EXPLORESPACE TECH
TECHNOLOGY DRIVES EXPLORATION

# *LIVE: Advanced Habitation Systems (AHS)*
# NASA Space Technology Mission Directorate

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# AHS Investments Support Multiple Strategic Outcomes and Primary Capabilities

| Thrusts | Outcomes | Primary Capabilities |
|---|---|---|
| **Go**<br>Rapid, Safe, and Efficient Space Transportation | • Develop nuclear technologies enabling fast in-space transits.<br>• Develop cryogenic storage, transport, and fluid management technologies for surface and in-space applications.<br>• Develop advanced propulsion technologies that enable future science/exploration missions. | • Nuclear Systems<br>• Cryogenic Fluid Management<br>• Advanced Propulsion |
| **Land**<br>Expanded Access to Diverse Surface Destinations | • Enable Lunar/Mars global access with ~20t payloads to support human missions.<br>• Enable science missions entering/transiting planetary atmospheres and landing on planetary bodies.<br>• Develop technologies to land payloads within 50 meters accuracy and avoid landing hazards. | • Entry, Descent, Landing, & Precision Landing |
| **Live**<br>Sustainable Living and Working Farther from Earth | • Develop exploration technologies and enable a vibrant space economy with supporting utilities and commodities<br>  • Sustainable power sources and other surface utilities to enable continuous lunar and Mars surface operations.<br>  • Scalable ISRU production/utilization capabilities including sustainable commodities on the lunar & Mars surface.<br>  • Technologies that enable surviving the extreme lunar and Mars environments.<br>  • Autonomous excavation, construction & outfitting capabilities targeting landing pads/structures/habitable buildings utilizing in situ resources.<br>• Enable long duration human exploration missions with Advanced Life Support & Human Performance technologies. | • Advanced Power<br>• In-Situ Resource Utilization<br>• Advanced Thermal<br>• Advanced Materials, Structures, & Construction<br>• Advanced Habitation Systems |
| **Explore**<br>Transformative Missions and Discoveries | • Develop next generation high performance computing, communications, and navigation.<br>• Develop advanced robotics and spacecraft autonomy technologies to enable and augment science/exploration missions.<br>• Develop technologies supporting emerging space industries including: Satellite Servicing & Assembly, In Space/Surface Manufacturing, and Small Spacecraft technologies.<br>• Develop vehicle platform technologies supporting new discoveries.<br>• Develop transformative technologies that enable future NASA or commercial missions and discoveries | • Advanced Avionics Systems<br>• Advanced Communications & Navigation<br>• Advanced Robotics<br>• Autonomous Systems<br>• Satellite Servicing & Assembly<br>• Advanced Manufacturing<br>• Small Spacecraft<br>• Rendezvous, Proximity Operations & Capture |

## Major AHS Interfaces to Other Capabilities

**In Space Transportation SCLT**
AHS technology improvements in $CO_2$ reduction ($O_2$ recovery), food, and other AHS areas along with increased reliability, reduce cargo mass ~5 MT x propulsion gear ratio

**Entry Descent and Landing SCLT**
AHS technology improvements in $CO_2$ reduction ($O_2$ recovery) and food technologies reduce landed cargo mass

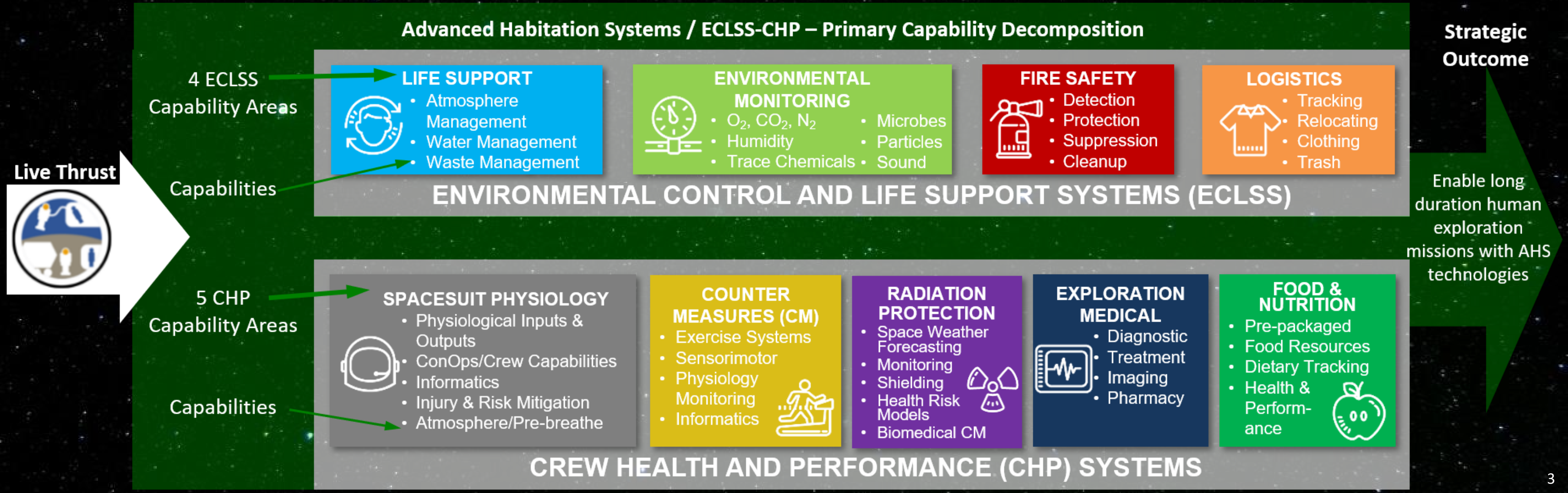
**ISRU SCLT**
AHS investments in $CO_2$ reduction ($O_2$ recovery), gas–phase contaminant separations, water contaminant removal, and monitoring are extensible to ISRU resource production

**AHS capabilities captured in NASA taxonomy in TX06 & TX07**
Largest technology challenges: $CO_2$ reduction ($O_2$ recovery), in-flight food nutrition, GCR shielding, and reliability (spares mass)

**Autonomous Systems SCLT**
Advances in robotics and autonomy support AHS system maintenance/operation to prepare for crew arrival, allow crew to focus on science, and allow ECLSS processing during uncrewed periods (smaller/lower power systems)

# Advanced Habitation Systems Capability Areas and Capabilities

- AHS capabilities keep astronauts healthy and productive while living in space and planetary vehicles
- Broadly characterized into vehicle Environmental Control and Life Support Systems (ECLSS) and Crew Health and Performance (CHP) Capability Areas
  - Capability Areas are further decomposed to capabilities and sub-capabilities to define gaps
  - Useful to discuss state of the art and envisioned futures for each capability area/capability
  - LIVE Thrust will evolve to include EVA suits In the future



# Mission Characteristics That Drive AHS Capability Needs

- Mission Duration
  - Crew consumables and waste generation are fixed kg/crew-day
  - Duration needs to be long enough to offset system closure mass
- Crew safety and mission success goals
  - Longer duration increases risk
  - Increased Probability of Sufficiency (POS) - increase spares & certainty of spares life
  - Increased ability for Earth independent diagnostics and repair
- Microgravity vs Surface
  - μg adds complexity to address liquid-gas-solids separation and other phenomena
- Frequent planned EVAs
  - Loss of water and oxygen (less available for recycling)
  - Increased crew fatigue and injury risk
  - Reduced cabin pressure to reduce pre-breathe time, impacts 14.7 psia/23% $O_2$ systems
  - Mitigating surface dust from EVA
- Number of crew members
  - Crew consumables are fixed kg/d
- Planetary protection and science integrity
  - Monitoring/sterilization/treatment/containment adds mass
- Long uncrewed periods
  - Adds mass to prevent or recover from microbial upset
  - Importance of habitat autonomy and robotic caretaking increases
- Availability of In-Situ Resource Utilization (ISRU) products (water and gases)
  - Influences recycling break-even point, possible ISRU-ECLS sensor and processor commonalities


# AHS Envisioned Future Decomposition by Capability Area

(Mission need)
- L = Lunar surface
- T = Transit to Mars
- M = Mars surface

## LIFE SUPPORT

- Reliable long-duration life support with Earth independent diagnostics and repair (L,T,M)
- >20% reduction in spares and installed mass (T)
- Enable single missions >800 days w/o resupply (T)
- Repeated missions with >9 months dormancy (L,T,M)
- >75% oxygen recovery at 2 mm-Hg $CO_2$ (T)
- High pressure oxygen recharge for EVA (L,M)
- >98% water recovery (L,T,M)
- Remove respirable lunar and Mars dust (L,M)
- Planetary protection compatible ECLSS venting (M)

## ENVIRONMENTAL MONITORING

- Identify and quantify chemical (>12 water, >33 air) and microbial species in-mission with out sample return (L,T,M)
- Ability to detect unknown constituents (T,M)
- Distinguish between fire, habitat dust, and surface dust particles (L,M)
- Support forward and backward planetary protection detection (both microbial and non-DNA techniques) (M)

## FIRE SAFETY

- Test-verified partial gravity flammability characteristics and countermeasures (L,M)
- ECLSS compatible fire suppression (L,T,M)
- Reduce post fire clean-up time (L,T,M)
- Common fire safety strategy across element architectures (L,T,M)

## LOGISTICS

- Jettison >90% of trash mass during Mars transit (T)
- Mars trash disposal compatible with planetary protection (M)
- In-flight autonomous logistics (L,T,M)
- Reducing clothing and wipes mass by >50% (L,T,M)
- Clothing flammability (and other non-metallics) >36% O2 (L,M)

## SPACESUIT PHYSIOLOGY

- 100% of tasks within human performance (L,T,M)
- Predict and mitigate decompression sickness for surface EVA (L,M)
- Predict and mitigate suited injury (L,M)
- 6 Major physiological informatics parameters provided in-suit to enable real time self-assessment or loss of communication areas (L,M)

## COUNTER-MEASURES

- Reduce mass and volume (L,T,M)
- Maintain/monitor fitness in-flight to enable unassisted landing egress & EVA (L,T,M)
- Validated lunar and Mars fitness standards (L,M)

## RADIATION PROTECTION

- 24-hr prediction of solar storm duration and intensity to >90% (L,T,M)
- High energy neutron detectors (L,T,M)
- Earth independent monitoring/forecasting (T,M)
- GCR shielding (T,M)

## EXPLORATION MEDICAL

- In-mission diagnostics and treatment for 100 of 120 medical risk conditions (L,T,M)
- Autonomous medical skill and & decision support systems (T, M)
- Integrated data architecture (L,T,M)

## FOOD & NUTRITION

- 100% of nutrient stability >5-year shelf life (T,M)
- Food acceptability >90% (L,T,M)
- <30% launched water content (T,M)
- Exploration counter-measure in-mission nutrition intake monitoring (L,T,M)

# Advanced Habitation Systems State-of-the-Art by Capability Area

## LIFE SUPPORT

- ISS life support demonstrations have identified required system reliability issues – fixes in work
- ~21,700 kg spares + food, 4 crew x 860days x Probability of Sufficiency (POS)=0.99
- Resupply every 2-6 months
- Nearly uninterrupted use of wetted systems
- ~47% oxygen recovery at 2 mm-Hg $CO_2$
- No in-flight EVA oxygen recharge capability
- ~93% water recovery
- HEPA filters require frequent manual cleaning

## ENVIRONMENTAL MONITORING

- Detailed gas/water chemical, microbial identification, and particle analysis only with samples returned to ground
- Major air constituents & limited targeted trace gases in flight
- Water analysis limited to total organic carbon
- Culture based microbial sample return, DNA sequencing limited to surface microbes
- Limited particle measurement capability demonstrated
- Mass intensive passive acoustic adsorption/damping

## FIRE SAFETY

- Partial understanding of large ug fire propagation and properties
- Very limited knowledge of partial gravity fire properties
- Obsolete monitoring
- Cleanup by depress/repress
- Limited mask emergency response
- $CO_2$ based fire extinguishers

## LOGISTICS

- Manual trash compaction, short storage time, module level jettison only
- No planetary protection compliance for waste disposal
- Manual & limited In-flight autonomous logistics tracking
- Disposable & flammable clothing, towels, & wipes

## SPACESUIT PHYSIOLOGY

- Physiological inputs/outputs adequately known for ISS EVA only
- Limited informatics; primarily ground-monitored
- Ground, ISS, and Apollo suit injuries occur (27 injury mechanisms identified)
- Prebreathe protocols for 14.7 and 10.2 psia microgravity only

## COUNTER-MEASURES

- 3+ large devices, large mass
- Returning crew egress from landing vehicle requires ground team assistance
- Exercise planning and monitoring via ground
- Limited sensorimotor countermeasures

## RADIATION PROTECTION

- Mature shielding design tools
- Reconfigurable SPE shielding & limited GCR shielding
- Crew radiation monitoring
- Short term space weather using earth centric assets

## EXPLORATION MEDICAL

- Evacuate <8 hrs
- Resupply 2-3 months
- Limited in-mission diagnostic, treatment
- Ground medical data & decision support systems

## FOOD & NUTRITION

- ~1.5 year shelf life, fresh food resupply every 2-3 months
- Only ~215 standard food items, µg plant experiments
- ~47% launched water content
- In-mission nutrient intake monitoring in development

# Advanced Habitation Systems – Examples of Current Investments (1/2)

(There are many SBIR/STTR/ECI/ECF/CIF/STRG investments supporting lower TRL innovation not list below)

## LIFE SUPPORT


Advanced Oxygen Generator


Urine Brine Processor Assembly


Compact Toilet System

- Long duration reliability testing on ISS & ground
- Oxygen generation improved maintainability
- High Pressure $O_2$ EVA resupply
- Sabatier enhancements
- 4-bed, Thermal amine, and CapiSORB $CO_2$ scrubbers
- Bosch $CO_2$ Reduction
- Methane Pyrolysis
- Hydrogen Separation
- Medical oxygen
- Long life condensing heat exchangers
- Wetted systems dormancy tolerance and recovery
- $I_2$ and Ag water biocides
- Partial-g water systems
- Compact toilet and lower mass fecal containers
- Urine pretreat storage and delivery
- Trace gas catalytic oxidizer
- Scroll & cyclone particulate filtration

## ENVIRONMENTAL MONITORING


SAM-2


MiniTOCA


Airborne Particle Monitor


MinIon/ Biomole

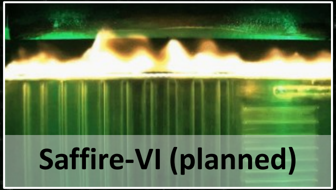
- Long duration reliability testing on ISS
- MinIon-DNA sequencer
- Air and water microbial sequencing sample preparation
- Air Particle Monitor
- Miniature air monitor
- Spacecraft Atmosphere Monitor (SAM)
- Potable Water Total Organic Carbon Analyzer
- Spacecraft Water Impurities Monitor (SWIM)
- Acoustic monitors, low mass acoustic materials, and quiet fan modeling

## FIRE SAFETY

- Anomaly Gas Analyzer
- Water Spray mist fire extinguisher
- Smoke cleanup device
- Improved realistic fire training
- Saffire VI on Cygnus – ug (varies ~2000-3700 $cm^2$)
- CLPS partial-g (~150 $cm^2$)
- Blue Origin partial-g (~40 $cm^2$)
- Partial gravity drop tower spin test and development of non-spin capability


Drop tower spin rig


Combustion Product Monitor

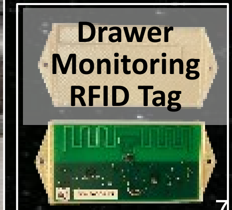

Saffire-VI (planned)

## LOGISTICS

- Trash Compactor Processing System (TCPS)
- Trash-to-gas / OSCAR
- RFID Enabled Autonomous Logistics Management (REALM)
- Long wear clothing / laundry
- In-flight disinfectant solution generation for reusable wipes
- ISS Bishop airlock jettison bag
- Exploration trash jettison trade study
- Lunar vacuum cleaner testing


REALM-2 on Astrobee


TCPS Tile

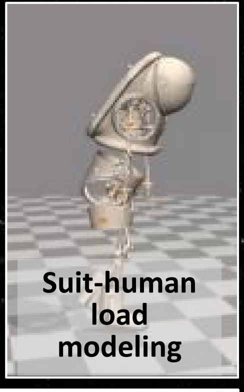

Drawer Monitoring RFID Tag

# Advanced Habitation Systems – Examples of Current Investments (2/2)

(There are many SBIR/STTR/ECI/ECF/CIF/STRG investments supporting lower TRL innovation not list below)

## SPACESUIT PHYSIOLOGY

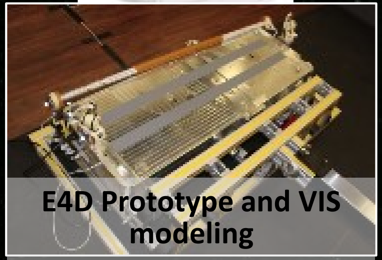
- Suit-independent analytics tool
- Suit user injury tracking system
- MEDPRAT
- Contingency $CO_2$ limits
- Crew state model & risk tool
- Physical & cognitive EVA simulations
- Personalized EVA informatics and decision support
- JARVIS informatics display
- Exploration Atmospheres pre-breathe validation
- Decompression sickness risk tool


Suit-human load modeling


Real-time NBL-suit expired CO2 informatics

## COUNTER-MEASURES

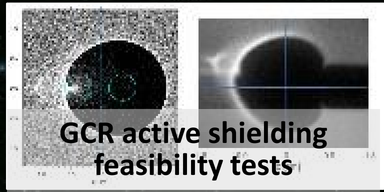
- Exploration exercise device (E4D) development
- Vibration isolation systems
- No-Treadmill (T2) exercise ISS evaluation
- EVA muscle/aerobic standards
- EPIC informatics tools
- Heart rate/blood pressure/OCT monitors
- In-flight sensorimotor balance trainer validation
- In-flight bone assessment

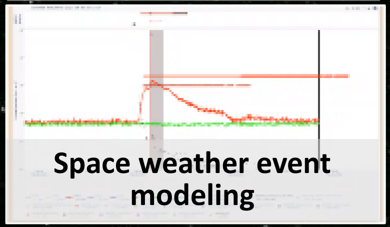

E4D Prototype and VIS modeling

## RADIATION PROTECTION

- Lunar/Mars space weather forecasting
- Solar particle event (SPE) forecasting ML
- HERMES Gateway suite
- Orion-HERA
- EVA-ARD
- Active electrostatic shielding modeling study
- ISS-RAD and Adv Neutron Spectrometer
- Bio-dosimetry Polaris Project


HERA


GCR active shielding feasibility tests


Space weather event modeling

## EXPLORATION MEDICAL

- Impact analysis tool
- Exploration medical risk database
- Medical levels of care tool
- Handheld microscope
- Multi Med device
- Mini IntraVenous-fluid Generation (mini-IVGen)
- HoloLens MedTED
- Integrated Sim test bed
- Exploration Formulary
- Stability/toxicity study
- Automated med inventory tool dev
- CHP Integrated Data Architecture

## FOOD & NUTRITION

- Crew Health And Performance Analog (CHAPEA)
- Ohalo/ROSbio plant growth facility
- Hurdle processing/ storage/temp study
- BPS crop evaluations
- CUBES & Synthetic Bio
- NextSTEP Xroots aeroponics
- Deep Space Food Challenge


CHAPEA


Synthetic nutrient production

# Advanced Habitation Systems – SCLT Top Priorities – indicated by white text

(Gray text goals are still important but not a top priority)

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# Acronyms

- AHS – Advanced Habitation Systems
- ARD – Active Radiation Dosimeter
- CHAPEA – Crew Health and Performance Analog
- CHP – Crew Health and Performance
- CIF – Center Innovation Fund
- CM – Counter Measures
- E4D – Exploration Exercise Device
- ECI – Early Career Initiative
- ECF – Early Career Faculty
- ECLS - Environmental Control and Life Support
- ECLSS – Environmental Control and Life Support System
- EPIC – Exercise and Performance Information Console
- EVA – Extravehicular Activity
- GCR – Galactic Cosmic Rays
- HEPA – High Efficiency Particulate Air
- HERA - Hybrid Electronic Radiation Assessor
- HERMES - Heliophysics Environmental and Radiation Measurement Experiment Suite
- ISRU – In-situ Resource Utilization
- ISS – International Space Station
- IVGen – IntraVenous Generation
- JARVIS – Joint Augmented Reality Visual Informatics System
- MEDPRAT - Medical Extensible Dynamic Probabilistic Risk Assessment Tool
- MedTED – Medical Technology Demonstration
- ML – Machine Learning
- NBL – Neutral Buoyancy Laboratory
- OCT - Optical coherence tomography
- OSCAR - Orbital Syngas/Commodity Augmentation Reactor
- POS – Probability of Sufficiency
- RAD - Radiation Assessment Detector
- REALM – RFID Enabled Autonomous Logistics Management
- SAM – Spacecraft Atmosphere Monitor
- SBIR – Small Business Innovative Research
- SCLT – System Capability Leadership Team
- SPE – Solar Particle Event
- STRG – Space Technology Research Grants
- STTR – Small Business Technology Transfer
- SWIM – Spacecraft Water Impurities
- TCPS – Trash Compactor Processing System
- TRL – Technology Readiness Level