Assurance Technology Challenges of Advanced Space Systems

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The Third US-Japan Symposium on Advancing
Applications and Capabilities in NDE

ABSTRACT

The initiative to explore space and extend a human presence across our solar system to revisit the moon and Mars post enormous technological challenges to the nation's space agency and aerospace industry. Key areas of technology development needs to enable the endeavor include advanced materials, structures and mechanisms; micro/nano sensors and detectors; power generation, storage and management; advanced thermal and cryogenic control; guidance, navigation and control; command and data handling; advanced propulsion; advanced communication; on-board processing; advanced information technology systems; modular and reconfigurable systems; precision formation flying; solar sails; distributed observing systems; space robotics; and etc.

Quality assurance concerns such as functional performance, structural integrity, radiation tolerance, health monitoring, diagnosis, maintenance, calibration, and initialization can affect the performance of systems and subsystems. It is thus imperative to employ innovative nondestructive evaluation methodologies to ensure quality and integrity of advanced space systems.

Advancements in integrated multi-functional sensor systems, autonomous inspection approaches, distributed/embedded sensors, roaming inspectors, and shape adaptive sensors are sought. Concepts in computational models for signal processing and data interpretation to establish quantitative characterization and event determination are also of interest. Prospective evaluation technologies include ultrasonics, laser ultrasonics, optics and fiber optics, shearography, video optics and metrology, thermography, electromagnetics, acoustic emission, x-ray, data management, biomimetics, and nano-scale sensing approaches for structural health monitoring.

Introduction:

On January 14, 2004, President George W. Bush announced a new vision for America's civil space program (Ref. 1) that calls for human and robot missions to the Moon, Mars, and beyond. This visions set forth goals of: returning the Space Shuttle safely to flight; completing the International Space Station; phasing out the Space Shuttle when the ISS is complete (about 2010); sending a robotic orbiter and lander to the Moon; sending a human expedition to the Moon as early as 2015; but no later than 2020; conducting robotic missions to mars in preparation for a future human expedition; and conducting robotic exploration across the solar system. Such a focus for the American space program has not existed since the Apollo era and established a much-needed direction and purpose for our national space efforts (Ref. 2).

The new vision for space exploration at the beginning of 2004 encompasses a broad range of human and robotic missions, including the Moon, Mars and destinations beyond. It established clear goals and objectives, but sets equally clear budgetary boundaries by stating firm priorities, including tough choices regarding current major Agency programs. The new vision establishes as policy the goals of pursuing commercial and international collaboration in realizing future space exploration mission. Also, the policy envisions that advanced in human and robotic technology will play a key role – both as enabling and as a major benefit of the new vision.

In particular, the Space Exploration Vision states that the fundamental goal of Vision is to advance U.S. scientific, security and economic interests through a robust space exploration program. In pursuit of this goal, the Vision states that in support of this goal, the U.S. will pursue four key objectives, these are to

- Implement a sustained and affordable human and robotic program to explore the solar system and beyond;
- Extend human presence across the solar system, starting with a human return to the Moon by the year 2020, in preparation for human exploration of Mars and other destinations;
- Develop the innovative technologies, knowledge, and infrastructures both to explore and to support decisions about the destinations for human exploration; and
- Promote international and commercial participation in exploration to further U.S. scientific, security, and economic interests.

Programmatic Approaches:

To better implement the Vision for Space Exploration, NASA has transformed its organization structure (Ref. 3) to better align with the Vision. This transformation fundamentally restructures NASA's six Strategic Enterprises: Aerospace, Biological and Physical Research; Earth Science; Education; Space Flight; and Space Science, into Mission Directorates (Fig. 1). The new Mission Directorate organizational structure includes:

- Aeronautics Research: Research and develop aeronautical technologies for safe, reliable and efficient aviation systems.

- Science: Carry out the scientific exploration of the Earth, Moon, Mars and beyond; chart the best route of discovery; and reap the benefits of Earth and space exploration for society. A combined organization is best able to establish an understanding of the Earth, other planets and their evolution, bring the lessons of our study of Earth to the exploration of the Solar System, and to assure the discoveries made here will enhance our work there.

- Exploration Systems: Develops capabilities and supporting research and technology that enable sustained and affordable human and robotic exploration; includes the biological and physical research necessary to ensure the health and safety of crew during long duration space flight.

- Space Operations: Direct space flight operations, space launches and space communications, as well as the operation of integrated systems in low-Earth orbit and beyond.

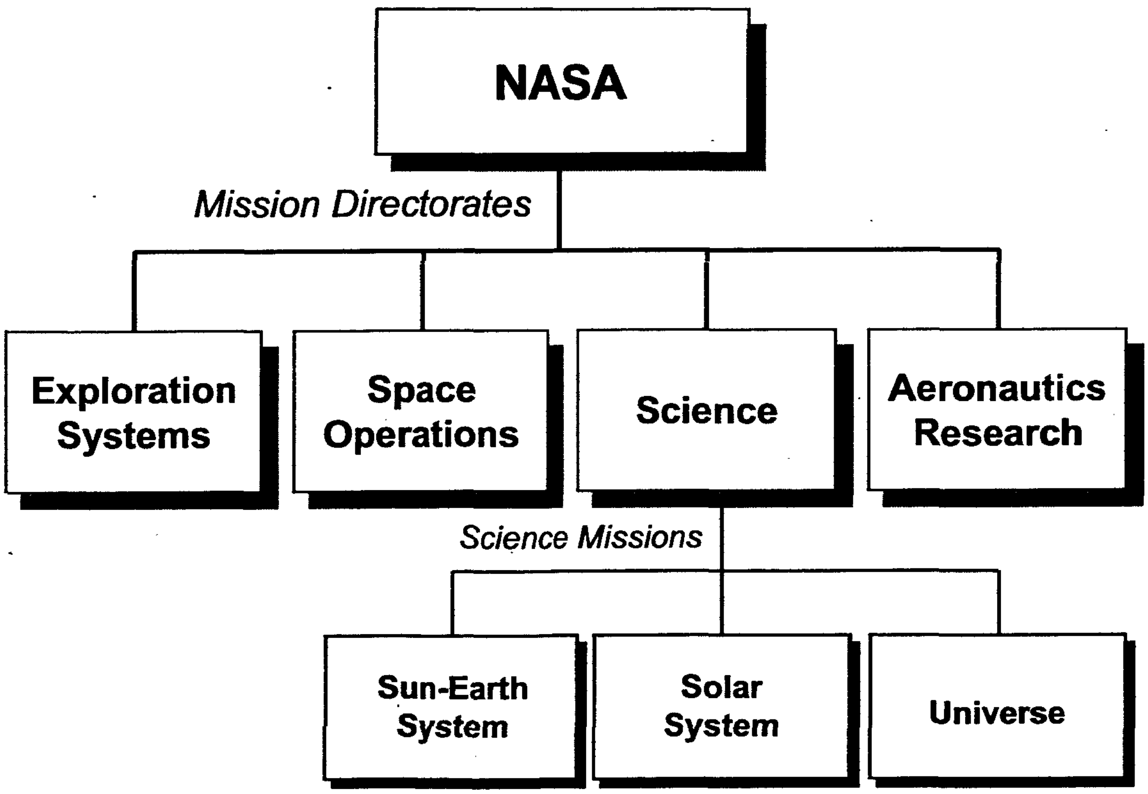

Figure 1. Transformed NASA organizational structure (excluding administrator's staff offices and mission support directorates.)

Furthermore, Research and Technology Development Division of the Exploration Systems Mission Directorate is the primary organization responsible for basic technology development efforts. The two main programs are Advanced Space Technology Program (ASTP) and Technology Maturation Program (TMP) (Ref. 4). Element programs of the ASTP and the TMP are identified based on the strategic-to-task-to-technology approaches.

The ASTP is the portion of the portfolio that addresses relatively low Technology Readiness Level (TRL, Fig. 2.) technologies, with the goal of exploring innovative concepts and advancing a range of high-leverage technologies. The goal is to validate these new concepts and technologies experimentally or analytically and to transition them for application in science and exploration missions. The nominal path is through the TMP, which will adopt mature and demonstrate the most promising candidates for ultimate transition to flight system development projects.

The TMP, comprising mid-to high-TRL technology maturation, demonstration and flight experiments, will pursue new technologies in the areas of high energy space systems, advanced space systems and platforms, advanced space operations, and lunar & planetary surface operations. The program will advance key technologies required to enable the U.S. Exploration Vision, with a focus on the human and robotic exploration of the Moon, Mars and other destinations. The TMP will rely on the ASTP for key products in support of ongoing program integration planning and management.

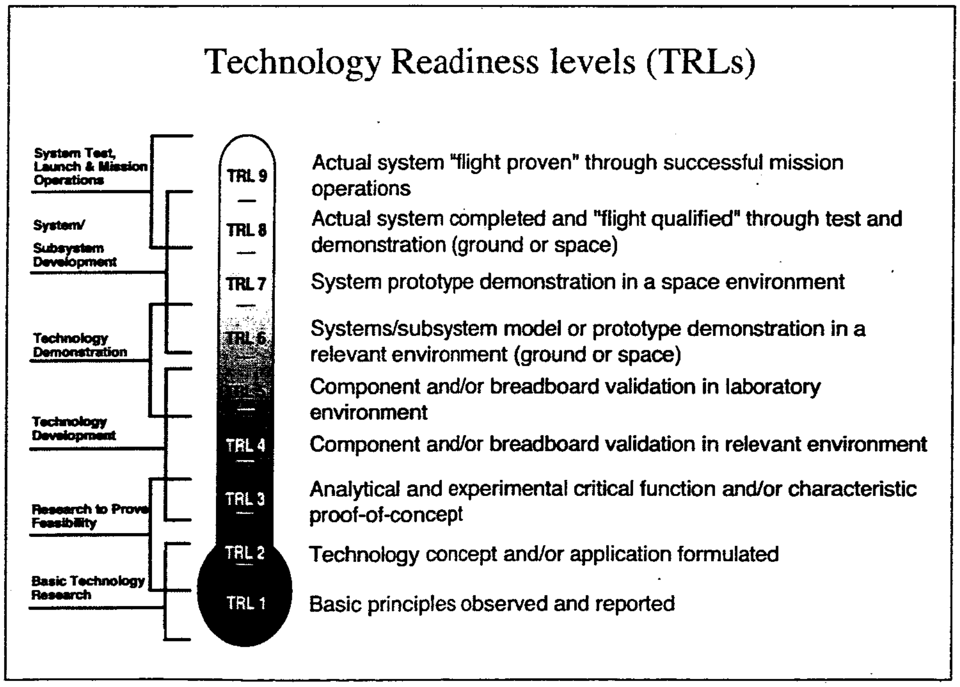

Figure 2. Definitions of the NASA Technology Readiness Level (TRL).

Practical Requirements:

The quality assurance measures are needed in virtually all aspects of advanced space systems and exploration – launch vehicles, crew exploration vehicle, upper stages, insertion/ascent stages, planetary habitats, etc. These requirements can be categorized into three states: condition characterization, health management, and maintenance and remedy. In addition to the three common states, there is an addition state - human intervention for manned missions.

For space applications, functional performance, structural integrity, radiation tolerance, health monitoring, diagnosis, and maintenance are critical to the performance of subsystems and systems. Especially, when reacting to environmental changes such as radiation, and sunlight, functional parameters have to be adjusted to return to the normal operations. One earthly example is that as fuel is consumed, airplane needs to pump the fuel between tanks to balance the weight distribution.

Assurance technologies are essential to assist in determining condition of components and subsystems for the purpose of informed-decision making either via autonomous controls or with human interventions. The technologies to support advanced space systems also have to be space qualified, i.e. meeting vibration, G-shock, acoustics, radiation, thermal extremes and thermal cycles requirements. Other key factors include

Sensors selection and deployment –sensor mechanisms need not to interfere with normal operation. Sensor locations should be strategic and incorporated as an integral part of the instrument or spacecraft.

Calibration, initialization, and validation – calibration and initialization are essential to ensure NDE signal correctness and provide accuracy information for disposition.

Autonomous operation – NDE sensors and sensor web need to be reconfigurable and self sustain. Sensor operations also need to be autonomous and free of maintenance.

Fault detection and diagnosis – the NDE assurance systems need to discern between sensor failures, component failures, actuator failures and nominal transients.

Information fusion – data collected from various NDE sensors that are based on their respective sensing principles need to be analyzed and infused and provide a wholesome assessment of the condition.

Health management – acquired NDE assurance data need to be able to determine health of components, subsystems and systems. The assurance data will then be used for informed-decision and actions.

Action actuation – if it is so required, the data need to result in a decision to actuate corrective actions to rectify anomalies, or for manned missions, inform human the condition and request intervention, if necessary.

Conclusions:

Missions to revisit the moon and to Mars pose tremendous challenges to advanced spacecraft systems. Though conventional NDE methods such as ultrasonics, electromagnetics, etc. can meet some of the assurance requirements. However, to achieve quality safety, and reliability dements on advanced space systems, advancements in integrated multi-functional sensor systems, autonomous inspection approaches, distributed/embedded sensors, roaming inspectors, and shape adaptive sensors are critically needed. Other associated and supporting technologies such as concepts in computational models for signal processing and data interpretation to establish quantitative characterization and event determination are also of high interest. Since miniaturization of instruments and systems is a prominent driving factor, biomimetics, and nano-scale sensing approaches for structural health monitoring of mini, micro and nano instrument and spacecrafts are also challenges to the NDE community.

In summary, assurance technologies as applicable to advanced space systems for space exploration are not only challenges for the government agencies but also opportunities industries, and academia. The NDE research communities as well as engineering firms shall gladly develop the appropriate assurance technologies and contribute to the nation's space exploration effort.

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