FY02 Highlights

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Hurdles: Space Systems

Space systems performance must be dramatically improved, including reductions in both cost and mass – coupled with significant improvements in reliability, lifetime, and operational robustness – to ensure exploration mission success.

FY02 Accomplishments Addressing Space Systems Hurdle:

- Demonstrated adaptive, ultra-long life avionics for space systems
- Validated first unit of self-assembling planetary surface telescope concept in the laboratory; analytically assessed integrated systems concepts
- Validated all-terrain robotic mobility systems—over a wide variety of physiologies and scales—for use on lunar and planetary surfaces as well as in space
- Demonstrated self-reconfigurable and evolvable machine systems
- Validated concept for a miniaturized and integrated stellar gyroscope
- Developed and began initial testing of a Mars drill prototype
- Began development of a compact, lightweight, portable Solid Freeform Fabrication system utilizing a low power (~ 1kW), low voltage (<15 kV) electron beam energy source and wire feedstock

Hurdles: Space Systems – Ultra-Long Life, Reconfigurable Avionic Space Systems

Current avionic systems have achieved long life through redundancy to overcome single point failure. This approach to system design has resulted in larger, heavier subsystems and systems that are expensive to launch. Although this approach is effective in extending the life of the avionics, it does not prevent the system from eventually failing as subsystem failures accumulate which exceed the redundancy designed into the system.

NASA is studying interstellar missions outside the solar system that might require a 30- to 40-year mission life. A breakthrough in system design has been discovered that may enable such ultra-long life missions. This avionic system technology breakthrough is based on "generic functional electronic blocks" that can not only change functionality depending on needs, but can function in different capability at different times.

This approach would not be possible if all of the electronics were hard wired. Therefore, a wireless interface has been developed. This approach saves power, reduces mass and volume, enhances performance, and dramatically increases the life of the avionic system.

Ultra-Long Life, Reconfigurable Avionic Space Systems

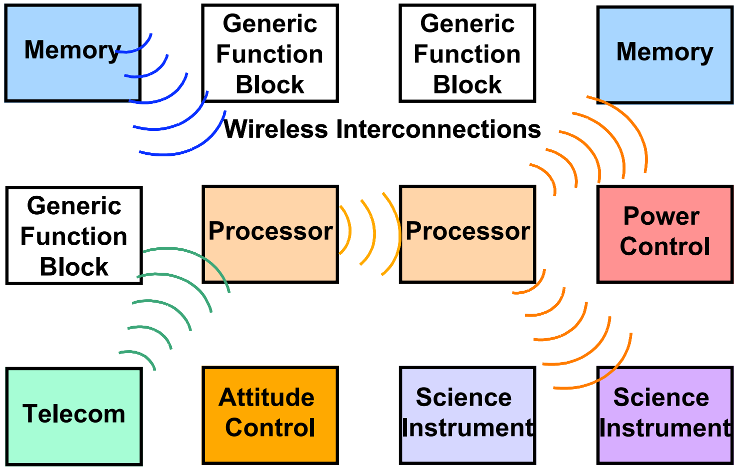
Challenge: Develop cost effective and highly reliable avionics systems applicable for long-life exploration missions. Current fault tolerant system architectures based on redundancy of single function modules for long-life missions are cost prohibitive.

Solution: Establish a paradigm shift in system architectures based on "generic function blocks" that can be reconfigured to replace any type of failed component. Use wireless interconnection to facilitate reconfiguration of connectivity among components, and implement distributed autonomous local testing for fault detection at the component level rather than a centralized fault detector.

Benefit: Generic function blocks will reduce the frequency of replacing failed satellites and reduce down time thereby minimizing the need and cost of maintaining communication with satellite networks. Generic function blocks will enable long term solar system exploration; e.g., Mars long-lived lander network, Kuiper Belt objects sample return and interstellar space probes.

Accomplishments: Constructed and successfully tested three generic function blocks; demonstrated navigation interface and established bi-directional communication between wireless transceivers. Each generic function block included:

- A blank field programmable gate array board
- A wireless transceiver and a custom-built daughter board for 32 Kbytes program memory



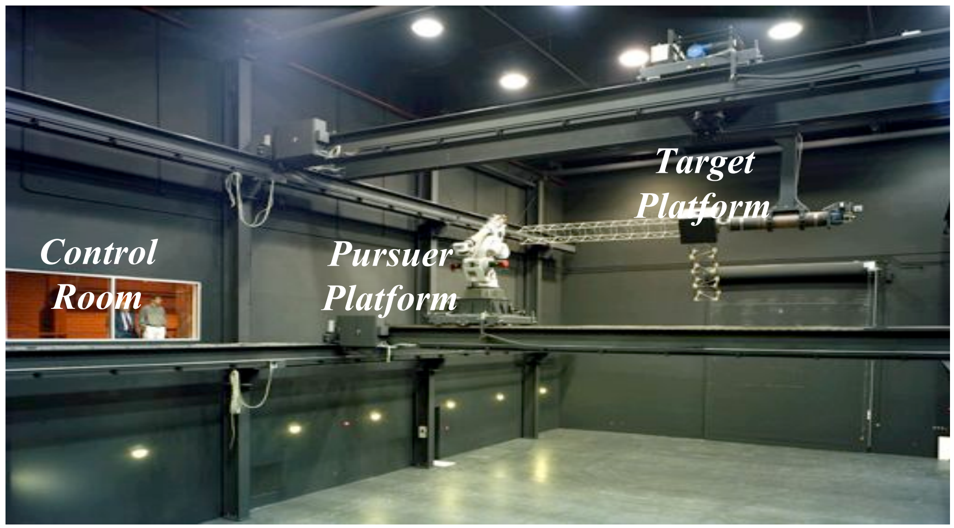
Hurdles: Space Systems –
Wireless Systems: Space Tracking, Acquisition and Ranging

Tracking, Acquisition and Ranging are key capabilities needed for multi-spacecraft systems either to dock with each other or fly in a constellation. Retromodulators can provide simultaneous spacecraft-to-spacecraft optical communication, power beaming, and line-of-sight navigation. The navigation solution potentially provides about 1 centimeter accuracy in positioning and 0.3 degrees accuracy in orientation for this system. The device and concept has reached Technology Readiness Level 5. This capability will allow a higher level of spacecraft modularity than achieved previously.

Wireless Systems: Space Tracking, Acquisition and Ranging

Plan:

Provide a compact, lightweight, low power method for inter-satellite acquisition, communications and navigation. Use code-tagged corner-cube multiple quantum well retromodulators to provide line-of-sight relative position and orientation between two spacecraft and demonstrate technique in the Naval Research Laboratory (NRL) Dynamic Motion Simulator Facility.



Results:

The retromodulators can provide simultaneous spacecraft-to-spacecraft optical communication and navigation. The navigation solution potentially provides about 1 cm in positioning and 0.3 degrees in orientation for this system. The device and concept has reached TRL 5. The method is potentially applicable for long (multiple km) to short (decameters) inter-platform ranges and can significantly reduce parasitic payload requirements of the onboard communications, acquisition, and navigation subsystems.

Applicability: Wireless transfer of information and power between generic function blocks to eliminate harness mass and complexity.

Hurdles: Space Systems –
A Robotically-Deployable Mobile Planetary Platform: A Conceptual Design for a Lunar Telescope

Most transportation on the surface of planetary objects has been accomplished by rovers which require collision avoidance software and other tools to wheel to their destination.   These are computationally intensive systems which are slow and unable to cross barriers. Also, a new rover is typically designed for each mission to support a different suite of scientific instruments.

A “generic all terrain chassis” has been developed which is capable of being deployed on any solid planet and has the ability to traverse almost any continuous terrain. This all terrain platform self deploys and will enable the formation of structures previously not possible. As an example, this platform can function as a continuous, large diameter optical system for a space telescope or serve as a four-meter interferometer array system.

Other potential applications of the all terrain chassis include human habitats, in-space processing facilities, fuel depots, and fuel farms.

A Robotically-Deployable Mobile Planetary Platform: A Conceptual Design for a Lunar Telescope

Challenge: The assembly of structures such as large telescopes on rough or varied lunar/planetary terrains requires the development of advanced, autonomous robotic capabilities.

Solution: Develop an articulated 6-legged platform that can be used as the basis for a self-deployable stack of mirrors that deploy from a single launch to a mobile carrier that (1) if physically integrated, can provide a 24-meter optical structure with very high articulated accuracy, or (2) if dispersed, functions as an interferometer.

Benefit: The lunar surface provides a stable structure with low contamination and nearly isothermal 100° K temperature. Arrays of six 4+ meter collector apertures and a 4.6-meter combiner can be landed on a surface within the payload constraints of the largest NASA launch vehicles. This system would provide 50% more light gathering area and twice the resolution of the upcoming 8-meter Next Generation Space Telescope and be able to image objects as faint as 35th magnitude. Additional launches could emplace a nearly "filled aperture" 30+ meter instrument with 0.005 arcsecond resolution. The deployable mobile platform is also applicable to Mars surface science.

Accomplishments: Developed and demonstrated a robotically self-deployable, all-terrain mobile planetary platform that can be used as a telescope with a 24-meter aperture.

(Animation)

Hurdles: Space Systems –
Cooperative “Insect-Like” Robotics Systems

Most current robots utilize two manipulators working together or in sequence. Exponential improvements in capabilities and reduction in risk are possible through an architecture based on modular robotic systems – each with their own power, computer memory, and sensor package.

A new concept utilizing “insect-like robots” has been developed in which modular robotic systems work in harmony with each other. In addition to being smaller, these robots can use 6 legs for working, or use 4 legs for support while the other 2 collect samples, dig, or perform minor repair activities such as soldering. These insect robots can carry sensors and communicate with a mother robot that acts as a “node” for data processing and communication with other nodes. The mother robot is larger in size and has long-distance communication capability while the baby robots serve as carriers for various in-situ sensors that communicate only with the mother robot.

Colonies of these robots are more effective than a single large robot at accomplishing many functions. Risk is also greatly decreased through the highly redundant, modular robotic architecture.

This new architecture in robotic systems can improve terrain coverage utilizing very little solar power. Because of their limited size and substantial agility, they can easily cover many kilometers per mission thereby enhancing science return.

Cooperative "Insect-Like" Robotics Systems

Challenge: Develop the technology enabling multiple robotic elements to function as complementary components to achieve the task at hand. In many future problems, group teamwork will be more efficient than individuals working alone. Just as ants and human teams benefit from cooperative efforts, robots may benefit from large scale teamwork. Robotic group architecture can be the cheapest way to accomplish many tasks by relying on strength in numbers and cooperative resources for mission success.

Solution: Develop small, flexible, mobile robotic systems to address problems in distributed robotics work and sensor networking. Since large scale systems are the goal, it is important that this robotic platform to be inexpensive and small – and perhaps even disposable. State-of-the-art legged platforms are being designed, built, and studied in distributed multi-robot experiments.

Benefit: Robotics research for exploration has centered on wheeled platforms of different types as these vehicles are the most efficient means of travel across a flat, solid surface. However, a legged platform could provide other capabilities in many areas including climbing, tool use, etc. The current design iteration is a biologically inspired 18 degree-of-freedom hexapod walker. Each joint is passively compliant which will be useful for future dynamic gaits, e.g., running.

Accomplishments:

- Conducted initial testing with a proof-of-concept robot complete with sensors, imager, processor, and radio
- Completed overall initial design and build of prototype robot including design of different walking and turning gaits
- Conducted "network repair" demonstration including deployment of radios and a communication network break and repair
- Demonstrated coordination and communication interfaces among various nodes of robots

Hurdles: Space Systems – Self-Reconfigurable and Evolvable Machine Systems

Robots have been a single point design for single functional capability. This approach to robotic systems is ineffective and inefficient and has dramatically increased the cost of space exploration.

The robotic systems of the future need to be multi-functional and need to be able to self-reconfigure to do whatever job is at hand. They need to be adaptable, self-healing, and self-repairing. Robotic software must be evolvable and self-learning. To overcome the present limitations, an approach was developed to design, build, and evaluate self-reconfigurable robots that can autonomously change their shape and size to accomplish diverse tasks in complex environments.

These robots consist of multiple autonomous and configurable modules that can dynamically rearrange their physical connectivity to form structures and capabilities that are beyond those of conventional, fixed-shape robots. These metamorphic robots are ideal for applications such as search and rescue in rubble or unstructured areas, inspection and repair in hazardous environments, fire fighting, space exploration, and remote intelligence gathering.

Self-Reconfigurable and Evolvable Machine Systems

Challenge: State-of-the-art robots are typically very limited in their ability to react to unplanned or unexpected situations. Optimal robotic performance in exploration mission applications requires the development of advanced, autonomous capabilities.

Solution: Develop self-reconfigurable robots that can autonomously change their shape and size to accomplish diverse tasks in complex environments. These robots consist of multiple autonomous and configurable modules that can dynamically rearrange their physical connectivity to form structures and capabilities that are beyond those of conventional, fixed-shape robots.

Benefit: These metamorphic robots are ideal for applications such as search and rescue in rubble or unstructured areas, inspection and repair in hazardous environments, fire fighting, space exploration, and remote intelligence gathering.

Accomplishments:

- Undertook analytical analysis to understand reconfiguration design trade-offs and limitations
- Developed dynamic graphical simulation of modular, 2-wheeled reconfigurable robotic vehicle traversing and completed detailed mechanical design of a reconfigurable robot
- Developed reconfigurable software to enable autonomous mobility operation independent of system configuration
- Created vision-based docking software to allow transformation of two robotic vehicles into a 4-wheeled reconfigurable robot
- Built and tested a prototype of the reconfigurable robotic exploratory vehicle

Hurdles: Space Systems – A Miniaturized and Integrated Stellar Gyroscope

The miniaturization of a gyroscope, its traditional star tracker, and its associated sun sensor on a spacecraft can reduce not only the mass and power consumption of the attitude determination and control subsystem by few orders of magnitude, but if properly designed, can improve performance and reduce cost.

With the proper architectural design, subsystem complexity will also be greatly reduced. The combination of inertial and celestial sensors used in today's attitude determination and control subsystems is typically massive (3 to 20 kg), physically large, and requires substantial power for operation (15 to 200 W). A need exists to develop a very fast and wide field-of-view star tracker that is able to operate at high update and slew rates. This will eliminate the need for a gyroscope (and other attitude determination sensors) on a spacecraft. A single stellar gyroscope will provide all the information traditionally gathered using other attitude sensors.

In support of goals to miniaturize attitude determination and control subsystem components, NASA has developed an integrated stellar gyroscope that has reduced mass by 50% while increasing performance by 20%.

A Miniaturized and Integrated Stellar Gyroscope

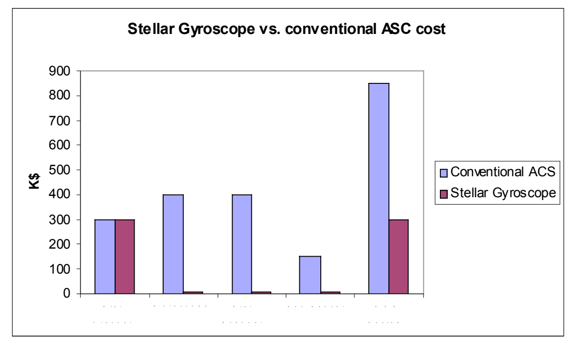
Challenge: Substantially reduce the mass and integrate the functionality of current attitude determination and control subsystem sensors. The combination of inertial and celestial sensors used in today's attitude determination and control subsystems is typically massive (3 to 20 kg), physically large, and requires substantial power for operation (15 to 200 W).

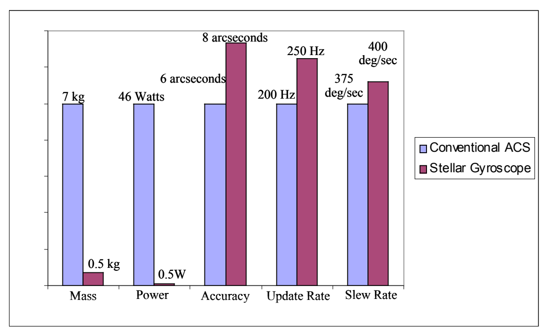
Solution: Develop a very fast and wide field-of-view star tracker that is able to operate at high update and slew rates. This will eliminate the need for a gyroscope (and other attitude determination sensors) on a spacecraft. A single stellar gyroscope will provide all the information traditionally gathered using other attitude sensors.

Benefit: The elimination of a gyroscope, a traditional star tracker and potentially a sun sensor on a spacecraft will reduce the mass and power consumption of the attitude determination and control subsystem by one to two orders of magnitude. Also, subsystem complexity will be greatly reduced.

Accomplishments:

- Completed conceptual design of a stellar gyroscope including radiometry calculations, sky coverage assessment, and algorithms for spin axis and spin rate determination
- Developed simulations of imagery from stellar gyroscope and a simulation of the stellar gyroscope algorithms
- Constructed an early prototype of the stellar gyroscope and field tested at an astronomical observatory





Hurdles: Space Systems –
Mars Drill Prototype

Extended duration human missions to Mars must be preceded by the infrastructure to support long term habitability. A potentially enabling capability, central both to science and human life support, is the acquisition and processing of liquid water.

Human missions face a number of barriers, not the least of which is cost. The availability of liquid water could impact the arrival date of the first humans. But an extensive precursor robotic program will be required to evaluate the technology necessary to access the water. To insure utilization of the state-of-the-art, while holding costs to a minimum, NASA has turned to the private sector. Commercially available technologies include means to locate drilling sites, methods of drilling in the Martian surface, a well-developed drill automation capability, and the technologies for in-situ analysis of samples.

A prototype drill is being developed and tested by NASA in collaboration with industry partner Baker Hughes Incorporated. This development is leading to a highly efficient, lightweight coring drill capable of 5-20 meters depth initially, and 3-5 kilometer depth in later versions. The 20-meter version will weigh approximately 50 kg. The 3-5 kilometer version will weigh slightly more (since mass does not scale linearly with core depth capability).

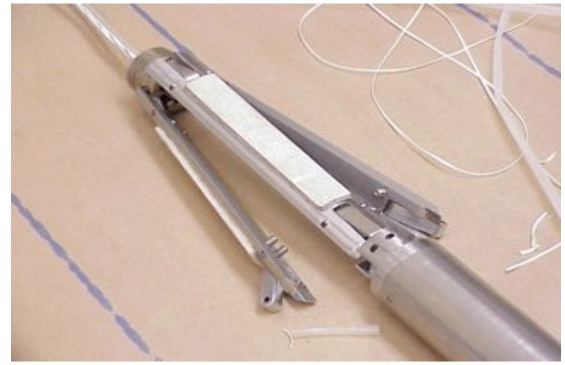
Hurdles: Space Systems

Mars Drill Prototype

Coring Drill Bit

Current Testing

Future Testing



Anchor Module

Challenge: Demonstrate a Mars "deep" drill concept to TRL 4 or 5 through design/build/test of an engineering prototype.

Solution: Develop and test a Mars Drill prototype; initiate tests on a 2.5 meter basalt sample

Benefit: In addition to Mars core sampling, this concept may potentially be adapted to other planetary core sampling applications

Accomplishments:

- Assembled, tested, and characterized performance of anchor, motor, force-on-bit, and auger subsystems
- Custom drill bit recently delivered by Baker Hughes
- Assembled end-to-end system
- Initiated performance testing on "small" basalt sample to characterize rate-of-penetration and power vs. speed and force-on-bit
- Project has passed final Test Readiness Review for testing on a vertical test rig with 2.5 meter basalt

Hurdles: Space Systems –
In-Situ Solid Freeform Fabrication System Development

Future long duration human exploration missions will be challenged by constraints on mass and volume allocations available for spare parts. Electron beam solid freeform fabrication offers the potential of providing an efficient process for producing structural and mechanical replacement components as needed during long duration space missions. Utilization of this process would eliminate the need to predict which spare parts must be included on a given mission and instead permit an estimation of the total mass of replacements required. Spare parts could be produced on an as-needed basis. Failed components may also be recycled back into feedstock to further reduce the mass of spare parts or feedstock supply for a long duration mission.

Electron beam freeform fabrication is an emerging technology being developed that produces structural metal parts directly from computer-aided design data. This process is well-suited for adapting to in-space manufacturing because it has high energy efficiency, high feedstock usage efficiency, and is operable in vacuum on a variety of metals.   By employing a relatively low accelerating voltage for the electron beam, the production of harmful radiation is avoided and the need for heavy protective shielding is eliminated. As a result, this system is portable. Not only is this an advantage for spaceflight applications, but a lightweight system has potentially broad application to terrestrial operations where it is desirable to have highly flexible fabrication capabilities in remote environments.

In-Situ Solid Freeform Fabrication System Development

Challenge: Provide sufficient sparing of hardware components on long-duration human exploration missions to minimize mission risk within the limitations of mass and volume capacity. Because of the random nature of hardware failures, it is impossible to accurately predict specifically which spares will be required. Carrying discrete, unique spares incurs the risk of having items that will not be used (wasted mass) or not having spares that are needed but were not anticipated (potential impact to mission success).

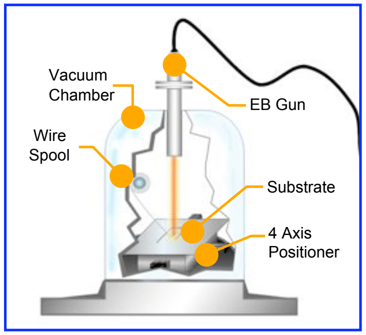
Solution: Develop capabilities to produce structural and mechanical replacement components as required from feedstock material. Focus on development of portable solid freeform fabrication technology – leveraging knowledge gained from Code R-funded high power electron beam solid freeform fabrication technology development.

Benefit: The mass of replacement items can be projected more accurately than the specific list of items comprising that mass. By carrying the appropriate amount of feedstock material and producing replacement components as needed mass can be optimized, volume can be minimized, and mission robustness can be significantly enhanced.

Accomplishments:

- Developed system design for portable low-voltage electron beam solid freeform fabrication system
- Initiated system element procurement and integration
- Completed assessment of potential risks (low) from radiation generation by system operation
- Established NASA/DoD Electron Beam Freeform Fabrication Interagency Coordinating Committee to provide a forum for technical interchange between NASA and DoD research communities

Electron beam freeform fabrication system: ground-based system (left); prototype schematic (right).



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