The Science Mission Directorate will carry out the scientific exploration of our Earth, the planets, moons, comets, and asteroids of our Solar System and beyond. SMD's future direction will be moving away from exploratory missions (orbiters and flybys) into more detailed/specific exploration missions that are at or near the surface (landers, rovers, and sample returns) or at more optimal observation points in space. These future destinations will require new vantage points, or would need to integrate or distribute capabilities across multiple assets. Future destinations will also be more challenging to get to, have more extreme environmental conditions and challenges once the spacecraft gets there, and may be a challenge to get a spacecraft or data back from. A major objective of the NASA science spacecraft and platform subsystems development efforts are to enable science measurement capabilities using smaller and lower cost spacecraft to meet multiple mission requirements thus making the best use of our limited resources. To accomplish this objective, NASA is seeking innovations to significantly improve subsystem capabilities while reducing the mass and cost, that would in turn enable increased scientific return for future NASA missions.

A spacecraft bus is made up of many subsystems like: propulsion; thermal control; power and power distribution; attitude control; telemetry command and control; transmitters/antenna; computers/on-board processing/software; and structural elements. This topic area addresses the future needs in many of these sub-system areas, as well as their application to specific spacecraft and platform needs. Innovations for 2010 are sought in the areas of:

- Command and Data Handling, and Instrument Electronics
- Thermal Control Systems
- Power Generation and Conversion
- Propulsion Systems
- Power Management and Storage
- Guidance, Navigation and Control
- Planetary Ascent Vehicles (non-Earth)
Unmanned Aircraft and Sounding Rocket Technologies

Terrestrial and Planetary Balloons

Earth Entry Vehicle Systems

Significant changes to the S3 Topic for 2010 are:

- Consolidation of spacecraft and platform related technologies from S4 Low-cost Small Spacecraft and Technologies into the applicable S3 Subtopics for a more integrated approach to spacecraft and platform subsystems technology development spanning from small to large spacecraft.

- Merged the 2009 subtopics of S3.01 Command, Data Handling, and Electronics, S3.07 Sensor and Platform Data Processing and Control, O1.01 Coding, Modulation, and Compression, and related content from the S4 Topic into a single Command and Data Handling, and Instrument Electronics subtopic.

- Merged the 2009 subtopics of Terrestrial Balloons with Planetary Balloons (from S5) into a single subtopic for balloon technologies.

- Added a new Earth Entry Vehicle Systems subtopic.

The following references discuss some of NASA's science mission and technology needs:

- The 2009-2010 Planetary Science Decadal Survey is currently ongoing and due in 2011. This decadal survey is considering technology needs. http://sites.nationalacademies.org/SSB/CurrentProjects/ssb_052412

Subtopics

S3.01 Command, Data Handling, and Electronics

Lead Center: GSFC

Participating Center(s): ARC, JPL, JSC, LaRC
NASA’s space based observatories, fly by spacecraft, orbiters, landers, and robotic and sample return missions, require robust command and control capabilities. Advances in technologies relevant to command and data handling and instrument electronics are sought to support NASA’s goals and several missions and projects under development.

http://science.nasa.gov/search/?q=missions+under+development
http://www.nap.edu/catalog.php?record_id=10432

The subtopic goals are to: (1) develop high-performance processors and memory architectures and reliable electronic systems, (2) develop an avionics architecture that is flexible, scalable, extensible, adaptable, and reusable, and (3) develop tools technologies that can enable rapid deployment of high-reliability, high-performance onboard processing applications and interface to external sensors on flight hardware. The subtopic objective is to elicit novel architectural concepts and component technologies that are realistic and operate effectively and credibly in environments consistent with the future NASA Science missions.

Successful proposal concepts should significantly advance the state-of-the-art. Proposals should clearly (1) state what the product is; (2) identify the needs it addresses; (3) identify the improvements over the current state of the art; (4) outline the feasibility of the technical and programmatic approach; and (5) present how it could be infused into a NASA program. Furthermore, proposals should indicate an understanding of the intended operating environment, including temperature and radiation. It should be noted that environmental requirements can vary significantly from mission to mission. For example, some low earth orbit missions have a total ionizing dose (TID) radiation requirement of less than 10 kRad, while some planetary missions can have requirements well in excess of 1MRad. For descriptions of radiation effects in electronics, the proposer may visit http://radhome.gsfc.nasa.gov/radhome/background.htm. If a Phase II proposal is awarded, the combined Phase I and Phase II developments should produce a prototype that can be characterized by NASA.

The technology priorities sought are listed below.

C&DH Architectures

- High performance hardware/software processor platform capable of implementing high-throughput numerically intensive real-time applications that entail autonomous landing and guidance and control. Sensor computations. Key performance metrics must achieve 40 GOPS, 20 GMACS, and 40,000 MIPS with EDAC-protected memory, comprising 256 (TBR) MB DDR volatile for flight software execution and 256 (TBR) MB non-volatile for image storage, respectively. Standard interfaces must include Gigabit Ethernet, RS232 UART serial ports, and control interfaces to Lidar/Camera with a maximum bandwidth of up to 1 Gbps. Platform should be in 6U form factor and consume no greater than 20 W. Processor trades should be conducted to balance size, weight, power against reliability, flexibility, and performance for future space missions. Radiation hardened by design best practices, rapid development tools, and a radiation-tolerant path to space qualification are appealing features. The platform should operate, at reduced capability, during high energy cosmic rays events. Principal capabilities will encompass command generation and handling, control of safe landing system, sensor data processing and storage, and on-board memory management, optimized for acceptable performance and reliability.

- Novel, miniaturized, low-power C&DH architectures tailored to small spacecraft. Solutions must perform functions of traditional C&DH systems at a fraction of the SWAP (Size, Weight, and Power). Proposed systems should be capable of supporting typical spacecraft C&DH functions and should be radiation
tolerant, and should further be compatible with Space Plug and Play (SPA) architectures, including SPA-1.

- Development system design tools that (a) take full advantage of rapid prototyping hardware-in-the-loop (HIL) environments for hybrid processing platforms, and (b) automate/accelerate the deployment of data processing and sensor interface design on flight hardware.

**Discrete Components for C&DH Subsystems**

- Processors - General purpose (processor chips and radiation-hardened by design synthesizable IP cores) and special purpose single-chip components (DSPs), with sustainable processing performance and power efficiency (>40,000 MIPS at >1,000 MIPS/W for general purpose processing platforms, >20 GMACs at >5 GMACS/W for computationally-intensive processing platforms), and tolerance to total dose and single-event radiation effects. Concepts must include tools required to support an integrated hardware/software development flow.

- Radiation-hardened non-volatile low power memories >100KRad.

- Radiation hardened DDR1, DDR2, and DDR3 high speed memories.

**Onboard Network Architectures and Devices**

- Radiation-hardened physical layer components for (copper/fiber-optic) onboard data busses (e.g., SpaceWire, Ethernet, Serial Rapid I/O, Ring Bus) speeds >1Gb/s.

- Power distribution through onboard data network technologies.

- Wireless data network architectures and components.

- Wireless RFID housekeeping sensors and interrogation hardware.

**Tunable, Scalable, Reconfigurable, Adaptive Fault-Tolerant Onboard Processing Architectures**

- Technologies Enabling Use of Commercial Devices for Spaceflight Applications, including Radiation Hardened By Software (RHBS) approaches.

- Highly adaptive reconfigurable computing platforms (including hybrid DSP/FPGA/CPU architectures).

- Tools and methodologies to accelerate development of highly reliable applications on reconfigurable computing platforms.

**Technologies Enabling Custom Radiation-Hardened Component Development**

- Radiation-Hardened-By-Design (RHBD) cell libraries.

- Radiation-hardened Programmable Logic Devices (PLDs) and structured ASIC devices (digital and/or mixed-signal).
Intellectual Property (IP) cores allowing the implementation of highly reliable System-On-a-Chip (SOC) devices for spacecraft subsystems or instrument electronics. Functions of interest include processors, memory interfaces, and data bus interfaces.

Novel, Ruggedized Packaging/Interconnect

- High density packaging (enclosures, printed wiring boards) enabling miniaturization.
- Novel high density and low resistance cabling, including carbon nanotube (CNT) based wiring.

Data Compression

- Ground-based high-speed data compression decoder capable of decoding coded bit stream conforming to CCSDS 122.0-B-1 Image Data Compression standard (www.ccsds.org), providing over 40 M samples/sec for up to 16-bit image data coded in an embedded bit stream. Spaceflight hardware currently exists to perform the encoding function. The requested decoder would be used for ground processing of a downlinked encoded data stream. The decoder shall not consume more than 5 watts of power at the specified speed.

Power Conversion and Distribution

- Radiation-hardened high efficiency Point-Of-Load (POL) down converter.
- Power distribution through onboard data network technologies.

S3.02 Thermal Control Systems

Lead Center: GSFC
Participating Center(s): ARC, GRC, JPL, MSFC

Future Spacecraft and instruments for NASA's Science Mission Directorate will require increasingly sophisticated thermal control technology. Innovative proposals for the cross-cutting thermal control discipline are sought in the following areas:

- Optical systems, lasers (ICESAT 2), and detectors require tight temperature control, often to better than +/- 1°C. Some new missions such as LISA require thermal gradients held to even tighter micro-degree levels. Methods of precise temperature measurement and control to tight temperature levels are needed.

- New generations of electronics used on numerous missions have higher power densities than in the past.
High conductivity, vacuum-compatible interface materials to minimize losses across make/break interfaces are needed to reduce interface temperature gradients and facilitate heat removal.

- Detectors and optical systems at infrared wavelengths require efficient cooling methods to low temperatures. Advanced thermoelectric devices with higher Coefficients of Performance (COP) are required.

- More sensitive instruments are resulting in increased requirements for high electrical conductivity on spacecraft instruments and surfaces. This has increased the need for advanced thermal control coatings, particularly with low absorptance, high emittance, and good electrical conductivity.

- Phase change systems are needed for Mars or Lunar applications. Reusable phase change systems are desired which can be employed to absorb transient heat dissipations during instrument operations. Technology is sought for phase change systems, typically near room temperature, which can then either store this energy or provide an exothermic process, which would provide heat for instrument power-on after the dormant phase.

- Future high-powered missions, some possibly nuclear powered, may require active cooling systems to efficiently transport large amounts of heat. These include single and two-phase mechanically pumped fluid loop systems which accommodate multiple heat sources and sinks; and long life, lightweight pumps which are capable of generating a high pressure head. It also includes efficient, lightweight, oil-less, high lift vapor compression systems or novel new technologies for high performance cooling up to 2 KW.

- Exploration science missions beyond earth orbit present engineering challenges requiring systems, which can withstand extreme temperatures ranging from high temperatures on Venus to the cryogenic temperatures of the outer planets. High performance insulation systems, which are more easily fabricated than traditional multi-layer (MLI) systems, are required for both hot and cold environments. Potential applications include traditional vacuum environments, low-pressure carbon dioxide atmospheres on Mars, and high-pressure atmospheres found on Venus.

- Low-Cost Variable Conductance Heat Pipes for Terrestrial Balloons - Please see sub-topic S3.07 Terrestrial and Planetary Balloons to respond to this requirement.

- Thermal Control Systems for S3.10 Earth Entry Systems. Low mass/cost/power/complexity payload thermal control systems are needed, which can maintain the sample temperature in-flight, through impact, and post landing. Candidate thermal control systems must be able to maintain a payload up to 10 kg at temperature levels ranging from cryogenic up to -20C (depending on specific mission requirements) for up to 1 day after landing/impact, and cannot exceed 20kg in total mass.

Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II hardware demonstration. Phase II should deliver a demonstration unit for NASA testing at the completion of the Phase II contract.

Note to Proposer: Subtopic X3.04 Thermal Control Systems for Human Spacecraft, under the Exploration Mission Directorate, also addresses thermal control technologies. Proposals more aligned with exploration mission requirements should be proposed in X3.04.

_S3.03 Power Generation and Conversion_
Future NASA science missions will employ Earth orbiting spacecraft, planetary spacecraft, balloons, aircraft, surface assets, and marine craft as observation platforms. Proposals are solicited to develop advanced power generation and conversion technologies to enable or enhance the capabilities of future science missions. Requirements for these missions are varied and include long life, high reliability, significantly lower mass and volume, higher mass specific power, and improved efficiency over the state of practice for components and systems. Other desired capabilities are high radiation tolerance and the ability to operate in extreme environments (high and low temperatures and over wide temperature ranges).

While power generation technology affects a wide range of NASA missions and operational environments, technologies that provide substantial benefits for key mission applications/capabilities are being sought in the following areas.

### Radioisotope Power Conversion

Radioisotope technology enables a wide range of mission opportunities, both near and far from the Sun and hostile planetary environments including high energy radiation, both high and low temperature and diverse atmospheric chemistries. Technology innovations capable of advancing lifetimes, improving efficiency, highly tolerant to hostile environments are desired for all thermal to electric conversion technologies considered here. Specific systems of interest for this solicitation are listed below.

**Stirling Power Conversion**: advances in, but not limited to, the following:

- System specific mass greater than 10 We/kg
- Highly reliable autonomous control
- Low EMI
- High temperature, high performance materials, 850-1200 C
- Radiation tolerant sensors, materials and electronics

**Thermoelectric Power Conversion**: advances in, but not limited to, the following:

- High temperature, high efficiency conversion greater than 10%
- Long life, minimal degradation
- Higher power density

### Cubesat and Nanosat On-orbit Power Generation
NASA desires to build smaller spacecraft types carrying smaller instrument packages. However, power requirements to accommodate these instruments and spacecraft systems will not necessarily scale down in a similar fashion as spacecraft size. Therefore, power generation and power management technologies are sought that are compatible with small spacecraft geometries and sizes, especially in cubesat and nanosat form factors.

**Photovoltaic Energy Conversion**

Photovoltaic cell, blanket, and array technologies that lead to significant improvements in overall solar array performance (i.e. conversion efficiency >30%, array mass specific power >300 watts/kilogram, decreased stowed volume, reduced initial and recurring cost, long-term operation in high radiation environments, high power arrays, and a wide range of space environmental operating conditions) are solicited. Technologies specifically addressing the following mission needs are highly sought:

- Photovoltaic cell and blanket technologies capable of low intensity, low-temperature operation applicable to outer planetary (low solar intensity) missions
- Photovoltaic cell, blanket and array technologies capable of enhancing solar array operation in a high intensity, high-temperature environment (i.e. inner planetary and solar probe-type missions)
- Lightweight solar array technologies applicable to solar electric propulsion missions. Current missions being studied require solar arrays that provide 1 to 20 kilowatts of power at 1 AU, are greater than 300 watts/kilogram specific power, can operate in the range of 0.7 to 3 AU, provide operational array voltages up to 150 volts and have a low stowed volume.

Thermophotovoltaic conversion is currently focused on follow-on technology for the International Lunar Network (ILN) and for the outer planets mission. Advances sought, but not limited to, include:

- Low-bandgap cells having high efficiency and high reliability
- High temperature selective emitters
- Low absorptance optical band-pass filters
- Efficient multi-foil insulation

Note to Proposer: Topic X8 under the Exploration Mission Directorate also addresses power technologies (X8.03 Space Nuclear Power Systems, and X8.04 Advanced Photovoltaic Systems). Proposals more aligned with exploration mission requirements should be proposed in X8.
The Science Mission Directorate (SMD) needs spacecraft with more demanding propulsive performance and flexibility for more ambitious missions requiring high duty cycles, more challenging environmental conditions, and extended operation. Planetary spacecraft need the ability to rendezvous with, orbit, and conduct in situ exploration of planets, moons, and other small bodies in the solar system (http://www.nap.edu/catalog.php?record_id=10432). Future spacecraft and constellations of spacecraft will have high-precision propulsion requirements, usually in volume- and power-limited envelopes.

This subtopic seeks innovations to meet SMD propulsion requirements, which are reflected in the goals of NASA's In-Space Propulsion Technology program to reduce the travel time, mass, and cost of SMD spacecraft. Advancements in chemical and electric propulsion systems related to sample return missions to Mars, small bodies (like asteroids, comets, and Near-Earth Objects), outer planet moons, and Venus are desired. Additional electric propulsion technology innovations are also sought to enable low cost systems for Discovery class missions, and eventually to enable radioisotope electric propulsion (REP) type missions.

The focus of this solicitation is for next generation propulsion systems and components, including high-pressure chemical rocket technologies and low cost/low mass electric propulsion technologies. Specific sample return propulsion technologies of interest include higher-pressure chemical propulsion system components, lightweight propulsion components, and Earth-return vehicle propulsion systems. Propulsion technologies related specifically to planetary ascent vehicles will be sought under S3.08 Planetary Ascent Vehicle.

Chemical Propulsion Systems

Technology needs include:

- Improved materials and manufacturing processes to produce Iridium/Rhenium apogee class thruster chambers with improved mechanical properties targeting a yield stress of 40ksi and an elongation of 10%;
- Advanced nontoxic mono-propellant rockets for in-space applications.

Electric Propulsion Systems

This subtopic also seeks proposals that explore uses of technologies that will provide superior performance in for high specific impulse/low mass electric propulsion systems at low cost. These technologies include:

- Efficient thrusters with up to 1 kW of input power that provide thrust up to 20 mN with a specific impulse between 1600 to 3500 seconds;
- A throttleable dual mode thruster that is capable of operating in both high thrust and high specific impulse modes for a fixed power;
- High power electric propulsion thrusters (>20 kW) and components including cathodes, ion optics, and low sputtering materials with long life (>1x108 N-s).
Proposals should show an understanding of the state of the art, how there technology is superior, and of one or more relevant science needs. The proposals should provide a feasible plan to fully develop a technology and infuse it into a NASA program.

Note to Proposer: Topic X2 under the Exploration Mission Directorate also addresses advanced propulsion. Proposals more aligned with exploration mission requirements should be proposed in X2.

**S3.05 Power Management and Storage**

Future NASA science objectives will include missions such as Earth Orbiting, Venus, Europa, Titan, Lunar Quest and Space Weather. Under this subtopic, proposals are solicited to develop energy storage and power electronics to enable or enhance the capabilities of future science missions. The unique requirements for the power systems for these missions can vary greatly, with advancements in components needed above the current State of the Art (SOA) for long life, high reliability, low mass/volume, radiation tolerance, and wide temperature operation.

**Energy Storage**

Future science missions will require advanced primary and secondary battery systems capable of operating at temperature extremes from -100°C for Titan missions to 400°C to 500°C for Venus missions, and a span of -230°C to +120°C for Lunar Quest. In addition, high energy-density rechargeable electrochemical battery systems that offer greater than 50,000 charge/discharge cycles (10 year operating life) for low-earth-orbiting spacecraft, 20 year life for geosynchronous (GEO) spacecraft, are desired. Advancements to battery energy storage capabilities that address one or more of the above requirements for the stated missions combined with very high specific energy (>200 Wh/kg for secondary battery systems) and energy density, along with radiation tolerance are of interest.

In addition to batteries, other advanced energy storage/load leveling technologies designed to the above mission requirements, such as flywheels, supercapacitors or magnetic energy storage, are of interest. These technologies have the potential to minimize the size and mass of future power systems.

**Power Management and Distribution (PMAD)**

The "New Frontiers in the Solar System: An Integrated Exploration Strategy" (http://www.nap.edu/catalog.php?record_id=10432), the 2006 Solar System Exploration Roadmap (http://nasascience.nasa.gov/about-us/science-strategy) and the Science Plan for NASA's Science Mission Directorate (http://nasascience.nasa.gov/about-us/science-strategy) all describe the need for radioisotope power systems (RPS) for planetary exploration. In conjunction with the RPS, intelligent, fault-tolerant PMAD technologies are needed to efficiently manage the system power for these deep space missions. Advances in electrical power technologies are required for the electrical components and systems for these future platforms to address program size, mass, efficiency, capacity, durability, and reliability requirements. Of importance are expected improvements in energy density, speed, efficiency, or wide-temperature operation (-125°C to over 450°C) with a number of
thermal cycles. Advancements are sought for power electronic devices, components and packaging for Venus type missions with power ranges of a few watts for minimum missions up to a few kilowatts for large missions.

For the lower power applications (up to 20 watts), NASA desires to build smaller spacecraft types carrying smaller instrument packages. However, power requirements to accommodate these instruments and spacecraft systems will not necessarily shrink in a similar fashion as spacecraft size. Therefore, power management technologies are sought that are compatible with small spacecraft geometries and sizes. These Electrical Power Systems should be compatible with Space Plug and Play (SPA) architectures.

Overall technologies of interest include:

- Intelligent, fault-tolerant electrical components and PMAD systems
- High temperature devices and components (up to 450°C)
- Advanced electronic packaging for thermal control and electromagnetic shielding
- Plug and Play compatibility for low power applications

Power Conversion and Distribution relevant to Command, Data Handling, and Electronics, will be covered under subtopic S3.01.

Power Storage for Terrestrial Balloons will be covered under sub-topic S3.07 Terrestrial and Planetary Balloons.

Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II, and when possible, deliver a demonstration unit for NASA testing at the completion of the Phase II contract. Phase II emphasis should be placed on developing and demonstrating the technology under relevant test conditions. Additionally, a path should be outlined that shows how the technology could be commercialized or further developed into science-worthy systems.

Other subtopics, which could potentially benefit from these technology developments include O5 - Low-Cost and Reliable Access to Space (LCRATS), S5.05 - Extreme Environments Technology, and S5.01 - Planetary Entry, Descent and Landing Technology. Battery development could also be beneficial to X6.02 - Advanced Space-rated Batteries, which is investigating some similar technologies in the secondary battery area but with very different operational requirements. Power Management and Distribution could be beneficial to X8.05 - Advanced Power Conversion Systems AND Management and Distribution (PMAD), which is investigating similar technologies, but with very different power levels.
S3.06 Guidance, Navigation and Control

Advances in the following areas of guidance, navigation and control are sought.

**Navigation systems** (including multiple sensors and algorithms/estimators, possibly based on existing component technologies) that work collectively on multiple vehicles to enable inertial alignment of the formation of vehicles (i.e., pointing of the line-of-sight defined by fixed points on the vehicles) on the level of milli-arcseconds relative to the background star field.

**Light-weight sensors** (gyroscopic or other approach) to enable milli-arcsecond class pointing measurement for individual large telescopes and low cost small spacecraft.

**Isolated pointing and tracking platforms** (pointing 0.5 arcseconds, jitter to 5 milli-arcsecond), targeted to placing a scientific instrument on GEO communication satellites that can track the sun for > 3 hours/day.

**Working prototypes of GN&C actuators** (e.g., reaction or momentum wheels) that advance mass and technology improvements for small spacecraft use. Such technologies may include such non-contact approaches such as magnetic or gas. Superconducting materials, driven by temperature conditioning may also be appropriate provided that the net power used to drive and condition the "frictionless" wheels is comparable to traditional approaches.

Proposals should show an understanding of one or more relevant science needs, and present a feasible plan to fully develop a technology and infuse it into a NASA program.

S3.07 Terrestrial and Planetary Balloons

All proposals should show an understanding of one or more relevant science needs, and present a feasible plan to fully develop a technology and infuse it into a NASA program.

Terrestrial Scientific Balloons Planetary Balloons

Innovations in materials, structures, and systems concepts have enabled buoyant vehicles to play an expanding role in planning NASA's future Solar System Exploration Program. Balloons and airships are expected to carry scientific payloads at Titan and Venus that will perform in situ investigations of their atmospheres and near surface environments. Both Titan and Venus feature extreme environments that significantly impact the design of balloons for those two worlds. Proposals are sought in the following areas:
Titan Montgolfiere Balloons: Recent NASA mission studies have recommended the use of radioisotope-heated Montgolfiere balloons for future in situ Titan exploration. Proposals are sought for the design, fabrication and Earth atmosphere flight testing of prototypes that can support an eventual Titan Montgolfiere balloon mission. Particular importance is attached to the acquisition of test data that can help validate thermodynamic and fluid mechanic models that will ultimately be used to design the Titan flight balloon. The size of balloon required for Titan will be approximately 10 m in diameter and will require 2 kW of thermal energy to float the balloon at an expected Titan temperature of 85 to 95 K. Any proposed Earth-test prototype will require an alternate heat source that nevertheless adequately mimics the effects of using radioisotope energy at Titan.

Gas Management Systems for Titan Aerobots: Hydrogen-filled aerobots at Titan must contend with the problem of gas leakage over long duration (1 year or more) flights. Proposals are sought for the development and testing of two kinds of prototype devices that can be carried on the aerobot to compensate for these gas leakage problems: one device is to produce make-up hydrogen gas from atmospheric methane; the other device is to remove atmospheric gas (mostly nitrogen) that leaks from the ballonets into the hydrogen-filled blimp. Both kinds of devices will need to operate on no more than 15 W of electrical power each while compensating for a leakage rate of at least 40 g/week of hydrogen or 500 g/week of nitrogen.

Metal Balloons for High Temperature Venus Exploration: Balloons made of metals are a potential solution to the problem of enabling long duration flight in the hot lower atmosphere of Venus. Proposals are sought for metal balloon concepts and prototypes that provide 1-5 m3 of fully inflated volume, areal densities of 1 kg/m2 or less, sulfuric acid compatibility at 85% concentration, and operation at 460 °C for a period of up to 1 year.

S3.08 Planetary Ascent Vehicles

NASA aims to design, build and test vehicles that will be launched from the surface of other planets and small bodies and place a payload, Orbiting Sample (OS), into orbit. We are seeking proposals for the development of innovative technologies to support future planetary ascent vehicles. Immediate focus is the Mars ascent vehicle. Technology innovations should either enhance vehicle capabilities (e.g., launch success probability, mission success, improved performance or margins, and improved environmental robustness) or ease implementation in space borne missions (e.g., reduce size, mass, power, and thermal requirements, improve reliability and ability to withstand the ~20 g lateral g-loading, or lower cost). The areas of interest for this call are listed below.

Alternate propellants, thrusters and propulsion system technologies for the planetary ascent vehicles:

- Higher performing monopropellants with specific impulse >240 secs;
- "Green" propellants;
- High chamber pressure thrusters > 500 psia;
• Pressurization component technologies to reduce system mass (filters, solenoid valves, latch valves, tanks, fill and drain and check valves);

• Small lightweight pump technologies to operate at >500 psi output pressure especially non-electrically driven;

• Non-pyrotechnic isolation valves.

Advanced solid propellant engine system technologies:

• Solid propellant technology with specific impulse performance potential higher than HTPB and CTPB;

• Propellant blend with high performance low storage impacts, and operating capability down to 150 K;

• Low temperature seals and components;

• Light weight and reliable thrust vector control;

• Other lightweight system and component technologies.

Proposals should show an understanding of one or more relevant science needs, and present a feasible plan to fully develop a technology and infuse it into a NASA program.

Launch vehicle technologies relevant to Earth are not sought under this sub-topic. For launch vehicle technologies related to Earth, see X2.01 Earth-to-Orbit Propulsion. Proposals more aligned with exploration mission requirements should be proposed in X2.01.

**S3.09 Unmanned Aircraft and Sounding Rocket Technologies**

**Sounding Rockets**

The NASA Sounding Rocket Program (NSRP) provides low-cost, sub-orbital access to space in support of space and earth sciences research and technology development sponsored by NASA and other users by providing payload development, launch vehicles, and mission support services. NASA utilizes a variety of vehicle systems comprised of military surplus and commercially available rocket motors, capable of lofting scientific payloads, up to 1300lbs, to altitudes from 100km to 1500km. NASA launches sounding rocket vehicles worldwide, from both land-based and water-based ranges, based on the science needs to study phenomenon in specific locations.

NASA is seeking innovations to enhance capabilities and operations in the following areas:
• Autonomous vehicle environmental diagnostics system capable of monitoring flight loading (thermal, acceleration, stress/strain) for solid rocket vehicle systems.

• Location determination systems to provide over-the-horizon position of buoyant payloads to facilitate expedient location and retrieval from the ocean.

• Flotation systems, ranging from tethered flotation devices to self-encapsulation systems, for augmenting buoyancy of seal payload systems launched from water-based launch ranges.

• High-glide parachute designs capable of deploying at altitudes above 25,000 ft to facilitate mid-air retrieval and/or fly-back/fly-to-point precision landing.

Unmanned Aircraft Systems

Unmanned Aircraft Systems (UAS) offer significant potential for Suborbital Scientific Earth Exploration Missions over a very large range of payload complexities, mission durations, altitudes, and extreme environmental conditions. To more fully realize the potential improvement in capabilities for atmospheric sampling and remote sensing, new technologies are needed. Scientific observation and documentation of environmental phenomena on both global and localized scales that will advance climate research and monitoring; e.g., U.S. Global Change Research Program as well as Arctic and Antarctic research activities (Ice Bridge, etc.).

NASA is increasing scientific participation to understand impacts associated with worldwide environmental changes. Capability for suborbital unmanned flight operations in either the North or South Polar Regions are limited because of technology gaps for extremely remote telemetry capabilities and precision flight path control requirements. It is also highly desirable to have UAS ability to perform atmospheric and surface sampling.

(1) Telemetry, Tracking and Control: Low cost over-the-horizon global networks are needed to enable unmanned collaborative multi-platform earth observation missions that are more efficient and cost effective.

(2) Avionics and Flight Control:

• Precision Flight Path Control solutions in smooth atmospheric conditions.

• Aircraft control in violent atmospheric conditions.

• Low cost (}

Precise/repeatable flight path control capabilities are needed to enable repeat path observations for earth monitoring on seasonal and multi-year cycles. In addition, long endurance atmospheric sampling in extreme inclement weather conditions (hurricanes) and volcanic plumes can provide high fidelity time and spatial resolution data

(3) UA Integrated Vehicle Health Management:
• Fuel Heat/Anti-freezing

• Unmanned platform icing detection and minimization

(4) Guided Dropsondes: NASA Earth Science Research activities could utilize more capable dropsondes than are currently available as market items. Specifically, dropsondes that could effectively be guided through atmospheric regions of interest such as volcanic plumes could enable unprecedented observations of important phenomena. Capabilities of interest include:

• Compatibility with existing drop-sonde dispensing systems deployed on the NASA/NOAA P-3 and planned for the NASA Global Hawk

• Guidance schemes, autonomous or active control

• Cross-range performance and flight path accuracy

• Operational considerations including airspace utilization and conflicting traffic

All proposals should show an understanding of one or more relevant science needs, and present a feasible plan to fully develop a technology and infuse it into a NASA program.

**S3.10 Earth Entry Vehicle Systems**

**S3.03 Power Generation and Conversion**

*Lead Center: GRC*

*Participating Center(s): ARC, GSFC, JPL, JSC, MSFC*

Future NASA science missions will employ Earth orbiting spacecraft, planetary spacecraft, balloons, aircraft, surface assets, and marine craft as observation platforms. Proposals are solicited to develop advanced power generation and conversion technologies to enable or enhance the capabilities of future science missions. Requirements for these missions are varied and include long life, high reliability, significantly lower mass and volume, higher mass specific power, and improved efficiency over the state of practice for components and systems. Other desired capabilities are high radiation tolerance and the ability to operate in extreme environments (high and low temperatures and over wide temperature ranges).
While power generation technology affects a wide range of NASA missions and operational environments, technologies that provide substantial benefits for key mission applications/capabilities are being sought in the following areas.

**Radioisotope Power Conversion**
Radioisotope technology enables a wide range of mission opportunities, both near and far from the Sun and hostile planetary environments including high energy radiation, both high and low temperature and diverse atmospheric chemistries. Technology innovations capable of advancing lifetimes, improving efficiency, highly tolerant to hostile environments are desired for all thermal to electric conversion technologies considered here. Specific systems of interest for this solicitation are listed below.

Stirling Power Conversion: advances in, but not limited to, the following:

- System specific mass greater than 10 We/kg
- Highly reliable autonomous control
- Low EMI
- High temperature, high performance materials, 850-1200 C
- Radiation tolerant sensors, materials and electronics

Thermoelectric Power Conversion: advances in, but not limited to, the following:

- High temperature, high efficiency conversion greater than 10%
- Long life, minimal degradation
- Higher power density

**Cubesat and Nanosat On-orbit Power Generation**
NASA desires to build smaller spacecraft types carrying smaller instrument packages. However, power requirements to accommodate these instruments and spacecraft systems will not necessarily scale down in a similar fashion as spacecraft size. Therefore, power generation and power management technologies are sought that are compatible with small spacecraft geometries and sizes, especially in cubesat and nanosat form factors.

**Photovoltaic Energy Conversion**
Photovoltaic cell, blanket, and array technologies that lead to significant improvements in overall solar array performance (i.e. conversion efficiency >30%, array mass specific power >300 watts/kilogram, decreased stowed volume, reduced initial and recurring cost, long-term operation in high radiation environments, high power arrays, and a wide range of space environmental operating conditions) are solicited. Technologies specifically addressing the following mission needs are highly sought:

- Photovoltaic cell and blanket technologies capable of low intensity, low-temperature operation applicable to outer planetary (low solar intensity) missions
- Photovoltaic cell, blanket and array technologies capable of enhancing solar array operation in a high intensity, high-temperature environment (i.e. inner planetary and solar probe-type missions)
- Lightweight solar array technologies applicable to solar electric propulsion missions. Current missions being studied require solar arrays that provide 1 to 20 kilowatts of power at 1 AU, are greater than 300 watts/kilogram specific power, can operate in the range of 0.7 to 3 AU, provide operational array voltages up to 150 volts and have a low stowed volume.

Thermophotovoltaic conversion is currently focused on follow-on technology for the International Lunar Network (ILN) and for the outer planets mission. Advances sought, but not limited to, include:

- Low-bandgap cells having high efficiency and high reliability
- High temperature selective emitters
- Low absorptance optical band-pass filters
• Efficient multi-foil insulation

Note to Proposer: Topic X8 under the Exploration Mission Directorate also addresses power technologies (X8.03 Space Nuclear Power Systems, and X8.04 Advanced Photovoltaic Systems). Proposals more aligned with exploration mission requirements should be proposed in X8.

S3.04 Propulsion Systems

Lead Center: GRC

Participating Center(s): JPL

The Science Mission Directorate (SMD) needs spacecraft with more demanding propulsive performance and flexibility for more ambitious missions requiring high duty cycles, more challenging environmental conditions, and extended operation. Planetary spacecraft need the ability to rendezvous with, orbit, and conduct in situ exploration of planets, moons, and other small bodies in the solar system (http://www.nap.edu/catalog.php?record_id=10432). Future spacecraft and constellations of spacecraft will have high-precision propulsion requirements, usually in volume- and power-limited envelopes.

This subtopic seeks innovations to meet SMD propulsion requirements, which are reflected in the goals of NASA's In-Space Propulsion Technology program to reduce the travel time, mass, and cost of SMD spacecraft. Advancements in chemical and electric propulsion systems related to sample return missions to Mars, small bodies (like asteroids, comets, and Near-Earth Objects), outer planet moons, and Venus are desired. Additional electric propulsion technology innovations are also sought to enable low cost systems for Discovery class missions, and eventually to enable radioisotope electric propulsion (REP) type missions.

The focus of this solicitation is for next generation propulsion systems and components, including high-pressure chemical rocket technologies and low cost/low mass electric propulsion technologies. Specific sample return propulsion technologies of interest include higher-pressure chemical propulsion system components, lightweight propulsion components, and Earth-return vehicle propulsion systems. Propulsion technologies related specifically to planetary ascent vehicles will be sought under S3.08 Planetary Ascent Vehicle.

Chemical Propulsion Systems

Technology needs include:

• Improved materials and manufacturing processes to produce Iridium/Rhenium apogee class thruster chambers with improved mechanical properties targeting a yield stress of 40ksi and an elongation of 10%;
• Advanced nontoxic mono-propellant rockets for in-space applications.

Electric Propulsion Systems

This subtopic also seeks proposals that explore uses of technologies that will provide superior performance in for high specific impulse/low mass electric propulsion systems at low cost. These technologies include:

• Efficient thrusters with up to 1 kW of input power that provide thrust up to 20 mN with a specific impulse between 1600 to 3500 seconds;
• A throttleable dual mode thruster that is capable of operating in both high thrust and high specific impulse modes for a fixed power;
• High power electric propulsion thrusters (>20 kW) and components including cathodes, ion optics, and low sputtering materials with long life (>1x108 N-s).

Proposals should show an understanding of the state of the art, how there technology is superior, and of one or more relevant science needs. The proposals should provide a feasible plan to fully develop a technology and infuse it into a NASA program.

Note to Proposer: Topic X2 under the Exploration Mission Directorate also addresses advanced propulsion. Proposals more aligned with exploration mission requirements should be proposed in X2.
S3.05 Power Management and Storage

Lead Center: GRC

Participating Center(s): ARC, JPL, JSC

Future NASA science objectives will include missions such as Earth Orbiting, Venus, Europa, Titan, Lunar Quest and Space Weather. Under this subtopic, proposals are solicited to develop energy storage and power electronics to enable or enhance the capabilities of future science missions. The unique requirements for the power systems for these missions can vary greatly, with advancements in components needed above the current State of the Art (SOA) for long life, high reliability, low mass/volume, radiation tolerance, and wide temperature operation.

Energy Storage

Future science missions will require advanced primary and secondary battery systems capable of operating at temperature extremes from -100°C for Titan missions to 400°C to 500°C for Venus missions, and a span of -230°C to +120°C for Lunar Quest. In addition, high energy-density rechargeable electrochemical battery systems that offer greater than 50,000 charge/discharge cycles (10 year operating life) for low-earth-orbiting spacecraft, 20 year life for geosynchronous (GEO) spacecraft, are desired. Advancements to battery energy storage capabilities that address one or more of the above requirements for the stated missions combined with very high specific energy (>200 Wh/kg for secondary battery systems) and energy density, along with radiation tolerance are of interest.

In addition to batteries, other advanced energy storage/load leveling technologies designed to the above mission requirements, such as flywheels, supercapacitors or magnetic energy storage, are of interest. These technologies have the potential to minimize the size and mass of future power systems.

Power Management and Distribution (PMAD)

The "New Frontiers in the Solar System: An Integrated Exploration Strategy" (http://www.nap.edu/catalog.php?record_id=10432), the 2006 Solar System Exploration Roadmap (http://nasascience.nasa.gov/about-us/science-strategy) and the Science Plan for NASA's Science Mission Directorate (http://nasascience.nasa.gov/about-us/science-strategy) all describe the need for radioisotope power systems (RPS) for planetary exploration. In conjunction with the RPS, intelligent, fault-tolerant PMAD technologies are needed to efficiently manage the system power for these deep space missions. Advances in electrical power technologies are required for the electrical components and systems for these future platforms to address program size, mass, efficiency, capacity, durability, and reliability requirements. Of importance are expected improvements in energy density, speed, efficiency, or wide-temperature operation (-125°C to over 450°C) with a number of thermal cycles. Advancements are sought for power electronic devices, components and packaging for Venus type missions with power ranges of a few watts for minimum missions up to a few kilowatts for large missions.

For the lower power applications (up to 20 watts), NASA desires to build smaller spacecraft types carrying smaller instrument packages. However, power requirements to accommodate these instruments and spacecraft systems will not necessarily shrink in a similar fashion as spacecraft size. Therefore, power management technologies are sought that are compatible with small spacecraft geometries and sizes. These Electrical Power Systems should be compatible with Space Plug and Play (SPA) architectures.

Overall technologies of interest include:

- Intelligent, fault-tolerant electrical components and PMAD systems
- High temperature devices and components (up to 450°C)
- Advanced electronic packaging for thermal control and electromagnetic shielding
- Plug and Play compatibility for low power applications

Power Conversion and Distribution relevant to Command, Data Handling, and Electronics, will be covered under subtopic S3.01.

Power Storage for Terrestrial Balloons will be covered under sub-topic S3.07 Terrestrial and Planetary Balloons.
Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II, and when possible, deliver a demonstration unit for NASA testing at the completion of the Phase II contract. Phase II emphasis should be placed on developing and demonstrating the technology under relevant test conditions. Additionally, a path should be outlined that shows how the technology could be commercialized or further developed into science-worthy systems.

Other subtopics, which could potentially benefit from these technology developments include O5 - Low-Cost and Reliable Access to Space (LCRATS), S5.05 - Extreme Environments Technology, and S5.01 - Planetary Entry, Descent and Landing Technology. Battery development could also be beneficial to X6.02 - Advanced Space-rated Batteries, which is investigating some similar technologies in the secondary battery area but with very different operational requirements. Power Management and Distribution could be beneficial to X8.05 - Advanced Power Conversion Systems AND Management and Distribution (PMAD), which is investigating similar technologies, but with very different power levels.

S3.06 Guidance, Navigation and Control

Lead Center: GSFC
Participating Center(s): ARC, JPL

Advances in the following areas of guidance, navigation and control are sought.

Navigation systems (including multiple sensors and algorithms/estimators, possibly based on existing component technologies) that work collectively on multiple vehicles to enable inertial alignment of the formation of vehicles (i.e., pointing of the line-of-sight defined by fixed points on the vehicles) on the level of milli-arcseconds relative to the background star field.

Light-weight sensors (gyroscopic or other approach) to enable milli-arcsecond class pointing measurement for individual large telescopes and low cost small spacecraft.

Isolated pointing and tracking platforms (pointing 0.5 arcseconds, jitter to 5 milli-arcsecond), targeted to placing a scientific instrument on GEO communication satellites that can track the sun for > 3 hours/day.

Working prototypes of GN&C actuators (e.g., reaction or momentum wheels) that advance mass and technology improvements for small spacecraft use. Such technologies may include such non-contact approaches such as magnetic or gas. Superconducting materials, driven by temperature conditioning may also be appropriate provided that the net power used to drive and condition the "frictionless" wheels is comparable to traditional approaches.

Proposals should show an understanding of one or more relevant science needs, and present a feasible plan to fully develop a technology and infuse it into a NASA program.

S3.07 Terrestrial and Planetary Balloons

Lead Center: GSFC
Participating Center(s): JPL

All proposals should show an understanding of one or more relevant science needs, and present a feasible plan to fully develop a technology and infuse it into a NASA program.

Terrestrial Scientific Balloons

NASA's Scientific Balloons provide practical and cost effective platforms for conducting discovery science, development and testing for future space instruments, as well as training opportunities for future scientists and engineers. Balloons can reach altitudes above 36 kilometers, with suspended masses up to 3600 kilograms, and can stay aloft for several weeks. Currently, the Balloon Program is on the verge of introducing an advanced balloon system that will enable 100 day missions at mid latitudes and thus resemble the performance of a small spacecraft at a fraction of the cost. In support of this development, NASA is seeking innovative technologies in three key areas to monitor and advance the performance of this new vehicle.
(1) Power Storage: Devices or methods to store electrical energy onboard the balloon with lower mass than current techniques are needed. Long duration balloon flights at mid-latitudes will experience up to 12 hours of darkness, during which electrical power is needed for experiments and NASA support systems. Typically, solar panels are flown to generate power during the daylight hours, and excess power is readily available. This excess power needs to be stored for use during the night. Current power storage techniques consist of rechargeable batteries which range from lead-acid to lithium-ion chemistries. Innovative alternatives to these batteries, either advanced chemistries or alternate power storage techniques such as capacitors or flywheels, which result in overall mass savings are needed. Nominal voltage levels for balloon systems are 28 volts DC, and nominal power levels can vary from 100 watts to 1000 watts. Therefore, power storage requirements range from 1000 watt-hours to 12,000-watt hours or more. Alternative power systems, which do not rely on solar panels, may also be proposed. These alternative systems may use energy storage techniques such as fuel cells or flywheels, which are prepared or charged on the ground prior to flight, and then would provide continuous power throughout the flight at the power levels specified above. Spacecraft power storage requirements are found under subtopic S3.05 Power Management and Storage.

(2) Balloon Instrumentation: Devices or methods are desired to accurately measure ambient air temperature, helium gas temperature, balloon film temperatures, film strain, and tendon load are desired. These measurements are needed to accurately model the balloon performance during a typical flight at altitudes of approximately 36 kilometers. The measurements must compensate for the effects of direct solar radiation through shielding or calculation. Minimal mass and volume are highly desired. Remote sensing of the parameters and non-invasive and non-contact approaches are also desired. The non-invasive and non-contact approaches are highly desired for the thin polyethylene film measurements used as the balloon envelope, with film thickness ranging from 0.8 to 1.5 mil. Strain measurements of these thin films via in-flight photogrammetric techniques would be beneficial. Devices or methods to accurately measure axially loaded tendons on an array of ~50 or up to 300 separate tendons during flight are of interest. Tendons are typically captured at the end fittings via individual pins with loading levels ranging from ~20 N to ~8,000 N per tendon, and can be exposed to temperatures from room temperature to the troposphere temperatures of -90 degrees Celsius or colder. The measurement devices must be compatible with existing NASA balloon packaging, inflation, and launch methods. These instruments must also be able to interface with existing NASA balloon flight support systems or alternatively, a definition of a data acquisition solution be provided. Support telemetry systems are not part of the this initiative; however, data from any sensors (devices) that are selected from this initiative must be able to be stored on board and/or telemetered in-flight using single-channel (two-wire) interface into existing NASA balloon flight support systems. The devices of interest shall be easily integrated and shall have minimal impact on the overall mass of the balloon system.

(3) Low-Cost Variable Conductance Heat Pipes for Balloon Payloads: With the ever-increasing complexity of both scientific instruments and NASA mission support equipment, advanced thermal control techniques are needed. The type of advanced thermal control techniques desired are similar to those utilized on large-budget orbital and deep space payloads (variable conductance heat pipes, diode heat pipes, loop heat pipes, capillary pumped loops, heat switches, louvers) are far more expensive to implement on balloon payloads that their limited budgets can afford. Innovative solutions are sought that would allow these more advanced thermal control measures to be utilized with reduced expense. Spacecraft thermal control requirements are found under subtopic S3.02 Thermal Control Systems.

Though not considered "cutting-edge technology", commercial quality, constant conductance, copper-methanol heat pipes have begun to be utilized on balloon payloads to effectively move heat significant distances. The problem with these devices is that the conductance cannot effectively be reduced under cold operating or cold survival environment conditions without expending significant energy in an active heater to maintain the condenser section warm. It is desirable to develop a cost-effective method of conducting the heat in this manner and allowing the flow to be reduced/eliminated when conditions warrant. Therefore, innovative thermal control techniques and devices developed must be inexpensive to implement. They must function reliably at balloon altitudes of 30-40km and temperature ranges from -90C to +40C. They should require little or no energy consumption and provide the capability of moderating heat flow autonomously or by remote control under certain thermal conditions.

**Planetary Balloons**

Innovations in materials, structures, and systems concepts have enabled buoyant vehicles to play an expanding role in planning NASA's future Solar System Exploration Program. Balloons and airships are expected to carry scientific payloads at Titan and Venus that will perform in situ investigations of their atmospheres and near surface environments. Both Titan and Venus feature extreme environments that significantly impact the design of balloons.
for those two worlds. Proposals are sought in the following areas:

(1) Titan Montgolfiere Balloons: Recent NASA mission studies have recommended the use of radioisotope-heated Montgolfiere balloons for future in situ Titan exploration. Proposals are sought for the design, fabrication and Earth atmosphere flight testing of prototypes that can support an eventual Titan Montgolfiere balloon mission. Particular importance is attached to the acquisition of test data that can help validate thermodynamic and fluid mechanic models that will ultimately be used to design the Titan flight balloon. The size of balloon required for Titan will be approximately 10 m in diameter and will require 2 kW of thermal energy to float the balloon at an expected Titan temperature of 85 to 95 K. Any proposed Earth-test prototype will require an alternate heat source that nevertheless adequately mimics the effects of using radioisotope energy at Titan.

(2) Gas Management Systems for Titan Aerobots: Hydrogen-filled aerobots at Titan must contend with the problem of gas leakage over long duration (1 year or more) flights. Proposals are sought for the development and testing of two kinds of prototype devices that can be carried on the aerobot to compensate for these gas leakage problems: one device is to produce make-up hydrogen gas from atmospheric methane; the other device is to remove atmospheric gas (mostly nitrogen) that leaks from the balloonets into the hydrogen-filled blimp. Both kinds of devices will need to operate on no more than 15 W of electrical power each while compensating for a leakage rate of at least 40 g/week of hydrogen or 500 g/week of nitrogen.

(3) Metal Balloons for High Temperature Venus Exploration: Balloons made of metals are a potential solution to the problem of enabling long duration flight in the hot lower atmosphere of Venus. Proposals are sought for metal balloon concepts and prototypes that provide 1-5 m³ of fully inflated volume, areal densities of 1 kg/m² or less, sulfuric acid compatibility at 85% concentration, and operation at 460 °C for a period of up to 1 year.

S3.08 Planetary Ascent Vehicles

Lead Center: GRC

Participating Center(s): AFRC, JPL, MSFC

NASA aims to design, build and test vehicles that will be launched from the surface of other planets and small bodies and place a payload, Orbiting Sample (OS), into orbit. We are seeking proposals for the development of innovative technologies to support future planetary ascent vehicles. Immediate focus is the Mars ascent vehicle. Technology innovations should either enhance vehicle capabilities (e.g., launch success probability, mission success, improved performance or margins, and improved environmental robustness) or ease implementation in space borne missions (e.g., reduce size, mass, power, and thermal requirements, improve reliability and ability to withstand the ~20 g lateral g-loading, or lower cost). The areas of interest for this call are listed below.

Alternate propellants, thrusters and propulsion system technologies for the planetary ascent vehicles:

- Higher performing monopropellants with specific impulse >240 secs;
- "Green" propellants;
- High chamber pressure thrusters > 500 psia;
- Pressurization component technologies to reduce system mass (filters, solenoid valves, latch valves, tanks, fill and drain and check valves);
- Small lightweight pump technologies to operate at >500 psi output pressure especially non-electrically driven;
- Non-pyrotechnic isolation valves.

Advanced solid propellant engine system technologies:

- Solid propellant technology with specific impulse performance potential higher than HTPB and CTPB;
- Propellant blend with high performance low storage impacts, and operating capability down to 150 K;
- Low temperature seals and components;
- Light weight and reliable thrust vector control;
- Other lightweight system and component technologies.
Proposals should show an understanding of one or more relevant science needs, and present a feasible plan to fully develop a technology and infuse it into a NASA program.

Launch vehicle technologies relevant to Earth are not sought under this sub-topic. For launch vehicle technologies related to Earth, see X2.01 Earth-to-Orbit Propulsion. Proposals more aligned with exploration mission requirements should be proposed in X2.01.

**S3.09 Unmanned Aircraft and Sounding Rocket Technologies**

**Lead Center:** GSFC

**Participating Center(s):** AFRC, ARC, GRC, JPL, LaRC

**Sounding Rockets**

The NASA Sounding Rocket Program (NSRP) provides low-cost, sub-orbital access to space in support of space and earth sciences research and technology development sponsored by NASA and other users by providing payload development, launch vehicles, and mission support services. NASA utilizes a variety of vehicle systems comprised of military surplus and commercially available rocket motors, capable of lofting scientific payloads, up to 1300lbs, to altitudes from 100km to 1500km. NASA launches sounding rocket vehicles worldwide, from both land-based and water-based ranges, based on the science needs to study phenomenon in specific locations.

NASA is seeking innovations to enhance capabilities and operations in the following areas:

- Autonomous vehicle environmental diagnostics system capable of monitoring flight loading (thermal, acceleration, stress/strain) for solid rocket vehicle systems.
- Location determination systems to provide over-the-horizon position of buoyant payloads to facilitate expedient location and retrieval from the ocean.
- Flotation systems, ranging from tethered flotation devices to self-encapsulation systems, for augmenting buoyancy of seal payload systems launched from water-based launch ranges.
- High-glide parachute designs capable of deploying at altitudes above 25,000 ft to facilitate mid-air retrieval and/or fly-back/fly-to-point precision landing.

**Unmanned Aircraft Systems**

Unmanned Aircraft Systems (UAS) offer significant potential for Suborbital Scientific Earth Exploration Missions over a very large range of payload complexities, mission durations, altitudes, and extreme environmental conditions. To more fully realize the potential improvement in capabilities for atmospheric sampling and remote sensing, new technologies are needed. Scientific observation and documentation of environmental phenomena on both global and localized scales that will advance climate research and monitoring; e.g., U.S. Global Change Research Program as well as Arctic and Antarctic research activities (Ice Bridge, etc.).

NASA is increasing scientific participation to understand impacts associated with worldwide environmental changes. Capability for suborbital unmanned flight operations in either the North or South Polar Regions are limited because of technology gaps for extremely remote telemetry capabilities and precision flight path control requirements. It is also highly desirable to have UAS ability to perform atmospheric and surface sampling.

(1) **Telemetry, Tracking and Control:** Low cost over-the-horizon global networks are needed to enable unmanned collaborative multi-platform earth observation missions that are more efficient and cost effective.

(2) **Avionics and Flight Control:**

- Precision Flight Path Control solutions in smooth atmospheric conditions.
- Aircraft control in violent atmospheric conditions.
- Low cost (<$20k), High precision inertial navigation systems (greater than 1/10th degree accuracy and knowledge)

Precise/repeatable flight path control capabilities are needed to enable repeat path observations for earth
monitoring on seasonal and multi-year cycles. In addition, long endurance atmospheric sampling in extreme inclement weather conditions (hurricanes) and volcanic plumes can provide high fidelity time and spatial resolution data.

(3) UA Integrated Vehicle Health Management:

- Fuel Heat/Anti-freezing
- Unmanned platform icing detection and minimization

(4) Guided Dropsondes: NASA Earth Science Research activities could utilize more capable dropsondes than are currently available as market items. Specifically, dropsondes that could effectively be guided through atmospheric regions of interest such as volcanic plumes could enable unprecedented observations of important phenomena. Capabilities of interest include:

- Compatibility with existing drop-sonde dispensing systems deployed on the NASA/NOAA P-3 and planned for the NASA Global Hawk
- Guidance schemes, autonomous or active control
- Cross-range performance and flight path accuracy
- Operational considerations including airspace utilization and conflicting traffic

All proposals should show an understanding of one or more relevant science needs, and present a feasible plan to fully develop a technology and infuse it into a NASA program.

S3.10 Earth Entry Vehicle Systems

Lead Center: LaRC

Participating Center(s): ARC

This subtopic seeks innovations to meet Science Mission Directorate (SMD) requirements for Earth Entry Vehicles (EEV). Advancements in materials, structures, and systems related to sample return missions to the Moon, planetary bodies (e.g., Mars and Venus), small bodies (e.g., asteroids, comets, and Near-Earth Objects) and outer planet bodies are desired.

EEVs provide several challenges to current material and structural designs in several areas. New classes of structure and impact materials are needed which are lightweight and versatile, remaining stiff during impact with soft surfaces while providing low impact loads when crushing with impact to hard surfaces. Lightweight structures that are suitable for thermal protection system (TPS) substructures, including serving as a thermal barrier or sink, are also desired. Current EEV concepts are blunt-body vehicles (60-degree sphere cones) that are 0.5 to 2.0 meters in diameter, entering Earth's atmosphere at 11-16 km/s.

This subtopic also seeks proposals that explore new technologies in several key vehicle systems that include:

- Low mass/cost/complexity, high reliability impact attenuation systems capable of keeping peak impact loads below 1500 g's under nominal conditions, or 2500 g's under off-nominal conditions (i.e. impact with a rock or hard man-made surface, e.g. concrete road). Payload stroke resulting from compression of candidate impact foam must not exceed 2.5% of the vehicle overall diameter.
- Lightweight structures that are suitable for TPS substructures (i.e., lightweight, stiff, good insulator).
- Mid-density robust ablator systems that can be tailored to entry heating for a range of missions from high speed to low speed, and are easy to manufacture across the range of possible vehicle scales.
- Adhesives that are compatible with lightweight structures and TPS.
- Passive (or nearly passive), self-contained methods of determining whether a micrometeoroid strike (of the TPS) has occurred.
- Low mass, low power, reliable self-contained beacon for EEV retrieval.
- Candidate beacon mass must not exceed 100g (including power and activation) and must provide a reliable
signal for up to 2 days after landing/impact.

- Low mass, low power, reliable, self-contained GPS with broadcast system and the antenna to beam the trajectory and landing location information to IRIDIUM or other easily accessible commercial global communication systems as an aid to locating the landed EEV.
- Thermal control system technologies for EEVs will be covered under sub-topic S3.02 Thermal Control Systems.
- EEV closing and locking mechanism(s) that are reliable and easily verifiable.

Proposals should show an understanding of one or more relevant science needs, and present a feasible plan to fully develop a technology and infuse it into a NASA program.

Other subtopics that could be soliciting entry, descent, and landing related technology developments include S5.01 Entry, Descent and Landing Technologies, X9.01 Ablative Thermal Protection Systems, and X9.02 Advanced Integrated Hypersonic Entry Systems. Proposals more aligned with exploration mission requirements should be proposed in X9.