NASA Technology Development Entries for ISECG TAT (Technology Assessment Team) - Rev 5/4/11

Agency	Discipline	Title	Description	Performance Characteristics	ISS Demo
NASA	Advanced Propulsion	Electric Propulsion & Power Processing	• Solar electric vehicles are required for the economical transport of crew from LEO to a NEO and cargo from LEO to Mars because they can significantly reduce the number of heavy lift launches required for the missions. They also increase crew safety by providing multiple engines for more robust off-nominal operations and decrease sensitivity to mass growth. • A propulsion system requiring nominally 300 kW of electrical power is required for these missions; likely an array of 30 kW or 50 kW thrusters will be used. Technology development is required because the state-of-the-art is 7 kW thrusters. In addition to designing, building, and testing high power thrusters, technology development is required for power processing and propellant storage. Determining the performance of the integrated system is needed to design the subsystems since the required performance represents such a large increase relative to the state-of-the-art. Data of interest includes the interaction of the thruster plumes with the solar array as they spiral through the Van Allen belts, including the effects on pointing stability and array degradation.	• High power (~400 kW power at beginning of life) • High thrust (~2000 seconds Isp) • Low mass (< ~45 mt wet mass with mass growth allowance to fit within a 100 mt launch vehicle) • Note: this requires an increase of ~600% in thrust-to-weight and ~500% in power density compared to the state-of-the-art.	Hall, Ion, VASIMR
NASA	Advanced Propulsion	Nuclear Thermal Propulsion (NTP) Engine	• Nuclear thermal propulsion (NTP) was identified by NASA's DRM 5.0 as required for economical transport of crew to Mars because it provides the high thrust and high specific impulse needed to significantly reduce launch mass for the heavy payloads identified. The NTP system would also reduce the cost of transits to the Moon, E-M L1, NEOs, and orbital missions to Mars and its moons. The NTP system consists of two principal components. The first component is the primary NTP stage that includes the nuclear thermal rocket engines, RCS, avionics, auxiliary power, long duration CFM for the LH2 propellant and docking capability. The second component is an integrated saddle truss and LH2 drop tank assembly connecting the NTP stage to the mission payload that provides additional propellant storage for a wide range of mission and payload needs. • NTP has strong synergy with chemical rocket hardware and can use the same LH2 tanks in the launch vehicle. It can be developed in a timely manner at reasonable cost and can service both NEOs and Mars with same vehicle components helping to reduce overall cost.	• Nuclear thermal propulsion (NTP) was identified by NASA's DRM 5.0 as required for economical transport of crew to Mars because it provides the high thrust and high specific impulse needed to significantly reduce launch mass for the heavy payloads identified. The NTP system would also reduce the cost of transits to the Moon, E-M L1, NEOs, and orbital missions to Mars and its moons. The NTP system consists of two principal components. The first component is the primary NTP stage that includes the nuclear thermal rocket engines, RCS, avionics, auxiliary power, long duration CFM for the LH2 propellant and docking capability. The second component is an integrated saddle truss and LH2 drop tank assembly connecting the NTP stage to the mission payload that provides additional propellant storage for a wide range of mission and payload needs. • NTP has strong synergy with chemical rocket hardware and can use the same LH2 tanks in the launch vehicle. It can be developed in a timely manner at reasonable cost and can service both NEOs and Mars with same vehicle components helping to reduce overall cost.	
NASA	Avionics & Software	Advanced Software Development/Tools	• Reliable software engineering to ensure system reliability and reduce software (and hence system and mission) costs	• Increase software design productivity and reduce lifecycle software DDT&E, lowering $cost/SLOC (source line of code) - Qualification of model-based software development methods - Dynamic certification / recertification of automated software development • Ensure on-board software reliability for long-duration human missions with light-time delay • Enable verification of advanced software-based functions for: crew autonomy, autonomous systems, vehicle systems health management, and situational awareness capabilities	
NASA	Avionics & Software	Autonomous Vehicle Systems Mgmt	• Enables autonomous vehicle operations with little to no crew or ground oversight. This capability is required to ensure safe vehicle operations and monitoring at increased distances from Earth where communications time delays are present.	• Enable on-board vehicle systems management for mission critical functions at destinations with > 6 second time delay• Enable autonomous nominal operations and FDIR for crewed and un-crewed systems• Reduce crew time to sustain and manage vehicle by factor of 2x at destinations with > 6 second time delay (see Crew Autonomy sheet)• Reduce mission ops "back room engineering" requirements for distant mission support delay (see Mission Autonomy sheet)	ISS Test Bed - Yes
NASA	Avionics & Software	Common Avionics	• Developing common avionics components such as flight computers, sensors, high performance, environmentally tolerant, interoperable computing and data busses which can be utilized by multiple vehicles.	• Exceed 75% commonality of avionics components across HEFT DRM elements for reusability (on-orbit spares) and supportability • Enable up to 1/3 of Planning and Analysis software tools (used in MCC "backroom" today) to be run onboard the vehicle • Reduce power use by 30% for same processing power • Reduce avionics weight by 50% for same processing power • Improve reliability of avionics components, thereby improving crew safety and reducing logistics mass	ISS Test Bed - Yes
NASA	Avionics & Software	Crew Autonomy beyond LEO	• Autonomous system operation at a remote planetary sites provides the crew with more independence from ground operations support. Such autonomy is essential to reduce operations costs and to accommodate the ground communication delays and blackouts at distant locations.	• Enable crew nominal operation of vehicle or habitat at destinations with > 6 second time delay to ground • Enable coordinated ground and crew nominal operations at destinations with > 6 second time delay (See Mission Autonomy Sheet) • Enable crew to detect off nominal situations and put vehicle in safe configuration without ground coordination	ISS Test Bed - Yes
NASA	Avionics & Software	Mission Control Autonomy beyond LEO	• Support autonomous crew problem solving activities during remote or long-duration exploration missions, where space crew reliance on mission control is critical and dependent upon minimum reaction time. Autonomous control systems are needed to reduce operations costs for manned space flight human crew and to facilitate independence of Earth-based operations.	• Enable earth-based nominal operation of vehicle or habitat at destinations with > 6 second time delay to earth • Enable hand-off's in Mission Ops between ground and crew for operations in transit and at destinations with > 6 sec time delay • Enable Mission Ops to help crew resolve off nominal situation after detection and initial response • Enable highly efficient, small staff Mission Operations for a Crewed Missions	

NASA	Chemical Propulsion	Heavy Lift Propulsion Technology (Oxygen-Rich Staged Combustion)	• ORSC LOX/RP engine supports the Space Launch Systems (SLS) evolution to larger Payloads. ORSC LOX/RP engine has significant DDT&E risks associated with closed cycle & high system pressures (combustor / turbomachinery. - Future U.S. engine system config., and component details to be defined, possibly significantly different than RD-170 family or NK-33 [In-depth knowledge only exists within limited pockets/individuals inside the US industry]	• Capability for Hydrocarbon performance +17% Isp, +60% T/W, -30% Cost, and -75% failure rate over SOA • NASA Engine development and technology is driven by rigorous systems engineering with risk-based decision making. Lessons from previous engines (H2-fueled RS-68, J-2X, IPD; and RP-fueled RS-84, TRW-107) are incorporated.	
NASA	Chemical Propulsion	In-Space Chemical (LOX/Methane Propulsion Stage)	• An In-Space Stage, powered by a demonstrated workhorse engine, intended for boosting crew and cargo from LEO to destinations well beyond LEO • The oxygen and methane propellant combination has the potential for greater engine performance, which can result in lower vehicle mass and greater payload-carrying capability.	• Improved handling & non-toxicity benefit of the LCH4/oxygen combination (hrs rather than days ground ops) • Approximately 10% specific impulse performance improvement relative to Hypergolic systems. • [OCT TA 2 roadmap member requested addition dev of a composite nozzle]	Candidate?
NASA	Chemical Propulsion	In-Space Chemical (LOX/Methane RCS)	• The oxygen and methane (LCH4) propellant combination has the potential for greater engine performance, which can result in lower vehicle mass and greater payload-carrying capability. • An existing Demonstrated performance of a TRL 6 engine include: - Specific impulse of 317-sec; Impulse bit of 4 lbf-sec; 50,000 cycles with a cryogenic valve; - Ignition & operation over a range of propellant inlet conditions (liquid/liquid to gas/gas)	• Improved handling & non-toxicity benefit of the LCH4/oxygen combination (hrs rather than days ground ops). • Approximately 10% specific impulse performance improvement relative to Hypergolic systems.	Candidate?
NASA	Chemical Propulsion	In-Space Chemical (Non-Toxic RCS)	• Propulsion system technologies for non-toxic or “green” propellants for use in reaction control systems. • Non-toxic technologies for RCS engines over the thrust range of 25-1000 lbf. Propellant options include hypergolic ionic liquids and nitrous oxides monopropellants, both of which can be easily stored in space and on the ground.	• Improved handling and non-toxicity benefit of hours rather than days ground ops. • Non-toxic bipropellant or monopropellants that have higher specific impulse (greater than hypergolic) and/or high specific impulse density (greater than hypergolic) with better safety and reduced handling risks	Candidate?
NASA	Cryo Fluids Systems	In-Space Cryo Propellant Storage (Zero Boil Off)	• Active refrigeration with multi-layer insulation for zero propellant boil off for long duration missions. This technology can significantly reduce propellant launch mass, required on-orbit margins, and the complexity of vehicle operations. Includes the development of a very low temperature (20 Kelvin) cryocooler, integration of a flight-like higher temperature cryocooler into a LO2 storage tank, and demonstration of a shield embedded in MLI with high structural integrity and thermal performance when applied to a LH2 tank. The current state-of-the-art for cryogenic propellant storage is less than 12 hours before boil off begins. • To achieve zero boil-off of an in-space LH2 storage tank the heat input must be intercepted both with a shield embedded in the MLI layers and at the storage tank wall. This requires two-stages of cryocooling, with the first stage operating at 90 Kelvin and connected to the shield and the second stage operating at 20 Kelvin and connected to the storage tank wall. No 20 Kelvin flight cryocooler exists. A shield embedded in MLI and used to intercept heat to a LH2 storage tank has not been demonstrated. Additionally a feasibility demonstration of zero boil-off of LN2 (simulant for LO2) with a small flight cryocooler developed for instrument cooling in space showed unacceptable cryocooler-to-propellant tank integration losses. A concept using a shield on the LO2 test tank has been proven analytically to significantly reduce the cryocooler integration losses but has not been verified through a ground demonstration. • These technologies are directly applicable to LOx/Methane propellant systems.	• LOx Storage: Less than 8.0 Watt of active storage system power per Watt of heat removal at 90K; Zero boil off for >400days • H2 Storage: Less than 120 Watt of active storage system power per Watt of heat removal at 20K; Zero boil off for >400days • Cryocooler mass must be less than mass of propellant saved	Cryostat Demo
NASA	Cryo Fluids Systems	Tank-to-Tank Cryo Propellant Transfer	• Efficient tank-to-tank transfer of cryogenic fluids in-space is a technology is required for propellant resupply to a Cryogenic Propulsion Stage (CPS), oxygen resupply to a Deep Space Habitat (DSH) and has direct application to ISRU Surface Systems. The current state-of-the-art for propellant transfer requires the use of settling thrust for propellant management (tank-to-engine transfer). This is not possible for tank-to-tank transfers (“unsettled condition”). An efficient transfer process requires acquiring vapor free liquid from the storage tank, assuring a leak-free fluid transfer coupling mating the storage tank and the receiver tank, minimizing the fluid used to chill down the transfer line and receiver tank, and adequate fill fraction of the receiver tank. Furthermore, the position of the liquid and vapor within the tank must be determined in zero- or micro-gravity. The maturation of in-space cryo propellant transfer requires the development of the following components – liquid acquisition devices (LADs), automated in-space cryogenic fluid couplings, space vacuum-rated leak detection systems and two-phase cryogenic transfer pumps (delivers liquid only).	• Operation in zero- or micro-gravity. • Liquid Acquisition Devices (LAD): Ratio of LAD delivery system pressure drop to BPP drop at maximum outflow rate - <0.75 to 0.5 (full to minimal success); % of LAD residual LH2 mass to total tank LH2 mass (Explusion efficiency) - <1% to 3% (full to minimal success) • 2 Phase Transfer pump: Operation to a vapor fraction of ~ 0.8 with cryogenic fluids • Automated Fluid Coupling: leakage less than 10-3 sccs gHe after 1000 cycles • Leak Detection: TBD • Fill Fraction of receiver tank: > 0.9 • Minimum Fluid used to chill transfer lines: <1% of receiver tank mass	RRM
NASA	EDL	Entry, Decent, and Landing (EDL) Technologies - Mars Exploration Class Missions	• Entry, descent and landing systems for Mars exploration-class missions requiring large surface payloads. This technology enables reliable and safe delivery of multiple 40 metric ton payloads to the surface of Mars in order to support human exploration. The benefits of focused EDL technology activities include: increased mass delivery to a planet surface (or deployment altitude), increased planet surface access (both higher elevation and latitudes), increased delivery precision to the planet’s surface, increased robustness of landing system to surface hazards, enhanced safety and probability of mission success for EDL phases of atmospheric flight, human safety during return from missions beyond LEO, and sample return reliability and planetary protection.	• Aeroassist, Aerocapture, and Entry- AAES are defined as the intra-atmospheric technologies that decelerate a spacecraft from hyperbolic arrival through the hypersonic phase of entry. Ablative materials are an enabling technology needed for dual heat pulse reentries and for high velocity entries (>8 km/s). • Descent – These technology advancements primarily focus on providing greater deceleration in the supersonic and subsonic regimes in a manner that does not reduce landing accuracy or result in transient unsteadiness or loss of performance in the transonic regime.• Landing – The key areas of technology development are the systems to sense the surface, descent propulsion motors and plume-surface interaction mitigation, touchdown systems, high-G survivable systems, and small-body guidance. Landed payloads include: Large Robotic Landers (100-1500 kg) and Human Class (1500-45000 kg)• Vehicle Systems - EDL systems are by their nature an integrated framework of technologies that necessitate system level efforts for robust maturation.	
NASA	EDL	Autonomous Rendezvous and Prox Ops	• Maturation of subsystem technologies (relative navigation sensors, GN&C flight software, system managers, and mechanisms) to accomplish autonomous rendezvous and proximity operations for various in-space destinations such as satellite servicing and NEA exploration. The benefit of this technology development is to improve human safety, improve mission performance and flexibility by enabling autonomous rendezvous and proximity operations in all lighting conditions.	• System performance driven by the need for autonomous operations; rendezvous with non-cooperative targets with unknown geometry, tumbling attitude, and unknown surface features; high reliability, and mass/power constraints.	

NASA	EDL	Precision Landing & Hazard Avoidance	• Need autonomous landing and hazard avoidance systems, including terrain relative navigation, that operate in all lighting conditions, including darkness. Autonomous Landing and Hazard Avoidance Testbed would enable a first of a kind development for planetary precision landing and hazard avoidance.	• The components and techniques have been simulated and tested to TRL 4 but a full set of integrated field test is needed to show TRL 6 and applicability to future missions • Need 100-m accuracy at 3-sigma certainty. Need 0.5 meter hazard recognition and avoidance.	
NASA	EVA	Deep Space Suit (Block 1)	• EVA suit with rear entry capability and crew-cabin pressure matching for compatibility with Suit Port; improved life support systems for increased life, reliability, and flexibility; and improved power-avionics-software to increase crew autonomy and work efficiency.	• Suit – rear entry suit, capable of operations at ~8 psid (state of the art is 4.3 psid) • Portable Life Support System (PLSS) – - Variable set point oxygen regulator provides more flexibility for interfacing with multiple vehicles, the ability to start an EVA at an 8 psid pressure driven by a suit port and then decrease pressure mid-EVA for improved mobility, and treat decompression sickness in the suit (variable between 0 and 9 psid) - On-back regenerable CO2 and humidity control (eliminates consumables) - Robust water loop that can handle low quality water, long duration missions, low pressure operations, and bubbles (> 50 EVA life) • Power-Avionics-Software (PAS) – - Compatible with high specific energy battery (> 235 kW-hr/kg) Assumed battery development is provided externally to EVA development projects - Radio that is network capable for missions involving multiple assets (vehicles and suits) and has data rates that support transmitting high definition video (> 10 Mbps) - EVA display (either helmet mounted or handheld) that improves upon the 12 character LCD and laminated flip cards used on ISS - EVA information system that increases crew autonomy and work efficiency	Flight Demo
NASA	EVA	EVA Tools for u-G Surface Operations	• Anchoring/mobility for a NEO mission, Exotic Geology Sample Acquisition, Real time Geology Sample Analysis	• Anchoring techniques for vehicles and EVA systems are needed for asteroid missions - ISS uses well defined interfaces such as hand rails as opposed to unknown rocky surfaces - The ability to collect geological samples without damaging the sample (minimal heat or stress) or from a location with difficult access (bottom of a crater or top of a cliff) is needed - Increased ability to analyze the chemical or physical properties of samples collected maximizes the useful data collected and minimizes the need to bring samples back to Earth - All tool development must consider environmental factors and EVA compatibility (safety, mobility limitations)	
NASA	EVA	Lunar Surface Space Suit (Block 2)	• Suit Port-compatible EVA suit for surface destinations with small gravity field and hard vacuum atmosphere (e.g. Lunar surface)	• Assumptions: - Block 2 development occurs after Block 1 (deep space suit). Block 1 development is successful and technologies can be transferred to Block 2 as appropriate - Pressurized rover concept of operations with suit port - Lunar surface or other mission with small gravity field and hard vacuum atmosphere For example, a Mars mission with 1/3 g and low pressure CO2 atmosphere would require additional development due to environmental constraints • Technical changes from Block 1 to Block 2 - Suit: improved lower torso mobility - Portable Life Support System (PLSS): upgrade to dust tolerant components (quick disconnects, relief valves, etc…) - Power-Avionics-Software (PAS): upgrade to dust tolerant electrical connectors, switches, and controls; increase the capabilities of the information system for additional autonomy; take advantage of advances in battery or avionics components as appropriate	
NASA	EVA	Mars Surface Space Suit (Block 3)	• Suit Port-compatible EVA suit for surface destinations with intermediate gravity field (1/3 g) and low pressure atmosphere (Mars)	• Assumes Block 3 development occurs after Block 1 (deep space suit) and Block 2 (surface suit for moons). • Technical changes from Block 2 to Block 3 - All EVA systems components have an increased need for decreased mass - Suit: additional emphasis on boots, thermal insulation for CO2 atmosphere - Portable Life Support System (PLSS): Evaluate existing technologies for use in CO2 atmosphere, may need to develop a new PLSS schematic - Power-Avionics-Software (PAS): increase the capabilities of the information system for additional autonomy (even bigger time delay); take advantage of advances in battery or avionics components as appropriate	
NASA	EVA	Suitport	• A suit port provides a method of rapidly starting and ending EVAs and provides an increased level of environmental containment of potentially hazardous substances that could be encountered during the EVA.	• Reduce airlock operations time from 4 hours pre- and post-EVA to 30 minutes • Reduce exposure of habitable volume to dust, particulates, heat transport fluids, propellants, gases such as atmospheric CO2, etc. • Reduce consumable losses from habitatable volume by 660 kg over two weeks (assumes multiple EVAs/day)	
NASA	ISRU	In-Situ Resource Utilization (ISRU) - Lunar	• Lunar in-situ resource utilization includes regolith processing for oxygen, hydrogen and water. Subsystems for soil processing include soil excavator and soil processor and water collection.• Beneficial to Long duration architectures, producing in-situ oxygen for reduce logistics mass transportation requirements and demonstrate technologies for Mars exploration.	* Excavation and Handling of Regolith for Oxygen Production: Capability is required to provide regolith feedstock for oxygen extraction.* Oxygen and Water Extraction and Production from Regolith: Need capability to produce a minimum of 1000 kg of oxygen and or 1000 kg of water per year.	

NASA	ISRU	In-Situ Resource Utilization (ISRU) - Mars	• Mars in-situ resource utilization as included in the Mars DRAY 5.0 evaluated the benefits of propellant production only, EVA and Life Support backup only, and combined propellant and EVA/Life Support backup. ISRU options include atmosphere processing for oxygen and methane with hydrogen supplied from Earth, soil processing for water, and atmosphere and soil processing for both oxygen and water from entirely in-situ resources. Subsystems for atmosphere processing include CO2 collection & conditioning, CO2 processing into oxygen, methane, and water, O2 and CH4 liquefaction and storage, and hydrogen storage. Additional subsystems for soil processing include soil excavator and soil processor and water collection	• Performance Characteristics TBD	
NASA	Life Science/HRP	Long Duration Spaceflight Human Factors and Habitability	• This technology area develops and maintains NASA's acquired knowledge in Space Human Factors from 50 years of space flight experience to create a safe and productive environment for humans in space. The discipline is underpinned by an understanding of human capabilities and limitations. Inadequate implementation of human factors for design and operations in work environments results in reduced human performance, an increased likelihood of human errors, and decreased mission safety. • This technology area also encompasses the food system and human environmental standards for air, water, and surface contamination (microbiology and toxicology) and exposure to volatiles and dust.	• On long duration missions (>1 year), the food system will have over 1.5 mt of mass and needs to be efficient, nutritious and contribute to well being. • Using current food packaging technology, the amount of food one crew member needs for one year is 670 kg occupying 1.7 m3 (the volume of about three household refrigerators). HRP is currently aiming for 30% and 34% reductions in volume and mass, respectively. If such reductions are achievable, supplies for one crew member for one year are 440 kg and 1.2 m3. Packaging materials must also be disposed. • Efforts in toxicology assessment will begin with robotic precursor missions to a target asteroid (applicable for NEA targets).	ISS Test Bed - Yes
NASA	Life Science/HRP	Long Duration Spaceflight Medical Care	• Strong evidence from spaceflight and analogs indicate that medical conditions of different complexity, severity, and emergency will inevitably occur during long-term Exploration missions. Long duration missions (>1 year) includes limited options for return to Earth, no resupply, highly limited mass, volume and some communication delays. Plans for medical care will be made with regard to balancing the most likely conditions with consequence of outcome including probability of mission failure or loss of crew. • The medical system must monitor and treat crewmembers during the mission. The requirements for this medical system are impacted by the following: age and gender of the crew; crew medical expertise (an experienced field physician would greatly reduce the requirements); and requirements to conduct in situ analysis and return biological samples to assess human system response to the mission in order to efficiently mitigate risks in future missions.	• Rapidly evolving technologies in this area will be developed to help select and prepare crew and optimize care during the mission. • HRP's Integrated Medical Model (IMM) simulates medical events during space flight missions and estimates the impact of these events on crew health and mission success. A three-crew, 386 day, asteroid mission simulation with 28, 2-crew EVAs suggests an optimized medical kit having a mass of 62 kilograms and a volume of 0.15 m3. (These figures do not include all of the medical equipment needed for diagnosis). IMM is best used to make relative comparison between different missions or sets of resources, but the estimated probability of evacuation for this scenario is 9.8% and the probability of loss of crew is 2.8%. Risks on this order of magnitude warrant active mitigation.	ISS Test Bed - Yes
NASA	Life Science/HRP	Long-Duration Spaceflight Behavioral Health	• From the earliest history of human exploration in isolated confined environments, behavioral health and interpersonal relations among crewmembers have been recognized as vitally important to the success of the mission. This recognition, although difficult to precisely quantify, is shared by science advisory groups, congress, the general public, and most importantly, astronauts. With the length and degree of isolation of long duration space missions (>1 year), behavioral health and performance research is critical to crew selection and composition, training, support and monitoring, and the ability to intervene if necessary.	• Research and technologies are being developed and will be tested on ISS and in flight analog environments to support the isolation and autonomous ops with long duration DRM's. • The habitable volume must be large enough and laid out to execute the necessary tasks and to provide a psychologically acceptable space for the long period of confinement. This risk of adverse behavioral health events is significant: based on estimates made for the MAWG, the probability of an adverse behavioral health event is 2% and 5% for 3 month and 6 month missions, respectively.	ISS Test Bed - Yes
NASA	Life Science/HRP	Microgravity Biomedical Counter-Measures - Optimized Exercise Equipment	• Countermeasures to prevent microgravity induced changes in musculoskeletal, cardiovascular system have evolved over 40 years to the current state on ISS. Other human systems: sensory motor, immunology, nutrition and others continue to be investigated to understand or control the adaptation. The challenge will be to adapt the successful aspects to a long duration mission (>1 year) with limited resources (mass, power, volume)• A JSC Space Life Sciences Directorate Top Program Risk, On-Orbit Intracranial Hypertension (IRMA #6169), would limit NEA missions to six months or less. 20% of long duration ISS crewmembers have experienced clinical symptoms. Observed physical findings in long-duration crewmembers include papilledema, choroidal folds, increased optic nerve sheath diameter, and a posterior flattened globe; some of these changes were temporary and others permanent. There is a high probability that all astronauts have idiopathic intracranial hypertension to some degree, and that those susceptible (via eye architecture, anatomy, narrow disc) have a high likelihood of developing either choroidal folds or papilledema, and that the degree of that edema will determine long-term or permanent vision loss, sequelae, or impairment. This risk is under active investigation.	• This problem which can bring progressive, permanent changes must be understood and prevented on ISS before undertaking exploration missions. Worst case – Artificial gravity would be required.	ISS Test Bed - Yes
NASA	Life Science/HRP	Microgravity Biomedical Counter-Measures for Long Duration Spaceflight	• Exercise equipment is necessary to address muscle atrophy, cardiovascular atrophy, and bone loss associated with long-duration missions in the microgravity environment of space.	• Current ISS exercise equipment is too large and heavy to be used on a long duration missions (~1yr duration): the latest equipment deployed on ISS (T2, CEVIS, ARED) occupies 3 ISPRs. • The development challenge will be to adapt the successful aspects of the current exercise hardware to a support long duration missions with limited resources (mass, power, volume).	ISS Test Bed - Yes
NASA	Life Science/HRP	Space Radiation Protection – Galactic Cosmic Rays (GCR)	• Current estimates of crew risk from GCR radiation exposure with long duration (~>1 year) missions beyond LEO exceed the NASA acceptable career standards for Risk of Exposure Induced Death for fatal cancers. In many cases, the risk estimates (Cancer Risk Projection Model currently under review with National Academy of Science) greatly exceed the acceptable limit. • Research indicates that mortality risk from radiation induced degenerative disease may further exacerbate problem. GCR is difficult to shield against due to its high charge and energy, however shielding systems must minimize exposure levels to the maximum extent practical. • In addition, there are large associated uncertainties in the modeling of the biological damage caused by GCR. These uncertainties limit our ability to accurately evaluate risks and the effectiveness of biological and physical mitigation strategies.	• Technological approaches include: risk quantification and uncertainty reduction through radiobiology research, selection of crew based on individual sensitivity for major risks, new biomedical countermeasures, cost/mass efficient multi-use shield systems, and mission planning away from solar minimum.	

NASA	Life Science/HRP	Space Radiation Protection – Solar Proton Events (SPE)	• NASA's radiation exposure standards permit a 3% risk of radiation exposure induced death (REID). This standard limits mission durations at solar minimum to 5-6 months for males and approximately 3 months for females. At solar maximum, the recommended limits become 154 days for 35-year old females to 300 days for 55-year old males. • Longer allowed mission durations would result from less conservative assumptions in the radiation carcinogenesis model. For example, REID would be reduced by accounting for the more comprehensive cancer surveillance program available to the astronaut corps, and by projecting an increase in survivability as medical knowledge and technology advances. Longer allowed mission durations might also result as further research decreases in the uncertainties of the risk estimates.	• Specific technology investments across multiple Programs (HRP, ETDD, LWS, Shuttle, ISS, Cx) and inter-governmental collaborations (NIH, NSF, NOAA, DOD) include: Active miniaturized dosimetry, Multi-functional SPE shield systems, Heliospheric environmental monitoring technology, Risk projection models, Acute biological countermeasures, Forecasting/probabilistic models of events and all-clear periods.• Accurate event alert, crew response, monitoring, and shelter are essential to protect crew against SPEs. Exposure must be minimized to mitigate the risk of early Acute Radiation Syndromes as well as increased risk of late radiation carcinogenesis. Improvements in SPE forecasting and alert systems, including orbital assets to monitor solar activity and dosimetry for real time assessment of crew exposure, are needed to minimize operational constraints for missions outside the protection of the Earth's magnetic field. Improved understanding of radiobiology and space weather are needed to establish a probabilistic risk assessment (PRA) across mission/architectural elements to aid in system optimization, operations, and mission planning to ensure crew performance and health while maximizing science return. Biological countermeasures against acute syndromes are needed to complete an overall mitigation strategy in the event of an unmitigated exposure incident.	ISS Test Bed - Yes
NASA	Life Science/HRP	Space Radiation Shielding – SPE	• Significant risk to crew, digital equipment, and vehicle systems associated with Solar Particle Events (SPEs). • Current NASA goals necessitate the need to develop radiation mitigation schema for the next generation of exploration including materials and their integration into vehicle architecture systems. • Technology development is required to ensure systems are capable of providing structural integrity for architectural element design, while also providing sufficient radiation protection (and potentially others, e.g. thermal, MMOD, etc.) properties to negate any need for the addition of parasitic shield mass.	• Candidate radiation protection materials currently exist but require ground and flight testing to vet candidates and ensure radiation protection viability and multi-functionality. • NASA should invest in both ground based testing and flight testing to investigate the feasibility of concepts to protect astronaut crews from the harmful effects of radiation, both in low Earth orbit and while conducting long-term missions away from Earth.	ISS Test Bed - Yes
NASA	Life Support	Closed-Loop, High Reliability, Life Support Systems	• Enhance and develop new Environmental Control and Life Support (ECLS) process technologies and systems to increase system closure, enabling long duration human exploration missions. • Based on systems analysis and trade studies, targeted functions and technologies may include: - Close the Atmosphere Revitalization (AR) loop by furthering CO2 reduction, O2 recovery, and reducing logistics. Technologies may include Bosch, methane processing, and solid oxide electrolysis as well as advanced trace contaminant control and filtration. - Further closure of the Water Recovery (WR) loop by processing new liquid wastes including brines and wastewater from hygiene, laundry and solid waste reclamation. May also include purification of water derived from ISRU sources. - Processing of solid waste to recover water, reduce volume, and stabilize for long term storage. Technologies include compaction, drying and mineralization of solid wastes, including trash, feces and solid byproducts from AR and WR processes. • Bring technologies to TRL 6 through ground-based integrated testing and ISS flight demonstrations. Perform long duration human in the loop testing to flush out hardware closed-loop issues such as contaminant buildup. • NOTE: "High Reliability Life Support Systems" is a subset of this technology item.	• Approach 100% closure for water and oxygen. Enable vehicle and mission autonomy through reduced dependency on logistics and consumable mass, and lower launch and mission costs. • Meet new vehicle requirements including high reliability, operation in more extreme cabin environments (reduced pressure [8 psia] and elevated O2 [≈32%]), reclamation of more complex process streams, and planetary protection.	ISS Test Bed - Yes
NASA	Life Support	Fire Prevention, Detection & Suppression (for 8 psi)	•For longer duration missions the habitable atmosphere may be at a lower pressure and higher %O2 (greater risk of fire) than on STS or ISS. Small crew cabins (e.g. MPCV, SEV) preclude some of the current countermeasures, and even with larger cabins (e.g. DSH, Surface Elements), immediate evacuation to Earth is not an available option. The best way to protect the Crew is to develop an integrated fire protection strategy.	•The best way to protect the crew is to develop an integrated fire protection strategy including: - Accurate definition of the risk from flammable materials in low-g - Define relevant material usage and storage controls - Develop/validate non-flammable materials - Early fire detection from structurally integrated distributed sensors - Emergency breathing apparatus with filtering respirator - ECLS-compatible and re-chargeable fire extinguisher - ECLS-compatible emergency air purifier - Contingency air monitor for relevant chemical markers of post-fire cleanup	ISS Test Bed - Yes
NASA	Life Support	High Reliability Life Support Systems	• Development and validation of open and closed-loop Environmental Control and Life Support Systems (ECLSS), including Atmosphere Revitalization, Water Recovery, Waste Management and Crew Accommodations, focused at improving reliability and reducing logistics over the state of the art. • Base technology selection and development on systems analysis and trade studies. Deliver new gap-filling technologies identified by vehicle elements including trash compactor, clothing, washer and dryer. • Bring technologies to TRL 6 through ground-based integrated testing and targeted flight demonstrations for selected process technologies. Perform long duration testing to address hardware reliability issues.	• Meet or exceed performance over current state of the practice (≈90% closure of water and ≈50% closure of O2). • Meet new vehicle element requirements: - Increased vehicle autonomy, including high reliability, reduced logistics and in-flight reparability; - More extreme cabin environmental conditions (reduced pressure [8 psia] and elevated O2 [≈32%]) - More complex process streams for recycling (wastewater from trash, hygiene and laundry).	ISS Test Bed - Yes

NASA	Life Support	In-Flight Environmental Monitoring and Control	• Extended duration missions will require improved capabilities for environmental monitoring and control to assess the habitation environment and its potential for degradation in order to enable the crew to react and mitigate any risks to continued human occupancy.	• Tallest tent pole: In-flight analysis capabilities are necessary—Returning samples to earth for ground analysis will not be feasible for future missions. Environmental habitat problems on ISS are solved by sending air & water samples to earth for lab analysis, which yields data for diagnosing the problems. • Separately, rapid detection of hazardous environmental events must be monitored and controlled with high accuracy. Chemical hazards are highest in urgency, followed by microbiological threats, based on rapidity of impact. • Detect contaminants introduced via surface activities (dust, etc.) • Air Monitoring is well developed but should be made much smaller. Some specific tests for chemicals in water and for microorganisms have been flown, but analysis needs must be specified and developed.	ISS Test Bed - Yes
NASA	Mechanical Systems	Mechanisms for Long Duration, Deep Space Missions	• Recent high impact, infant mortality and pre-mature hardware failures aboard the ISS (e.g. SARJ, Urine Processor bearings, Ammonia cooling pump, Canada Arm LEE, etc.) accentuate the need for tribological and mechanical component innovations to enable future HSF missions. Reliable, long-life, mission critical systems such as cooling pumps, circulators and components for Zero-Boil-Off systems, control moment gyros, robotic manipulation hardware, docking/hatch devices and pointing mechanisms must be more resilient and capable than current COTS technology allows. New lubricants, bearing and gear materials and designs are needed to ensure mission success. • Emerging lightweight superelastic materials (Nitinol alloys), advanced lubricants (ionic fluids), and novel mechanism designs (low sliding high contact ratio gears) are poised to help avoid mission ending/crippling mechanism failures but must be matured. Such innovations will enable silent, ultra-reliable spacecraft systems such as cabin blower motors and fans, thermal management pumps, etc. Innovative power transfer technologies (magnetic gears), can significantly reduce cabin noise levels enhancing astronaut health and operational efficiency over long duration missions.	• Mission critical systems (e.g. cooling pumps, circulators, control moment gyros): - Current SOA: <10yr, sustain 6 g loads (designs must be 2X mission life and 2X Shuttle launch load) - Goal: >10 yr at + or -50°C from operating temperature sustaining 10 g loads (2X mission life, 2X launch load of 5g's)• Bearing and Gear Materials to handle higher loads: - Current SOA: steel - Goal: 15% weight reduction with comparable capability (superelastic materials)	Candidate?
NASA	Nav/Comm Systems	High Data Rate Forward Link (Flight)	• Combine transmitters on the ground across an array of antennas to produce uplink data rates 3-4 orders of magnitude higher performance than current DSN capabilities to support uplinked video, imagery and software uploads, enable spacecraft receiver to receive high data rate with reduction avionics size, weight and power (SWaP) burden to Elements, and leverage navigation improvements in orbit determination accuracy and trajectory management from improved communication link.	• Enable uplink rates: >50-100 Mbps at 1 AU using Ka-band) • Size and weight reduction: compared to currently achievable receiver: >50 % • Leverage navigation improvements in orbit determination accuracy and trajectory management from improved communication link	
NASA	Nav/Comm Systems	High Rate, Adaptive, Internetworked Proximity Communications	• Enable high data rate communications between multiple in-space elements for situational awareness, enable element proximity radios to sense RF conditions and adapt autonomously, enable elements to store, forward, and relay/route information to other elements intelligently and when communications is available, enable element radios to be reprogrammed from ground based on in-situ characterization of the NEO environment. The benefit of this technology development is to improve situational awareness and communications, improving operational efficiency.	• data rate: >20 Mb/s simultaneously between peers • Employ multiple frequency/modulation/coding/power schemes, including low frequency schemes to enable low rate, non-line of sight comm through small NEO's when relay through other elements is not available. (Max range: < 20km. Max NEO size for penetration: < 50 m) • Max storage time: <5 min/Element@ 20 Mb/s, Max routing: <20 destinations/Element • Enable radios to be adapted in frequency of operation, modulation and coding to information as it is discovered about the NEO environment in near real-time. (Near real-time: < 30 minutes of each NEO characterization performed by in-space elements)	
NASA	Nav/Comm Systems	In-Space Timing and Navigation for Autonomy	• Enable elements to perform independent navigation during complex in-space maneuvers, enable precision required for absolute and relative navigation for in-space elements, enable increased element onboard reference timing generation, timekeeping[1], distribution and inter-element synchronization to eliminate dependence on Earth-based systems. The benefit of this technology development is to improve situational awareness and communications, improving operational efficiency. High-precision timekeeping significantly reduces accumulated navigation error over long periods of time, enabling mission autonomy for long periods of time without synchronization events with ground or other (X-ray, etc) synchronization.	• Complex maneuvers: navigating to amongst multiple in-space elements plus 1-3 NEO objects in dynamic motion in proximity to elements • Absolute position required for navigation: < 0.4 m. Relative position required for navigation: < 0.4 m • This requires space-qualified clocks that are orders of magnitude more accurate than existing space qualified clock. (Element timekeeping accuracy required: milliseconds to nanoseconds depending on mission)	ISS Test Bed - Yes
NASA	Nav/Comm Systems	Quad Function Hybrid RF/Optical Comm, Optical Ranging, RF Imaging System	• This technology provides the capability to perform four functions with a single system: RF and optical communication, optical ranging and RF imaging, enable reduced avionics Size, Weight and Power (SWaP) burden to Elements through combined RF/Optical capability in a single system, enable multiple elements to aggregate communications through a single element to solve spectrum and 'multiple spacecraft located in the same aperture' issues on the Earth side, enable reliable high data rate communications between in-space elements and ground regardless of distance from Earth and availability of assets on the ground-side, to conserve element power whenever possible, enable simplified tracking of terminal by providing simultaneous RF beacon capability with terminal while optical system is operating. This is a recommended technology for missions where both imaging and long-range, high rate communications are required for the mission.	• Power savings during optical mode: < TBD Watts. Size and weight reduction compared to dual systems: <40 %• Optical data rate to 0.5 AU from Earth: >1 Gb/s simultaneous U/L and D/L with ground• NEO's/NEA's at 0.5 AU distance or greater, including Mars missions	OPALS
NASA	Power Systems	200 kWe Fission Power for Electric Propulsion	• Fission power systems being developed for surface applications can be used to power electric propulsion vehicles.	• Moderate power, low mass (<30 kg/kWe) power system for NEP • 1300 K reactor, 50 kWe Brayton conversion, 1000 V PMAD	

NASA	Power Systems	Autonomously Deployable 10-100 kW Surface Solar Arrays	• High power, high voltage, autonomously deployable surface solar arrays in $1/6^{th}$ to $1/3^{rd}$ gravity environments are needed to generate reliable electric power for surface outpost elements over the mission duration. Enabling features include compact stowage, reliable deployment in partial gravity, on an irregular surface & dusty environment, Martian wind load strength, EVA compatibility, dust mitigation to limit photovoltaic power degradation and robust to surface arcing environment (Martian surface triboelectric charging). Few options exist and only at the conceptual level. These include mast deployed vertical, sun-tracking blanket solar arrays for lunar polar surface mission and horizontally deployed , fixed tent like solar arrays. Solar array panels would employ low mass, flexible panel substrates populated with advanced photovoltaic cells, like inverted metamorphic (IMM) triple junction solar cells, with bandgap tuning for the Martian surface solar spectrum. substrates. • These solar arrays would power outpost surface elements (habs/labs, rovers, ISRU, lander/ascent stages, etc.)	• High power (10-100 kW), • High voltage (<~200 V) • Autonomously deployable surface solar arrays in 1/6th to 1/3rd gravity environments	
NASA	Power Systems	Autonomously Deployable 300 kW In-Space Solar Arrays	• High power, high voltage, autonomously deployable solar arrays are required to generate reliable electric power for the SEP Stage over its mission duration. Enabling features include compact stowage, reliable deployment, ~0.1-g deployed strength and robust performance through the mission end-of-life. Leading options include large, dual-wing structures (2 x 200 kW) and modular, sub-wing structures (20 x 20 kW) employing advanced photovoltaic cells on flexible substrates. Fine pointing requirements for concentrator-based arrays may limit functionality for some missions, so both planar and concentrator architectures should be considered.	• High power (~400 kW BOL) • High voltage (~ 350 V) • Low mass (TBD W/kg)	Candidate?
NASA	Power Systems	Fission Power for Surface Missions	• Abundant power for surface missions is enabled by a surface-emplaced fission reactor. The availability of substantial amounts of continuous power provides opportunities for significant science, exploration, and engineering activities on Mars and the Moon.	• 40 kWe Fission Power System (reactor, power conversion, heat rejection, PMAD) • 900 K reactor, 10 kWe Stirling convertors, 400 K radiators, 400 V PMAD • 150 kg/kWe for surface missions	
NASA	Power Systems	High Specific Energy Battery	• Batteries with very high specific energy and energy density are required to enable untethered EVA missions lasting 8 hours within strict mass and volume limitations. Batteries are expected to provide sufficient power for life support and communications systems, and tools including video and lighting. Advanced batteries are enhancing for every other vehicle.	• Battery-level specific energy > 220 Wh/kg and energy density > 410 Wh/liter at a C/10 discharge rate • 80% capacity retention after ~200 cycles	
NASA	Power Systems	Multi-MWe Nuclear Power for Electric Propulsion	• Nuclear power system development for very high power electric propulsion vehicles to deliver cargo and/or crew to Mars. Once built, this system would also reduce the cost of transits to the Moon, E-M L1, NEOs, and the Martian moons.	• High (>1 MWe) power, low mass (<15 kg/kWe) power system for nuclear electric propulsion.• Flight power system development and qualification	
NASA	Power Systems	Regenerative Fuel Cell	• Long duration energy storage is required for extended surface missions to store solar energy and provide power during low insolation. Applicable to Lunar or Mars surface applications requiring high power and/or long sortie durations. RFC system includes a fuel cell and an electrolyzer, each of which can be used independently for power/water generation and H2/O2 generation, respectively. Electrical power can be used for any vehicle. Water and O2 can be used for life support for crewed vehicles. Also applicable to ISRU. • Technology development includes reducing the number of ancillary components to increase reliability and operational lifetime, and reduce parasitic power losses, mass, and volume.	• Power generation >10 kWe for 8 hours or more • Operable with reactants at >2000 psi to reduce tank volume • Round trip energy conversion efficiency > 50% • Minimize mass (TBD Wh/kg) • Operational life >10,000 hours	ISS Test Bed - Yes
NASA	Robotics & Mobility	Robots Working Side-by-Side with Suited Crew (w/ Demos)	• Human mission activities can be performed more effectively if robotically assisted. Coordinated efforts between humans and machines/robots can improve the mission risk/productivity trade space. • The top technical challenges in human-robot interactions are multi-sensor feedback, understanding and expressing intent between humans and robots, and supervised autonomy of dynamic/contact tasks. • When robots and humans need to work in close proximity, sensing, planning, and autonomous control system for the robots, and overall operational procedures for robots and humans, will have to be designed to ensure human safety around robots. • The goal is to enable EVA crew and machine interaction without real-time control and support needed from IVA or ground control personnel.	• Overcome limits of state of the art with ETDD Foundation Work (i.e. HRS) - Avoid need for IV robot controller (like with RMs) - Avoid need for IV spotter/checker (like with SSRMS) - Avoid dependence on Mission Control (like SPDM) - Create force level safety for proximity operations - Create multi-modal human-robot interfaces and autonomy software - Create fault tolerant free flyer and EVA positioning technology - Create asteroid sampling, processing, manipulation - Create asteroid grappling & anchoring technology • Test prototypes to mature technology with ETDD Demonstrations (i.e. HET) - Analog testing of prototypes with science, operations and other communities on Earth - Prototypes, flight DTO's, experimental payloads on ISS, and other demonstrations	ISS Test Bed - Yes
NASA	Robotics & Mobility	Surface Mobility	• Surface mobility systems allow for the movement of cargo, instruments and crew on the surface of an object or planetary body. Examples include roving, climbing, crawling, hopping or burrowing into the surface. Systems for moving cargo include prepositioning cargo for future human use, or repositioning payloads for re-use. Instruments can be pointed by mobility systems, or pushed into contact for data collection, approaching simple manipulation by using the mobility system's transport mechanisms. Crew mobility aids expand crew range, speed and payload capacity while also providing power, habitation and environmental shelter. NASA's experience with crew mobility on the lunar surface was limited to unpressurized rovers for short stays. NASA now faces new challenges of working on the exteriors of satellites, on asteroid surfaces, on planetary surfaces for long durations, or providing access to lunar craters. Complexities of dust management and human interaction with NEA during extended stay should also be addressed.	• Technology investment areas can include: - Micro gravity climbing for satellite or asteroid missions - Precursor roving in soft/steep soils for lunar crater access - Ballistic crater explorer, fires projectile into crater for data - Concurrent design of crew rover and SEV for re-use - Mobile landers for repositioning spacecraft on small bodies	

NASA	Robotics & Mobility	Telerobotic control of robotic systems with time delay (w/ Demos)	• Current State-of-Art (SOA) of telerobotic control is insufficient for human missions beyond LEO• Enable astronauts in vehicle, habitat, or EVA to remotely operate robots at NEO (natural environment & variable time-delay) to collect samples, deploy instruments, etc. - IVA SOA = control of robot arm in structured environment with man-made payloads and zero-delay (e.g., ISS crew uses SSRMS to move/position cargo modules). - EVA SOA = none (no EVA control of external space robots exists).• Enable Earth ground control to remotely operate robots in dynamic environments beyond LEO to support crew (e.g., recon, survey, site prep, follow-up, etc. during sleep periods) . - Ground control SOA = Single command sequence per day of slow ground robot in static environment without humans (e.g., Mars Exploration Rovers driving few m/day).• Enable use of robots deployed by precursor mission, race-ahead or crew in mixed ops modes: before – supporting – after crew, ground control & crew, IVA & EVA.	• IVA: Advance SOA to enable telerobotics from inside crew vehicle (approach/orbit NEO) - Robot functions: detail reconnaissance, sample collection, worksite prep, etc. - Time-delay: 5 sec (orbit-to-surface) to 5 min (for race-ahead mission architectures)• EVA: Advance SOA to enable telerobotics from suited crew (in-space or on-surface) - Robot functions: mobile camera, materials/payload transport, etc. - Time-delay: up to 10 sec• Ground control: Advance SOA to enable telerobotics in dynamic environments (e.g., tumbling NEO) - Robot functions: initial reconnaissance, systematic survey, site prep, follow-up, etc. - Time-delay: up to 40 min (Earth to Mars orbit round-trip)	ISS Test Bed - Yes
NASA	Space Environment	Dust Mitigation	• Technologies are required to address adverse regolith effects in order to reduce life cycle cost and risk, and increase the probability of mission success. Based on Apollo lunar surface experience, there is a risk of regolith induced system degradation. The NEO environment may include suspended “clouds” of particulates, and is in any case an unknown. Particulate mitigation will be accomplished by: - Identification of NEO soil contamination issues for mechanisms and thermal systems. - Investigate specific risk mitigation technologies (e.g. seals) applicable to NEO missions. Develop technologies to limit regolith contamination, or mitigate its effects. - In a relevant environment, integrate and test mechanical component-level technologies to TRL 6. • Required for both robotic and human missions, NEO, Lunar Surface, Phobos/Deimos, and Mars destinations. NEO simulants are required to develop tools for anchoring, sample acquisition, etc, and Mars simulants are needed to develop ISRU technology.	• Mitigation technologies must: - maintain the solar absorptivity of a dust contaminated radiator surface within +20% of the pristine surface value, and - provide negligible dynamic seal wear to 2 million cycles (approx. 6 month life) or 20 million cycles for a 5 year life.	Candidate?
NASA	Structures/Materials	Inflatable: Structures & Materials for Inflatable Modules	• The primary advantage of inflatable/expandable structures are the readily collapsible walls that reduce stowage volume for the launch package, but provide extra volume for living space when expanded. The resulting volume-to-mass ratio for expandable structures can be significantly higher than that for conventional hard shell structures.• The objective is to develop expandable structures technology for application as pressurized elements such as crew habitats and airlocks. The goal is to develop expandable technology for increased habitable volume for minimal mass, with improved confidence in structural and thermal performance in the space environment.	• Long-term creep performance characterization of the structural shell of the inflatable module (material testing). - How do these materials (Kevlar & Vectran) perform after being under constant load for many years. Will also influence what Structural Factor of Safety to use.• Inflatable Structure Restraint Layer damage tolerance (predictive modeling validated with testing). - How to predict what type of damage the restraint layer can withstand and still be structurally sound & human-rated. This is analogous to "leak before burst" and "fracture analysis" for metallic pressure vessels.• Multi-layer Insulation performance degradation prediction after folding/deployment (predictive modeling validated with testing). - Obtain thermal performance of MLI after undergoing folding, launch vibration, and deployment. We must understand the MLI performance so that we can accurately predict the thermal environment of the inflatable through the various mission phases.• Bladder material selection. - Perform a full-scale leak test of an inflatable module with the representative bladder material and representative seal interface. Bladder is Critical and very sensitive to puncture, tear, folding, handling, flex cracking, brittleness at cold, etc.• Bladder-to-metal interface seal. - Crit-1 interface. Never been done on a large scale. How to do it? Repeatable process?• Predictive modeling of deployment dynamics. - Obtain torques & loads that will be imparted to any mated module/interface during the deployment and inflation process.	HAB Demo - Yes
NASA	Structures/Materials	Lightweight Structures and Materials	• Efficient Structures and Materials that demonstrate significant weight and cost savings for aerospace applications to provide a total systems based efficiency. This includes multifunctional, lightweight and robust (i.e., inspectable, repairable, damage tolerant, etc.) structures and materials specifically tailored for mission applications. • Emerging Innovations in Manufacturing Technology that offer significant improvement over SOA, critical to achieving the destination, performance, and affordability objectives for exploration • Design and Certification Methods to ensure timely introduction of advanced, multifunctional structures and materials into future reliable space systems - Damage models for reliability (certification and sustainment) - Optimized analysis and test for verification and validation - Streamlined Design-Analysis-Certification processes - Rapid material properties development	• Lightweight structures and materials optimization to realize a minimum of 20-30% structural system weight savings and operational cost savings. • Multifunctional structures that offer improvements in radiation protection, MMOD shielding, thermal management, structural health management, and system damping benefits over conventional structures. Includes composite and metallic structures & materials.	
NASA	Structures/Materials	Robust Ablative Heat Shield (Beyond Lunar Return)	• A robust, scalable heat shield TPS architecture is required that can be used for multiple missions. Ablative TPS solution for primary MPCV heatshield protection for beyond Lunar return conditions. Improve human safety by detecting critical issues with MPCV TPS or structure prior to entry.	• Ablative TPS Solution for primary CTV heatshield capable of withstanding ~2500 W/cm^2 under 0.8 atmosphere pressure - Beyond Avcoat performance capability, maybe beyond PICA performance capability - Either new ablative material, existing ablative material in new system, or new ablative material in new system will be required• Peak heat rate dominated (~90%) by shock layer radiation• Technology needs to enter DDT&E cycle include TPS development, shock layer radiation modeling validation, and hyperthermal ground test capability to approximate convective-radiative environment	

NASA	Structures/Materials	Robust Ablative Heat Shield (Lunar Return)	• A robust, scalable heat shield TPS architecture is required that can be used for multiple missions. Ablative TPS solution for primary MPCV heatshield protection. Improve human safety by detecting critical issues with MPCV TPS or structure prior to entry.	• Capable of withstanding ~1000 W/cm^2 and ~1 atmosphere pressure • Technology needs to enter DDT&E cycle include TPS development to verify Avcoat capability at updated higher reentry environments, shock layer radiation modeling validation, and hyperthermal ground test capability to approximate convective-radiative environment • Assumes Avcoat capability has not been previously extended to Lunar return environments under Orion	
NASA	Thermal Systems	Thermal Control	• Improve thermal control system performance and reliability to reduce mass transportation requirements and enable performance in a wide range of mission requirements. • Several technologies will be evaluated via ISS demonstrations due to unique environment (atomic oxygen, ultraviolet, prolonged microgravity, vacuum, temperature cycling, etc…) • Technologies that could be required include: - Thermal Control System (TCS) fluids and variable heat rejection radiators enabling single-loop TCS architecture - Low mass/volume heat exchangers & coldplates - Advanced Supplemental Heat Rejection Devices including evaporative heat sinks & fusible heat sinks - Solid state devices (thermal electrics) - Thermal sensors and health monitoring	Performance Characteristics TBD	ISS Test Bed - Yes
NASA	Other	Supportability and Logistics	Description TBD	Performance Characteristics TBD	