
  Particulate pre-filtering (MCA)
  Fine particles in miniaturized monitoring systems

• Health issues associated with PM$_{10}$ and less?