Potential Gap Closure Option: **4.1 Academic Partnerships**

Divis	Domain	Area of Emphasis	Pathstone	Goal/AOE/Pathstone Statement/Description
Rows shaded this color do not represent a gap; they are provided for context.				
Crew and Thermal Systems				
EC	Active Thermal Control			
EC	Active Thermal Control	**Provide Adequate Active Thermal Control to handle the vehicle heat load during transit mission phases and handle the thermally cold heat sink environment**	**Single Loop Architecture Trade/Analysis**	Documents benefit of going to a single loop ATCS (mass, power, etc. savings) verses staying with the historical dual loop. Trade Study will provide data to show system level impact for a heat rejection turn down requirement of 6 to 1, allowing stakeholder buy in to pursue variable heat rejection technologies. Complete this task no later than FY2017
EC	Active Thermal Control	**Provide Adequate Active Thermal Control to handle the vehicle heat load during transit mission phases and handle the thermally cold heat sink environment**	**Variable Conductance Technologies**	Part of the solution to enable single-loop ATCS is the use of variable conductance technologies such as novel heat pipes (VCHPs, loop heat pipes, etc.) and advanced thermal switches to tailor the amount of waste energy transfered in a vehicle. This tailoring allows for an increase or reduction in waste energy rejection.
EC	Active Thermal Control	**Provide Adequate Active Thermal Control to handle the vehicle heat load during transit mission phases and handle the thermally cold heat sink environment**	**Thermal transport fluid development**	The ultimate goal in variable heat rejection is to create a thermal control fluid that will freeze at relatively low temperatures (<90°C) while maintinating good thermophysical properties, is nonflammiabe, and is not toxic to the crew. This would in therefore allow for the use of tradiational active thermal control hardware in a single loop.
EC	Active Thermal Control	**Provide Adequate Active Thermal Control to handle the vehicle heat load during Lunar and Mars Orbit mission phases and handle the thermally warmer heat sink environment.**	**Advanced Phase Change Material**	Advanced phase change material could enable smaller PCM HX in the future, reducing the HX's mass and volume. An optimal PCM would freeze between 8-12°C and have a heat of fusion above 225 kJ/kg.

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EC	Active Thermal Control	**Thermal Control System Repair and Maintenance**	**In-Situ Thermal Fluids Chemical Analysis**	In-situ thermal fluids chemical analysis to monitor thermal transport fluid health status provides health monitoring and real-time system performance status and allows crew and ground personnel to take action to assure continued operation. Understanding of thermal transport fluid health through in-situ chemical analysis provides insight into when fluid replacement or treatment is needed. The technology challenge related to developing in-situ thermal fluids chemical analysis is developing autonomous, low-volume and low-power sampling and analysis with accuracies sufficient for the mission application. This technology is desired to be at TRL 7 by 2019 in order to support a longduration mission such as ARCM. This is a technology that could benefit other systems such as ECLSS and EVA (TA6).
EC	Active Thermal Control	**Thermal Control System Repair and Maintenance**	**Radiator Repair/Maintenance**	Radiator repair includes the equipment, materials and processes required to perform repair of spacecraft radiator systems in a space environment in order to maintain heat rejection capability and conserve transport fluids after damage to spacecraft radiator system. Current external cooling loop repair technologies are limited to fluid line repair capability on ISS (Fluid Line Repair Kit - FLRK). There is currently no radiator panel coolant line repair capability. The technology challenge is to develop a repair capability for radiator panel flow tubes, as well as different coolant line sizes that may be used on different spaceflight vehicles. Early availability for ISS may result in significant operational flexibility and cost savings, and evolution of designs may have applicability for all future spaceflight vehicles with radiators. Desired availability for a repair system is 2018 in order to support ISS requirements through the end of the program. The other component of this is radiator maintenance on a planetary surface. Where radiators and/or solar panels are needed in a planetary environment there is a need to maintain a clean surface for energy collection and heat rejection. Development is needed of dust mitigation as part of the radiator repair and maintenance to maintain the efficiency of the thermal control system.
EC	Active Thermal Control	**Two-Phase Pumped Loop System**	**Two-phase pumped loop system trade**	Gather any previous data on two-phase systems and most recent advances and determine from a systems level if this is a vialbe approach primarily from a mass and reliability standpoint.
EC	Active Thermal Control	**Provide Active Thermal Control for Mars surface systems**	**Non-Venting Ascent/Decent Supplemental Heat Rejection**	Investigate non-venting technologies such as PCM, SWME Evaporator Absorber Radiator (SEAR) to reject heat loads during ascent/descent phases to the surface of Mars.

Potential Gap Closure Option:

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EC	Active Thermal Control	**Provide Active Thermal Control for Mars surface systems**	**Non-Venting Space Suit Thermal System**	
EC	EVA			Developing EVA and IVA capabilities to enable LEA, microgravity (sis-lunar, Phobos, vehicle based contingency), and partial gravity (moon, Mars) missions.
EC	EVA - Pressure Garment	**Pressure Garment**		
EC	EVA - Pressure Garment	Exploration PGS - **Microgravity**		Develop an Exploration PGS design compatible with microgravity EVA and the complete antthropometric range of the crew population.
EC	EVA - Pressure Garment	Exploration PGS - **Microgravity**	Evaluate scalability of pressure garment design to accommodate crew anthro range and all required system interfaces (e.g. DCM, purge valve, umbilical services, positive pressure RV, etc.) for performing ISS EVA taks.	Conduct testing with Z-2 to evaluate usability with small-mid size crew members and complete complement of system interfaces while performing representative ISS tasks. Conduct design exercise to assess additional sized components needed to outfit the full anthropometric range of the crew office.
EC	EVA - Pressure Garment	Exploration PGS - **Microgravity**	Ground testing of durable and highly mobile EVA gloves.	Conduct testing of new gloves in relevant environments (NBL and ARGOS).
EC	EVA - Pressure Garment	Exploration PGS - **Surface Mobility**		Develop an Exploration Pressure Garment designed for surface environments that includes protection from a radiative thermal environment, MMOD & secondary ejecta protection, good upper body mobility, good lower body mobility (walking, kneeling, etc.) and increased dust protection (consistent with falling/kneeling on a planetary body).
EC	EVA - Pressure Garment	Exploration PGS - **Surface Mobility**	Identify and develop suit materials capable of long duration exposure to dust, and abrasive activities without compromising mobility (walking, kneeling, etc).	Identify candidate materials and layups then test at the samples for compatability with the lunar surface dust/dirt, thermal, and radiation environments.
EC	EVA - Pressure Garment	Exploration PGS - **Surface Mobility**	Evaluate prototype components of new suit materials capable of long duration exposure to dust, and abrasive activities without compromising mobility (walking, kneeling, etc).	Conduct cycle testing of components in revelant environments.

Potential Gap Closure Option: **4.1 Academic Partnerships**

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EC	EVA - Pressure Garment	Exploration PGS - Mars **Atmosphere**		Develop an Exploration Pressure Garment designed for operations in Martian atmosphere that includes protection from a seasonally variable (convective thermal environment, MMOD & secondary ejecta protection, good upper body mobility, good lower body mobility (walking, kneeling, etc.) and increased dust protection (consistent with falling/kneeling on a planetary body and surviving blowing dust).
EC	EVA - Pressure Garment	Exploration PGS - Mars **Atmosphere**	Identify and develop suit materials capable of long duration exposure to dust, and abrasive activities without compromising mobility (walking, kneeling, etc).	Identify candidate materials and layups then test at the samples for compatability with the Mars surface dust/dirt, thermal, and radiation environments.
EC	EVA - Pressure Garment	Exploration PGS - Mars **Atmosphere**	Evaluate prototype components of new suit materials capable of long duration exposure to dust, and abrasive activities without compromising mobility (walking, kneeling, etc).	Conduct cycle testing of components in revelant environments.
EC	EVA - Pressure Garment	Exploration PGS - Mars **Atmosphere**	Develop low volume/high flexibility thermal protection for a seasonally variable convective thermal environment.	Identify candiate materials and lay-ups.
EC	EVA - Avionics	**EVA Avionics**		
EC	EVA - Avionics	Crew Autonomy		Develop an integrated crew interface that provides real-time system updates, buddy status information, task information, and surface navigation.
EC	EVA - Avionics	Crew Autonomy	Develop a low power, multi-color graphical display compatible that can be mounted on/in the suit helmet.	Build a prototype display that can be mounted inside or outside the suit helmet and function within the associated environment without obstructing primary crew tasks/FOV.
EC	EVA - Avionics	Crew Autonomy	Develop a control interface for the graphical display that can be actuated by the suited, pressurized EVA rewmember.	Build a prototype control system that can be mounted on the suit and function within the associated environment without obstructing primary crew tasks/FOV.
EC	EVA - Tools	**EVA Tools**		
EC	EVA - Tools	Tools for Surface EVA		Develop the tools and translation aids for EVA tasks on a planetary surface.
EC	EVA - Tools	Tools for Surface EVA	Develop tools to aid EVA task completion.	Develop a standard set of contruction and science tools to meet the needs identified in the ops con.
EC	Habitation Systems			To enable highly effective crew accommodations and optimization of logistical mass to support exploration class missions of increasing length and distance from earth

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EC	Habitation Systems	RFID Enabled Autonomous Logistics Management (REALM)	REALM-2 Flight Experiment	Develop and deliver Mobile reader for ISS flight experiment that will provide RFID reconnaissance or survey capability in locations where REALM-1 can not be utilized.
EC	Habitation Systems	RFID Enabled Autonomous Logistics Management (REALM)	CEP Flight Experiment	Integrate CEP application on ISS with zone readers to improve real-time on-demand tag identification and location.
EC	Habitation Systems	RFID Enabled Autonomous Logistics Management (REALM)	REALM-6DOF Flight Experiment	New hybrid infrared-RFID tag and projector system based on SBIR phase II development. Provides cm level accuracy and object orientation capability.
EC	Habitation Systems	Trash Management	Trash-to-Gas (TtG) Technology Development	Provide gasification of trash to enable overboard venting or conversion to mission required gases (e.g. methane or carbon oxides). Storage or jettison of residual material (ash/tar) depends on mission objectives. Water recovery is desirable but not required unless required by mission objectives.
EC	Habitation Systems	Multipurpose Cargo Transfer Bag (MCTB)	Develop MCTB Lightweight CQ/Storm Shelter	Develop minimal mass crew quarters to provide crew volume for sleeping and privacy in smaller vehicles for longer missions. Constructed from MCTBs to provide acoustic mitigation and radiation shielding (compacted trash or food packages) as well as repurpose logistical items that would normally be trashed.
EC	Habitation Systems	Acoustic Control	Active Acoustic Control System Prototype Development	Develop active noise control systems to reduce noise levels in private volumes (CQ).
EC	Habitation Systems	Laundry/Clothing	Laundry Sanitation System Technology Down select	Laundry sanitation freshens clothes so that they can reused a few times before discarding. This is unlike laundry which returns clothes to nearly new condition and allowing the to reused almost indefinitely.
EC	Habitation Systems	Laundry/Clothing	Sanitation System Flight Hardware Development	Demonstrate microgravity performance of gas/liquid generation (depending on tech). Utilize RFID tracking of clothing to determine effectiveness.
EC	Habitation Systems	Food and Nutrition	Refrigeration Hardware Development	Development of large volume (2-6 m^3) refrigeration technologies for exploration that require less mass, insulation volume, and power than the previous ISS Refrigerator Freezer Racks (never flown)
EC	Habitation Systems	Food and Nutrition	Long Shelf Life Food Development	Being addressed by HRP through a combination on internal work and external grants. Includes temperature, pressure, modeling, and food densification studies. Additional an on-orbit crew acceptance survey is planned.
EC	Habitation Systems	Housekeeping and Maintenance	Reusable Wipes and hygiene towels	After the clothing sanitation down-select and the solvent selection, develop reusable wet wipes that can be sanitized to allow for multiple reuses.
EC	Habitation Systems	Housekeeping and Maintenance	Solvent Generation for Reusable Wipes	The clothing sanitation down select influence solvent generation and vice versa. Select solvents that are compatible with closed loop ECLSS and can be generated on-orbit.
EC	Habitation Systems	Housekeeping and Maintenance	Antimicrobial omniphobic surface coatings	Develop coatings and surface treatments for crew contact surfaces that resist the accumulation of dust, dander, body oils, food residual, and microorganisms

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Aerosciences & Flight Mechanics				
EG	**Entry, Descent, and Landing**			Develop capabilities to safely deliver humans and equipment to the surface of destination bodies (with or without atmospheres) and then to return them safely to the Earth's surface.
EG	Entry, Descent, and Landing	**Large Mass Mars Hypersonic Aerocapture/Entry**		Improve mass capability to Mars surface to meet requirements of human Mars mission. **The key technology issues to resolve are:** **1) guidance and control for performing an aerocapture and entry of a large mass vehicle** **2) design of an aeroshell (including flexible TPS if required) which can package in the shroud of an SLS and still provide ample protection for a large human-scale payload during Mars aerocapture/entry.** If payload delivered to Mars surface exceeds 30 mt, then inflatable (HIAD) or deployable (ADEPT) heat shield technologies will be required. If payload mass is in the range of 10 to 30 mt, then rigid mid-L/D technology may be most cost-effective and least risk, although HIAD and ADEPT technologies could still apply. If payload mass is about 10 mt or less, then an MSL type rigid aeroshell should suffice and no technology development required.
EG	Entry, Descent, and Landing	**Large Mass Mars Hypersonic Aerocapture/Entry**	Mid-L/D Wind Tunnel Test program	Determine the aerodynamic, aerothermodynamic, and controllability properties of a selected mid-L/D configuration.
EG	Entry, Descent, and Landing	**Supersonic Deceleration of Large Mass Payloads**		Develop capability to decelerate large mass spacecraft from the end of the Entry phase to start of the Terminal Landing phase. **The key technology issues to resolve are:** **1) a supersonic deceleration device, such as parachutes or an inflatable structure, or** **2) supersonic retro-propulsion (SRP)**
EG	Entry, Descent, and Landing	**Supersonic Deceleration of Large Mass Payloads**	SRP Wind Tunnel Test program	Determine the aerodynamic, aerothermodynamic, and controllability properties of a selected SRP configuration. (proposed as part of Red Dragon analysis)
EG	Entry, Descent, and Landing	**Safe Precision Landing**		Develop NASA ALHAT (Autonomous precision Landing and Hazard Avoidance Technology) capability: the capability to safely, precisely and softy land in close proximity of surface destinations.
EG	Entry, Descent, and Landing	**Safe Precision Landing**	Development of terrestrial testbed for V&V of prototype ALHAT algorithms and future hardware	Develop testbed for benchmarking and maturing ALHAT algorithms and hardware with space-qualified processors, as well as conducting V&V of ALHAT components for infusion into future robotic and human missions. (iPAS)
EG	Entry, Descent, and Landing	**Safe Precision Landing**	Development of 4th-generation, integrated, space-qualifiable ALHAT NDL targeting robotic mission infusion	Complete development and environmental testing of the flight-qualifiabl, 4th-generation NDL velocimeter.
EG	Entry, Descent, and Landing	**Safe Precision Landing**	Revisions to ALHAT Navigation filter based on testing and flight lessons learned	Revise Navigation filter that will fuze traditional landing sensor measurements with the ALHAT Navigation Doppler Lidar (NDL) and a Terrain Relative Navigation (TRN) sensor for precision landing navigation.

Potential Gap Closure Option:

4.1 Academic Partnerships

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EG	Entry, Descent, and Landing	**Safe Precision Landing**	Development of 2nd-generation ALHAT HDS (utilizing current space-qualified processing)	Complete development of a prototype Hazard Detection system based on currently-available processing and sensing capabilities that can be infused (and matured) with near-term robotic landing missions (Discovery, New Frontiers, etc).
EG	Entry, Descent, and Landing	**Safe Precision Landing**	Terrestrial flight demonstratino of 2nd-generation ALHAT Hazard Detection System (HDS)	Terrestrially flight test prototype Hazard Detection System in relevant dynamic profiles for near-tear robotic landing missions (Discovery, New Frontiers, etc.)
EG	Entry, Descent, and Landing	**Safe Precision Landing**	Development of 3rd-generation, space-qualifiable ALHAT HDS (with full functionality for human Mars mission)	Infuse NASA high-speed processing, perform sensor-development trades, and architect the HDS capable of onboard hazard detection for a human-class Mars lander.
EG	Entry, Descent, and Landing	**Safe Precision Landing**	Revisions to ALHAT Navigation filter to incorporate Hazard Relative Navigation (HRN)	Revise Navigation filter that will fuze traditional landing sensor measurements with the ALHAT Navigation Doppler Lidar (NDL) and a Terrain Relative Navigation (TRN) sensor for precision landing navigation.
EG	Entry, Descent, and Landing	**Safe Precision Landing**	Software development for precision landing	Develop the precision landing guidance and autonomous flight management algorithms to perform Mars precision landing, which includes potentially large-divert maneuvers, as well as landing-hazard avoidance maneuvers.
EG	Entry, Descent, and Landing	**Safe Precision Landing**	Terrestrial demonstrations of complete, integrated ALHAT system	Implement an integrated ALHAT system, perform V&V with the previously developed iPAS testbed, and perform a terrestrial validation of capabilities in a dynamically relevant flight profile that includes TRN, hazard detection and avoidance, HRN, and precise soft landing.
EG	Entry, Descent, and Landing	**Safe Precision Landing**	Software development for crew-supervisor control during precision landing and hazard avoidance	Develop interfaces and GN&C logic to blend crew supervisory and control inputs into the onboard ALHAT autonomy software that is enabling safe and precise soft landing.
EG	Autonomous Rendezvous & Docking (AR&D)			Develop capabilities enabling the autonomous construction or reconfiguration of vehicles in space
EG	Autonomous Rendezvous & Docking (AR&D)	Develop relative navigation algorithms		Create and demonstrate software that can integrate sensor information into a navigation solution within mission time constraints on flight computer architecture
EG	Autonomous Rendezvous & Docking (AR&D)	Develop relative navigation algorithms	Visual Odometry	Software that utilitizes data from the AR&D common sensor suite for navigation.
EG	Autonomous Rendezvous & Docking (AR&D)	Software		AR&D software can be shared among SMD and HEOMD projects, saving time and leveraging cost
EG	Autonomous Rendezvous & Docking (AR&D)	Software	Software capture and reuse (AR&D warehouse)	Support cross-project product deployment by providing a warehouse of software for infustion with other projects
EG	Deep Space GN&C			Develop capability for spacecraft to evaluate on-board state while many light minutes from Earth or during comm outage, and provide on-board capabilites to execute nominal or abort trajetory maneuvers with minimal ground assist to support crew safety

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4.1 Academic Partnerships

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EG	Deep Space GN&C	On-board Navigation		To date, on-board vehicle sensors are insufficient to calculate navigation state without growth of error. Periodic nav updates to the vehicle from the ground are required to correct from on-board error growht. This pursuit is focused on identifying navigation sensors and algorithms, that will allow the vehicle systems to autonomously develop an absolute navigation state with a bounded error. The nav state must be known with sufficient resolution to make on-board judgements and to be able to execute GNC commands safely (such as abort initiation.)
EG	Deep Space GN&C	On-board Navigation	Follow-up Optical Navigation Misison	Continue to develop Optical Navigation Techniques
EG	Deep Space GN&C	On-board Navigation	Develop X-Ray Nav beyond SEXTANT	Next generation X-ray navigation hardware, need to reduce SWAP
Propulsion and Power				
EP	Reliable Pyrotechnics			More reliable pyrotechnic systems are needed to lower LOC/LOM probabilities over long duration Mars missions. Develop methods for improving pyrotechnic reliability in separation systems and advance Non-Destructive Evaluation (NDE) methods and addressable firing circuitry.
EP	Reliable Pyrotechnics	NDE Method Development	Certification of new NDE tools for pyrotechnic devices.	New NDE tools become available for pyrotechnic device verification programs.
EP	Integrated Propulsion, Power, and ISRU for Exploration			Overall: Eliminate requirement to carry reactants to Mars Surface By 2020, develop to TRL 6+ integrated LOX/CH4-based ISRU and propulsion & power systems for flight on 2028 Mars Precursor mission and which are directly scalable to Human Mars surface mission requirements. By 2023, develop to TRL 6+ integrated LOX/LCH4 ISRU, propulsion, and power systems which use common reactant storage for Main & RCS propulsion and fuel cell power, which can be fully integrated with ECLSS and thermal management systems and which are scaled from Mars Precursor systems. Integrated LOx/LCH4 system includes high reliability propulsion and fluid systems that integrate with a reactant grid common to Mars surface, Mars Atmosphere and Regolith collection and processing for ISRU O2 and CH4 production, LOX/LCH4 solid oxide fuel cell technology, and O2 and CH4 cryogenic reactant storage, both stationary and mobile.
EP	Integrated Propulsion, Power, and ISRU for Exploration	Cryogenic Methane Storage		Technology to passively store methane in space and Martian atmosphere
EP	Integrated Propulsion, Power, and ISRU for Exploration	Cryogenic Methane Storage	TBD	TBD program (STMD or AES) to continue advance of methane reactant storage technology to TRL 6

Potential Gap Closure Option: **4.1 Academic Partnerships**

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EP	Integrated Propulsion, Power, and ISRU for Exploration	LOx/LCH4 Power Generation		Technology of chemical power generation from LOx and LCH4 reactants
EP	Integrated Propulsion, Power, and ISRU for Exploration	LOx/LCH4 Power Generation	STMD New Seedling and New Start	STMD program to continue advance of SOFC technology to TRL 6
EP	Integrated Propulsion, Power, and ISRU for Exploration	LOx/LCH4 Propulsion		Technology of propulsion from LOx/LCH4
EP	Integrated Propulsion, Power, and ISRU for Exploration	LOx/LCH4 Propulsion	TBD	TBD program to continue advance of LOx/LCH4 propulsion technology to TRL 6
EP	Breakthrough Power & Propulsion "Eagleworks"			By 2025, build and leverage partnerships to bring to TRL 3+ power/propulsion technologies that can enable human missions to Mars of round-trip duration and full mission IMLEO of less than half that of DRM 9.0
EP	Breakthrough Power & Propulsion "Eagleworks"	Quantum Vacuum Propulsion	Flight demonstration of QV Thruster.	Develop thruster technology based on control and acceleration of the Quantum Vacuum, requiring no propellant be provided to the system.
EP	Breakthrough Power & Propulsion "Eagleworks"	Quantum Vacuum Propulsion	~1 kW in-space test campaign	Validate QV thruster performance in space via operation on ISS or free-flying payload
EP	Breakthrough Power & Propulsion "Eagleworks"	Quantum Vacuum Propulsion	15 kW in-space demonstration	Validate QV thruster high power capability in deep space mission.
EP	Breakthrough Power & Propulsion "Eagleworks"	Solid State Energy Conversion	Conceptual system design of integrated nuclear electric propulsion (NEP) system with thermionic energy conversion	Develop solid state thermionic energy conversion technology capable of reliable operation at >1800 K and at >20% thermodynamic efficiency and integrate into a complete NEP system concept.
EP	Breakthrough Power & Propulsion "Eagleworks"	Solid State Energy Conversion	Full scale convertor module design and development	Partner to design, build, and test thermionic convertor module that meets overall performance goals in environments (TRL 6)
EP	Breakthrough Power & Propulsion "Eagleworks"	Solid State Energy Conversion	NEP Design Study with GRC	Work through full Nuclear Electric Propulsion system design based on thermionic convertor
EP	Breakthrough Power & Propulsion "Eagleworks"	Advanced Electrostatic Energy Source	Prototype Reactor Operation	Partner with industry to develop ground prototype aneutronic fusion reactor with direct energy conversion.
EP	Breakthrough Power & Propulsion "Eagleworks"	Advanced Electrostatic Energy Source	Plasma confinement analysis complete	Conduct intensive analytical studies to determine confinement design for aneutronic fusion plasma

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EP	Breakthrough Power & Propulsion "Eagleworks"	Advanced Electrostatic Energy Source	"Building Block" confinement experiments	Conduct low cost experimental program to validate computational predictions of different aspects of plasma confinement.
EP	Breakthrough Power & Propulsion "Eagleworks"	Advanced Electrostatic Energy Source	"Wrapper" confinement experiments	Conduct subcritical experimental studies in a complete plasma confinement system
EP	Breakthrough Power & Propulsion "Eagleworks"	Advanced Electrostatic Energy Source	Ground prototype reactor	Build and operate a full scale, critical prototype fusion reactor.
Software, Robotics, Simulation				
ER	Robotics			Development of advanced robotic systems to support Human Robotic Systems interaction for human space exploration
ER	Robotics	Dynamic Systems Testing and Simulation		Robotic technologies that provide analog environments for testing products under development for the Evolvable Mars Campaign (docking/berthing systems, EVA mobility and tools, robotic mobility systems, etc.)
ER	Robotics	Dynamic Systems Testing and Simulation	Robotic Motion Simulators	Develop new human-rated 6DOF motion base to pair with Virtual Reality (VR) applications for mission simulation and astronaut (and Robot/machines) training, Timeframe FY16-FY25
Structural Engineering				
ES	**Entry, Descent & Landing**	**Entry**		
ES	Entry, Descent & Landing	Heatshield for High Speed Atmospheric Entry (return from Cis-lunar velocities and above)		Develop and test the next generation Human Spaceflight Vehicle TPS and materials capable of achieving a >12km/s entry environment by 2025.
ES	Entry, Descent & Landing	Heatshield for High Speed Atmospheric Entry: **Modeling**	Graduate Research: Early Rise Phenomena	To understand the complex physics of the early rise in TPS material temperature witnessed in material test.
ES	Entry, Descent & Landing	Heatshield for High Speed Atmospheric Entry: **Modeling**	Research: End-game-recession	Define physics driving late in flight recession estimates to improve overall sizing of heatshield.
ES	Entry, Descent & Landing	Heatshield for High Speed Atmospheric Entry: **Modeling**	Integrated Thermoelastic Design/Analysis Methods	Develop a multidisciplinary analysis tool that integrates thermal and stress analysis into one tool for design of heatshields and systems.
ES	Entry, Descent & Landing	Heatshield for High Speed Atmospheric Entry: **Environment**	Torch	Develop testing capability and perform material characterization to test key phenomena of early rise and end game recession.
ES	Entry, Descent & Landing	Heatshield for Large Mass (>18MT) EDL on Mars		

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4.1 Academic Partnerships

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ES	Entry, Descent & Landing	Heatshield for Large Mass (>18MT) EDL on Mars: **Material**	Mars Entry at conjunction class velocities (7.5 km/s) does not require significant new rigid heatshield material development. Alternate options, including inflatable materials are being investigated by LaRC and ARC.	
ES	Entry, Descent & Landing	Heatshield for Large Mass (>18MT) EDL on Mars: **Environment**	CO2 Testing Capability: TORCH	Testing in CO2 necessary to get representative flight environments.
Avionic Systems				Give Humans exploring space the Avionics capabilities they need (and some they want) within current SWAP limitations (x2?).
EV	Human/ System Interfaces			Develop and apply innovative human interface technologies to human spaceflight to increase crew efficiency, reduce costs and SWAP, and support changing future exploration mission needs.
EV	Human-System Interfaces	Audio		By 2022, demonstrate the use of advanced commercially available Audio hardware and speech/voice/text algorithms to realize a 30% crew time reduction and 20% weight reduction (WAG).
EV	Human-System Interfaces	Audio	Array Microphones Development for AdvSS	Application of beam forming technology for hands-free voice communication, sound source localization and tracking.
EV	Human-System Interfaces	Wearable Technology		By 2020, Demonstrate onboard ISS wearable sensing and hands-free control (Reduce crew tasking by X%, potentially reduce Avionics mass by X%)
EV	Human-System Interfaces	Wearable Technology	On-Body Visual Display Development and Evaluation	Evaluate and integrate a wrist worn display within the communication/network architecture of the ISS and A&S. Evaluate wrist worn device verses head mounted display technology.
EV	Command & Data Handling			
EV	Command & Data Handling	High Performance Super Computer (HPSC) for future spacecraft	Dual Cluster (Quad-Core ARM) Chiplet architecture (8-core) for 75X the performance of the RAD750 (200 MOPS), and 2 Chiplets (16-core) for 100X perfomance at 10W- development by a Radiation Hardened By Design (RHBD)	By 2021, Guide industy to develop high performance multi-core super computer that is homogeneouly architected to support tightly coupled applications of future spacecraft for NASA and USAF.
EV	Command & Data Handling	High Performance Super Computer (HPSC) for future spacecraft	Learn from COTS version of HPSC	Evaluate and get trained with COTS solution that is comparable to HPSC (Xilinx' Zynq Ultrascale MPSoC)
EV	Command & Data Handling	Processor Performance Assessments & Benchmarking		By 2021, Guide and access data through NSF Center of High performance Reconfigurable Computing (CHREC) Consortium enabling undergrad- ane grad-students to get smart on research and development of processors and their performance assesment
EV	Command & Data Handling	Board Level Developments for Distributed Processing system - CHREC and MISL		By 2021, Modular, Scaleable, Reconfiguable, Distributed lower level control system development to enhance further reduction of SWAP at subsystem needs

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EV	Command & Data Handling	Radiation hardened/tolerant (RH/T) Memory Storage		By 2021, Modular, Scaleable, Reconfiguable, Distributed lower level control system development to enhance further reduction of SWAP at subsystem needs
EV	Command & Data Handling	Rad-Hard High Speed Interconnects for Onboard Spacecraft Data Networks	Guide industry towards developing a non-proprietary radiation-hard Ethernet PHY transceiver.	Monitor the progress of the SEPHY project to develop a non-proprietary rad-hard 100 Base-T Ethernet PHY.
EV	Command & Data Handling	Rad-Hard High Speed Interconnects for Onboard Spacecraft Data Networks		Promote industry to develop rad-hard PHYs supporting higher throughput (>5 Gbit/s) and fiber-based physical layers.
EV	Command & Data Handling	Instrumentation		By 2021, Develop/Demonstrate lightweight Instrumentation systems in a variety of environments which are modular, scalable, reconfigurable for both flight and prototype applications.
EV	Command & Data Handling		Rad tolerant DAQ and sensor systems	By 2021, Modular, Scaleable, Reconfiguable, Distributed lower level control system development to enhance further reduction of SWAP at subsystem needs
EV	Radiation & EEE Parts			Reduce the overall cost of electronics parts and improve performance by using a combination of new test, analysis, and manufacturing techniques.
EV	Radiation & EEE Parts	State of Art Electronics		By 2020, Reduce the cost of electronics parts 30% by expanding manufacturing techniques to allow the use of state of the art electronic components in critical HSF applications.
EV	Radiation & EEE Parts	State of Art Electronics	Engage with Auburn Center for Advanced Vehicle & Extreme Environment Electronics ($CAVE^3$)	
EV	Radiation & EEE Parts	State of Art Electronics	University of Texas - El Paso (UTEP) Advanced Manufacturing	