National Aeronautics and Space Administration

NASA ENGINEERING & SAFETY CENTER

NESC

2009 TECHNICAL UPDATE

www.nasa.gov

CONTENTS

(Left) Ares I-X in the Vehicle Assembly Building during stacking.

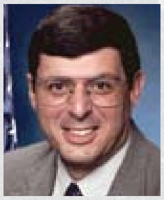
On the cover: Launch of the Max Launch Abort System Flight Test Vehicle from Wallops Flight Facility. Inset photos: top, Shell Buckling Test Facility at MSFC; middle, Composite Crew Module at ATK facilities in Iuka, Mississippi; bottom, Finite Element Models of Anthropomorphic Test Devices.

Back cover: MLAS crew module descends under fully deployed main parachutes. Photo by Ryan Henriksen/The Virginian-Pilot.

All photos in this publication are credited to NASA except where indicated.

It is reassuring to me to know that the Agency has an independent, technically competent and reliable resource in the NASA Engineering and Safety Center (NESC). I have already seen how engaged they have been in many different arenas. The NESC is always there to ensure the tough questions are asked and to help find the answers. The success of the Max Launch Abort System flight demonstration test this summer was a tremendous example of the best NASA has to offer. As the Agency moves forward, I am glad that there is a resource available to all of NASA to help address the technical challenges we are sure to face.

Charles F. Bolden, Jr., NASA Administrator



The NESC has continued to serve the Agency this year by engaging top-notch experts to address the most challenging technical issues we have faced. The NESC is there to respond to real-time problems in our operational programs, to provide alternative solutions to our design efforts and to provide leadership for our technical disciplines. This year, with the successful flight test of the Max Launch Abort System, the NESC vividly demonstrated the power of bringing together engineers, scientists, researchers and technicians from across the Agency. By enabling collaboration and teamwork across the Centers and with industry, great things can be accomplished.

Christopher J. Scolese, NASA Associate Administrator

The NESC is a strong technical resource for the benefit of the Agency. Always willing to take on new challenges and tackle the toughest engineering challenges, the NESC stands ready at a moment's notice. No matter what the program, project or institution, the NESC can be counted on to jump in to help solve any technical issue – with the goal of making NASA successful. This year we have selected additional NASA Technical Fellows to provide the Agency's technical leadership for our engineering disciplines. In this capacity, they respond to the needs of programs and projects, while looking forward to address discipline issues for the future. The NESC also provides a rich training ground for younger engineers through their engagement on assessments and through the Resident Engineer Program. The NESC sets an example in the Agency for engineering excellence, collaboration and a can-do attitude.

Michael G. Ryschkewitsch, NASA Chief Engineer

The NESC continues to support my office as well as the Chief Engineers Office at our joint Safety and Mission Success Reviews by providing timely and accurate independent assessments of our toughest and most important mission safety and mission success problems. I continue to be impressed by the depth and ability of the NESC team and the ability of the NESC to assemble the best and brightest from both within and outside the Agency to focus on these problems.

I am equally impressed with their efforts at developing and maintaining the Agency's engineering competencies through hands-on efforts, with both the Max Launch Abort System, a launch integration project which launched successfully from Wallops Flight Facility in July and their work with the Composite Crew Module, an in-house fabrication project.

In this their 6th year, the NESC continues to be a dominant force and a role model in supporting and cultivating both the engineering excellence and mission success of the Agency.

Bryan D. O'Connor, NASA Chief Safety and Mission Assurance Officer

(Left to right) Timmy R. Wilson, Deputy Director; Ralph R. Roe, Jr., Director; Dawn M. Schaible, Manager of the Systems Engineering Office; Daniel J. Tenney, Manager of the Management and Technical Support Office; and Michael P. Blythe, Deputy Director for Safety.

The NASA Engineering and Safety Center (NESC) celebrated many accomplishments this year. Most notable was the very successful pad abort demonstration test of the Max Launch Abort System from Wallops Flight Facility in July. In addition, the Composite Crew Module completed manufacturing and was delivered to the Langley Research Center in September for full-scale structural testing. These achievements provided concrete examples of how Agency-wide, diverse, multi-generation teams enable robust, timely and innovative solutions to NASA's tough technical problems. The NESC remains focused on providing real-time problem solving for the Space Shuttle and International Space Station Programs, with particular attention to the Space Shuttle as it safely flies out its remaining missions. We also continued to actively support numerous critical robotic spacecraft missions, including the Mars Science Laboratory and the James Webb Space Telescope.

The NESC expanded the NASA Technical Fellows program this year to include Passive Thermal and Electrical Power disciplines. In addition, we are partnering with the newly established Technical Fellows within the NASA Safety Center and expanding collaboration across the Agency. This year we also increased our efforts to share lessons learned from our technical assessments and advocated for the benefits of broad-based, multi-disciplinary teams and value-added independent assessments. This publication highlights many of those lessons as well as the contributions of hundreds of experts from across the Agency. This allowed the NESC to successfully provide the engineering data and recommendations needed for NASA Centers and Mission Directorates to make informed decisions.

As the Agency moves into a new decade and the next era of space exploration, the NESC stands ready as a value-added independent technical resource ensuring engineering excellence and mission success. The NESC consistently demonstrated the ability to reach across NASA, industry, academia and other government agencies to rapidly respond and address the most critical technical issues the Agency faces. The broad-based, diverse teams the NESC forms have truly been our most valuable and powerful asset. We are pleased to highlight some of the most significant contributions from these teams in this year's NESC Technical Update.

The NESC Review Board (NRB) holds weekly video conferences to peer review and approve all NESC technical assessments and reports. All technical decisions made by the NESC are products of the NRB.

Building on a Culture of Engineering Excellence

NASA has the people and resources to explore the universe and redefine the limits of science and technology, but one of the systematic challenges has been how to maximize its resources by distributing knowledge and experience across the breadth of the Agency. One of the achievements of the NASA Engineering and Safety Center (NESC) is its success in promoting intercenter cooperation to surmount the toughest and most pressing obstacles that the Agency encounters.

The NESC was formed in 2003 with a charter to ensure safety and mission success by performing independent testing, analysis, and assessments of NASA's high-risk projects. To accomplish this, the tiger team approach is used by forming dedicated teams (called assessment teams) to target specific technical problems. The members of assessment teams are drawn from all across NASA, and also from industry, academia, and other government agencies. This gives the assessment teams an unmatched depth of expertise. Another strength of the NESC is the diversity achieved by bringing together people from different disciplines, locations, and experience bases to collaborate and develop solid technical solutions.

A unique feature of the NESC is that more than half of the people working for the NESC are in temporary positions. After their temporary assignments are completed, they return to their Centers and programs and apply their NESC experience, thereby allowing others to have the same NESC opportunity. The NESC organization is divided into six offices: NASA Technical Fellows, NESC Chief Engineers, Systems Engineering, Principal Engineers, Management and Technical Support, and the Director's Office.

NASA Technical Fellow Disciplines

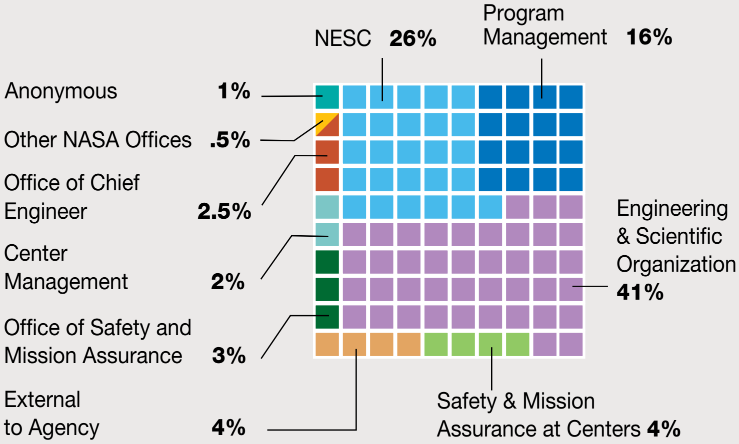
- Aerosciences*
- Avionics
- Electrical Power
- Flight Mechanics
- Guidance, Navigation and Control*
- Human Factors
- Life Support/Active Thermal
- Loads and Dynamics*
- Materials
- Mechanical Systems
- Nondestructive Evaluation*
- Passive Thermal*
- Propulsion
- Software
- Structures*

*Community of Practice Available

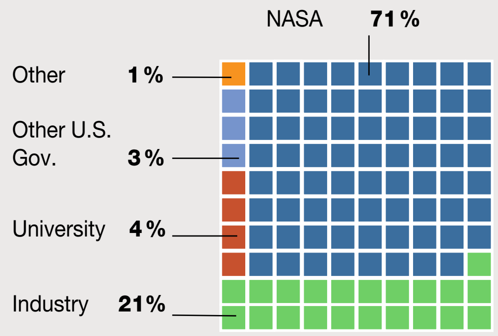
NASA Technical Fellows

The NASA Technical Fellows are NASA's senior technical experts in 15 engineering disciplines. They are the problem-solving leaders of Technical Discipline Teams (TDTs), which are composed of the technical specialists, from inside and outside of NASA, for their respective

Source of Accepted Requests: 323 Total

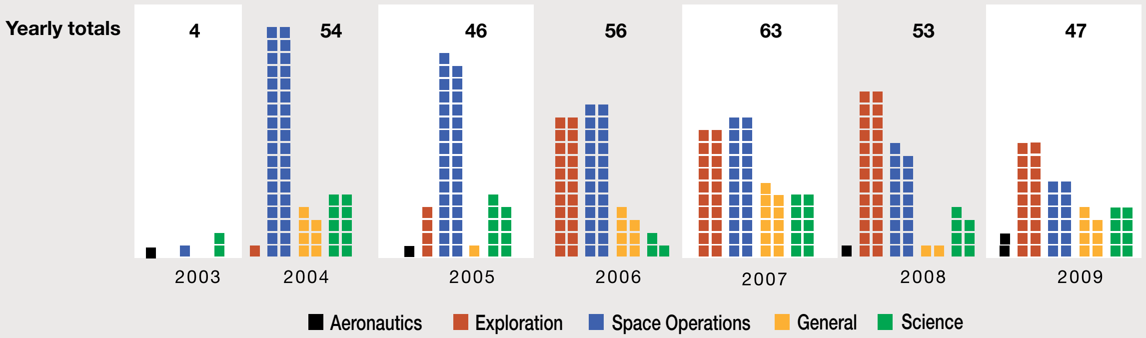


2009 Technical Discipline Team Composition



All statistics as of Oct. 20, 2009

Source of Accepted Requests by Mission Directorate: 323 Total



disciplines. TDT members are called on to support assessment teams and help address issues being investigated by the NESC. The NASA Technical Fellows are also the stewards of their discipline and as such they identify technical challenge areas, review and prioritize engineering standards, educate the Agency through workshops and conferences, and oversee online Communities of Practice. Another responsibility of the NASA Technical Fellows is to periodically produce a state-of-the-discipline review for NASA's engineering and safety communities.

NESC Chief Engineers (NCEs)

The NESC Chief Engineers are the primary NESC points of contact at each Center. The NCEs' proximity ensures that they can closely track the projects that are active at their Centers. They also help to coordinate the facilities and resources of each Center as required to support NESC assessments and activities.

Principal Engineers Office (PEO)

The Principal Engineers Office carries the primary responsibility for the performance of technical assessments. The principal engineers and back-up principal engineers lead assessment teams and provide guidance and assistance for assessments led by individuals from outside of the NESC.

Systems Engineering Office (SEO)

The Systems Engineering Office provides systems engineering and integration for NESC assessments and other activities. The SEO and the SEO-led Systems Engineering TDT also provide technical expertise in systems engineering processes such as systems analysis, statistics, data mining and trending, and requirements analysis. In addition, the SEO provides the technical integration for the NESC's internal operations, including processing all requests for NESC support. These requests can come from anyone within or external to NASA.

Management and Technical Support Office (MTSO)

The Management and Technical Support Office is the business office of the NESC and performs the necessary work for contracting and maintaining partnerships. This past year, the NESC has worked with over 100 companies or individual consultants, with the companies ranging in size from major corporations down to small consulting firms. In addition, several universities and academic institutions such as the Missouri University of Science and Technology, The University of Alabama, the Scripps Institute of Oceanography, and government agencies like the Naval Research Laboratory, National

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Oceanographic and Atmospheric Administration, and Sandia National Laboratories have contributed to NESC activities. Many of the experts from these sources are members of TDTs, while others were brought in for individual assessments.

Office of the Director

The top tier of leadership for the NESC is the Office of the Director, which includes the NESC Director, Deputy Director, Deputy Director for Safety, Chief Scientist, and a representative from the astronaut corps detailed to the NESC as the NESC Chief Astronaut. The Office of the Director also chairs the NESC Review Board (NRB). All decisions made by the NESC are products of the NRB, with each member having equal representation and bringing his or her background to the decision-making process. The voting members of the NRB are the NESC Director and Deputies, NASA Technical Fellows, NCEs, Principal Engineers, the Chief Scientist and Chief Astronaut, and the managers of the SEO and MTSO. The success of the NRB, like that of the entire NESC, is a result of its broad diversity combined with outstanding technical competence.

A NASA-Wide Resource

Beyond leading Agency-wide teams and assessments, the NESC serves as a centralized source of diverse technical expertise for activities such as technical review boards, mishap investigations, and real-time mission support. It has also instituted the Resident Engineer Program, where early-career engineers are detailed to the NESC for 1 year to give them the opportunity to gain first-hand experience working with NESC technical experts and leaders. This benefits the NESC as well as the residents because it forges connections to the younger generation and gives fresh perspectives on technical activities.

Members of the NRB vote on acceptance of an NESC report prior to release.

By combining a concentration of technical expertise and leadership with a structure that facilitates interaction between Centers and programs, the NESC can deliver the best of NASA to where it can be most effective. For more information on the NESC, or to submit a request, visit the NESC website, e-mail the NESC, or contact your Center NCE.

NASA Technical Fellows Give State-of-the-Discipline Presentations

The NASA Technical Fellows perform state-of-the-discipline (SoD) assessments of their respective engineering disciplines. In their SoD assessments, the NASA Technical Fellows highlight successes, trends, challenges, and other issues facing their individual disciplines and provide a roadmap for improvement. These SoD summary reports are presented to the NASA Chief Engineer, the Center engineering directors, and the NASA Chief Safety and Mission Assurance Officer. The NASA Technical Fellows have a common three-point focus for performing these assessments of NASA's internal engineering capabilities. They first look across the Agency to assess their discipline's readiness to support the goals and objectives of each Mission Directorate. Secondly, with the support of their TDT, they identify the top three current technical challenges and/or barriers for their discipline. Finally, they formulate advocacy recommendations for their discipline, which serve as a roadmap to address the identified discipline technical challenges.

NASA Technical Fellow for Life Support/Active Thermal, Henry (Hank) Rotter (left) discusses Apollo life support systems with Apollo 11 Commander Neil Armstrong. Mr. Rotter is the NASA architect for the life support system in the new lunar lander, Altair.

"Our Orion/Mars Science Laboratory EDL Workshop demonstrated how the NASA Technical Fellows can stimulate technical collaboration between some of NASA's most important projects and across multiple engineering disciplines. We are always looking for opportunities to help foster technical collaboration throughout the Agency."

— NASA Technical Fellows Cornelius Dennehy and Daniel Murri

An NESC-sponsored Entry, Descent, and Landing (EDL) workshop in April 2009 provided an opportunity for the Orion and Mars Science Laboratory scientists and engineers to exchange and compare their EDL design requirements, technical approaches, testing strategies, top concerns, and lessons learned, as well as to extend their collaboration to other technical areas.

NASA Technical Fellows Developing Communities of Practice

A Community of Practice (CoP) is a network of individuals who are dedicated to, passionate about, and have personal experience in a given engineering discipline. The NASA Technical Fellows have developed online communities as part of their discipline stewardship charter. The fundamental objectives of the CoP sites are to first provide an online environment that connects NASA's engineers to both the experts within their particular discipline and the collective body of discipline expertise and second, accomplish NASA's goal of being a learning organization.

Through these online communities, engineers can ask experts questions, collaborate on solutions to common problems, find standards and references, take part in online discussions, and find contacts at each Center. The NASA Technical Fellows and TDT members determine the structure and technical content of their individual sites. The CoPs are part of the NASA Engineering Network (NEN) and are accessible to anyone with NASA intranet access.

The NASA Technical Fellows also strongly encourage all members of each community to contribute their individual knowledge, lessons learned, and other discipline expertise to the CoP sites. Feedback on the structure, content, features and capabilities of each CoP is welcomed and should be directed to the appropriate NASA Technical Fellow.

On the Web

NESC **nesc.nasa.gov**

E-mail **nesc@nasa.gov**

NESC Academy **www.nescacademy.org**

NASA Engineering Network **nen.nasa.gov**

Dr. Raju named AIAA Engineer-of-the-Year

Dr. Ivatury S. Raju, NASA Technical Fellow for Structures, was selected as the recipient of the American Institute of Aeronautics and Astronautics (AIAA) Hampton Roads Section 2009 Engineer-of-the-Year Award. Dr. Raju is nationally and internationally known for his contributions to fracture mechanics, finite element analysis, and computational mechanics. Dr. Raju was selected for his outstanding technical contribution in fracture mechanics for the investigation of the Space Shuttle wing leading edge Reinforced Carbon-Carbon spallation root cause.

NESC Communications and Education

Resident Engineer Program

The newly created NESC Resident Engineer (RE) Program for 2010 was a direct result of the successful pilot of this approach during the Max Launch Abort System (MLAS) Project. Young engineers are selected to join the NESC to gain hands-on experience solving the Agency's toughest challenges. Each RE is assigned to a TDT allowing the RE an opportunity to gain first-hand experience with the technical experts in their field. They will participate on a multi-Center NESC assessment team and work other projects assigned by a mentor. The goal is to provide the REs with diverse assignments and exposure to multiple sub-disciplines, while developing a broader system engineering perspective.

Ultimately, the experience should give the RE a greater understanding of the Agency's program and projects, an enhanced ability to solve complex technical problems, improved leadership skills, and an increased network of technical experts in their discipline.

The NESC leadership welcomes the new Resident Engineers named for 2010. They are, from left, Joseph Gasbarre/LaRC, Courtney Flugstad/KSC, Christopher Regan/DFRC, and Brandon Florow/JPL.

The NESC Academy: Learning From the Past, Looking to the Future

The NESC Academy was established to help ensure that the body of knowledge of retiring NASA scientists and engineers remains viable and accessible. The NESC Academy provides the forum through which recognized discipline experts can teach the critical competencies to the NASA workforce.

An instructor-led course on Space Propulsion Systems with George Hopson and Len Worlund was repeated in April at the long-standing Joint Army Navy NASA Air Force (JANNAF) Interagency Propulsion Committee meeting.

To date, 10 discipline courses have been delivered and nine are available as online courses via the Academy website – http://www.nescacademy.org. The online courses include:

- Active Thermal Control and Life Support Systems by **Hank Rotter**
- Space Propulsion Systems by **George Hopson**
- Power and Avionics by **Robert Kichak**
- Satellite Attitude Control Systems by **Neil Dennehy**
- Human Factors by **Dr. Cynthia Null**
- Software as an Engineering Discipline by **Michael Aguilar**
- Materials Durability – Understanding Damage Modes by **Dr. Robert Piascik**
- Loads and Dynamics by **Dr. Curtis Larsen**
- Structures/Nondestructive Evaluation by **Drs. Ivatury Raju** and **William Prosser**

Learning About the NESC Through Our Website

The NESC website is a communications tool that makes information available on the NESC's current and past activities. It has a large collection of technical reports and bulletins and information on how to contact the NESC. The information highlights include:

NESC Technical Reports: All publicly available NESC engineering reports can be downloaded.

NESC Technical Bulletins: A one-page bulletin released when new engineering data is developed or learned that could be broadly applicable to the larger technical community.

Technical Update: An annual summary of the NESC's technical activities.

NESC News: A newsletter designed to help keep the NASA community and public informed of NESC activities. A free subscription is available from the NESC website.

Contact Information: NASA engineers can contact the NESC either directly or anonymously to request NESC engagement in NASA's technical problems, or contact the NCE at their Center to discuss a potential request for NESC assistance.

A technician instruments the Composite Crew Module for testing.

Photo/ATK-Steve Jones

The Composite Crew Module is mounted in LaRC's Combined Loads Test System facility, which is used to verify large structural components by applying combined mechanical, internal pressure and thermal loads.

Composite Crew Module Pressure Vessel Pathfinder Completes Elemental Testing

Problem: In January 2007, the NASA Administrator and Associate Administrator for Exploration Systems Mission Directorate chartered the NESC to design, build, and test a full-scale crew module primary structure, using carbon fiber reinforced epoxy based composite materials. The overall goal of the project was to develop a team from the NASA family with hands-on experience in composite design, manufacturing, and testing in anticipation that future exploration systems may be made of composite materials. The project was planned to run concurrent with the Orion Project baseline metallic design so that features could be compared and discussed without inducing risk to the Constellation Program (CxP).

NESC Contribution: Led by the NESC, the Composite Crew Module (CCM) Project team is a collaborative partnership between NASA and industry, which includes design, manufacturing, tooling, inspection, and testing expertise. Partners include civil servants from nine Centers, the Air Force Research Laboratory, and contractors from Alcore, Alliant Techsystems (ATK), Bally Ribbon Mills, Collier Corporation, Genesis Engineering, Janicki Industries, Lockheed Martin, and Northrop Grumman. The team is organized such that all participants conduct in-line work based on their individual expertise and irrespective of their company or Center affiliation. The net result is an integrated team with civil servant and contractor participants distributed within and across each of the project disciplines.

The CCM team operates across four time zones, in a virtual environment, connecting participants across the country. During the design phase, the team constrained the design to match interfaces with the then-current Orion crew module including the internal packaging system that utilizes a backbone for securing internal components. The team evaluated several design solutions and focused on one that uses composite sandwich structure with transitions to composite laminate at heavily loaded attachments. A unique feature of the composite design is the use of lobes between the webs of the backbone structure. This complex shape, enabled by composite technologies, places the floor into a membrane-type loading condition and provides mass savings for the composite design and the adjacent heat shield system. The highly loaded and geometrically complex backbone-dome attachment was enabled by three-dimensional woven preform technology. By connecting the aft dome to the backbone and placing lobes into the floor, a mass savings of approximately 150 pounds to the overall primary structure design was realized.

The test article is constructed in two major components: upper and lower pressure shells. The two halves are joined in a process that does not use an autoclave and enables subsystem packaging of large or complex subsystems, such as plumbing and cabling, prior to assembly. Throughout the project, independent technical reviews by government and

Dr. Sotiris Kellas (LaRC) provides a pre-test briefing at the LaRC Combined Loads Test Facility to the CCM test, analysis, and control team prior to a pressure test. (Right) As-built CCM prior to shipment from ATK in Iuka, Mississippi.

Photo/ATK-Steve Jones

industry structural experts were conducted at key project milestones including: conceptual design, preliminary design, detailed design, manufacturing plan, and test plan to challenge assumptions and identify potential problems. The team conducted building-block testing of critical design and technology areas, which were used to validate critical assumptions, design allowables, and manufacturing approaches for the final design. The critical design was completed in January 2008 enabling the fabrication of full-scale manufacturing demonstration units to verify manufacturing processes. Manufacturing of the full-scale test articles started in October 2008 and was completed 10 months later in July 2009. The full-scale test article was delivered to LaRC in September 2009 and testing of critical features started in October 2009. The test article was subjected to combined loads of internal pressure and static pull on critical interfaces to design limit loads and to ultimate loads to verify how the analysis models predicted the response of the structure under load. Test instrumentation includes approximately 280 traditional strain gauges, 3500 fiber optic strain sensors, four regions of full-field strain measurement, 80 acoustic emission sensors, and two system health management systems; one from Metis Corporation and one from Acellant. Future plans call for inducing damage to critical areas of the design, and repeating the tests to limit and ultimate levels and characterizing the effects of damage. Eventually, the test article will be tested to destruction.

Results: The integrated project team formed by NASA and contractor participants was successful by providing a detailed design of the crew module including all computer aided design (CAD) and analytical models, manufacturing plans with detailed drawings and work instructions, cure and inspection specifications, and test plans with detailed test procedures and results. The success criteria for the project was that preliminary design-level CAD models would predict the as-built mass and that analytical models would predict the strain levels of the structure under load within 20 percent during structural testing. The mass prediction during the preliminary design review was 1441 pounds. The as-built mass with 280 strain gauges including approximately 50 pounds of wire was within 3.8 percent of the mass predicted during the preliminary design review. The recorded strains for each of the strain measurement systems fell within 20 percent of the predicted values, with most being much closer. Additionally, the test article was subjected to ultimate design loads with no evidence of detrimental damage.

Lessons Learned: Throughout the manufacturing phase a number of anomalies (unknown unknowns) materialized giving the team an opportunity to evaluate and demonstrate the inspectability and repairability of the CCM design. Even though the Orion crew module primary structure is an aluminum lithium alloy, other parts of the structure, 40 percent by weight, are composite. The lessons learned are directly feeding the design of Orion and Ares I and V composite components, as well as the operations planning being developed by the CxP.

Design lessons show non-autoclave splices allow concurrent fabrication, assembly, and integration of major structural components and subsystems, and provide a lower cost cure tooling option. Through the use of complex shapes enabled by composites, a membrane-lobed floor, integrated with a backbone subsystem packaging feature, offers potential weight savings over a comparable metallic design. A honeycomb core, combined with mature secondary attachment technology, provides flexibility and robustness in secondary attachment locations. As loads and environments change with program maturation, inner mold line tooling offers the opportunity to optimize or change the design through tailoring of layups or core density. Composite solutions offer opportunity for lower tooling and piece-part numbers resulting in a lower drawing count which helps minimize overall life-cycle costs.

Flight force measurement strain gauges and wiring harnesses can be seen on the Fermi PAF prior to final mating with the booster and Fermi satellite.

Flight Force Measurements to Improve Coupled Loads Analysis Enters Data Analysis Phase

Problem: The standard approach over the last 40 years for predicting spacecraft response to the launch environment has been to measure accelerations on the launch vehicle and derive a coupled loads analysis (CLA) simulation that matches these acceleration levels. While acceleration measurements are easy to obtain, they do not directly indicate the loads and stresses that a structure will experience during launch. The penalties of using only acceleration measurements are the weak correlation of CLA and conservative qualification testing. Thus, a need exists to utilize force measurements in the CLA process. The inclusion of force measurements will greatly benefit all future missions and could assist the Orion crew module requirements and development process.

NESC Contribution: An NESC team chose to acquire interface force measurements during flight from strain gauges on the trussed Payload Adaptor Fitting (PAF) of the Gamma-Ray Large Area Space Telescope spacecraft, now called the Fermi Telescope, in such a way that forces and moments might be derived. The PAF design used on this flight was the most suitable test article for resolving forces based on strain measurements. The NESC approach was first demonstrated through both static and dynamic ground testing and then flown successfully on the Fermi mission. Measurement of interface forces during flight provided a direct metric for assessing how well acceleration-based methods predicted the loads that were generated during launch.

The Fermi satellite stands mated to the Payload Adaptor Fitting inside the mobile service tower on Launch Pad 17-B at Cape Canaveral Air Force Station.

Results: Processing of the data from the Fermi flight has indicated that making force measurements on additional flights may result in improvements in the accuracy of the CLA methodology and could provide a means for reducing the conservatism in the design tools. However, it was difficult to draw definitive conclusions from force data from a single flight since a statistical envelope is desired when comparing it to an analytical methodology. A database of additional flight force measurements would be a useful tool for increasing the accuracy of the predictive tools.

Assessment of Ocean Wave Models Used to Analyze the Orion Crew Module Landing Conditions

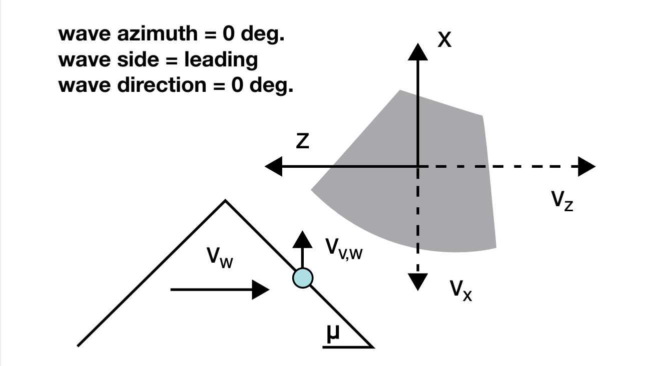
Problem: The Orion Project requested the NESC provide assistance in the refinement and verification of the ocean wave model, developed by Analytical Mechanics Associates, Inc., used to determine water-landing conditions for the Orion crew module (CM). The model is used in conjunction with the overall CM landing model to provide a probabilistic model for design loads.

NESC Contribution: Due to the critical nature of the wave model and unique subject matter, the NESC brought together the National Oceanic and Atmospheric Administration, National Data Buoy Center, Naval Research Laboratory, Army Corp of Engineers, and Scripps Institute of Oceanography to provide independent perspectives on wave modeling. The NESC team outlined recommendations on buoy data selection and limitations, the statistical treatment of the data, numerical and verification methods, and other oceanographic considerations.

NOAA

3-meter discus buoy.

Results: The inclusion of other government agencies outside of NASA's experience base yielded improved solutions and valuable domain specific knowledge early in the ocean wave model design process for Orion. The team developed a website that can routinely provide real-time wave slope velocity and azimuth statistics in the abort and recovery regions.



AMA, Inc.

Ocean landing scenario depicting the CM impacting the face of a wave. Six major ocean landing scenarios have been developed.

Ares I-X Thruster Pressure Cartridge Inadvertent Ignition Hazard — Real-Time Assessment

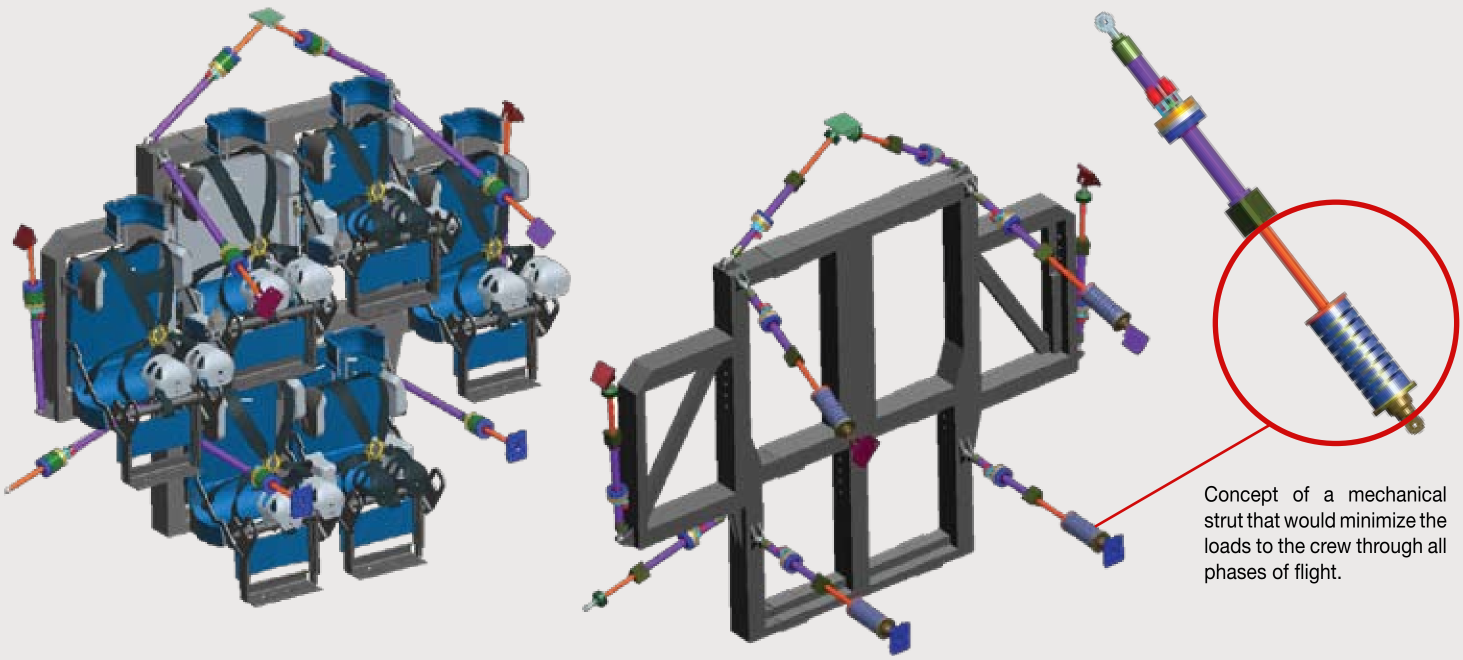
Problem: The Ares I-X launch vehicle uses pyrotechnic thruster pressure cartridges (TPCs) for aeroshell separation. Nondestructive evaluation (NDE) during TPC acceptance testing indicated that internal assemblies moved during shock and vibration testing due to an internal epoxy bond anomaly. This caused concerns that the launch environment might produce the similar displacement and release propellant grains that might be prematurely ignited through impact or electrostatic discharge (ESD) as grains vibrated against internal surfaces. Since a new lot could not be fabricated in time, the Ares I Project required a determination as to whether the lot was acceptable to fly.

NESC Contribution: A real-time assessment of inadvertent TPC ignition hazard allowed the WSTF-led multi-center NESC team to assist the Ares I Project. The NESC hazard analysis identified conservatism in previous analysis and determined that an uncommanded ignition was unlikely. However, propellant grain impact and ESD testing were performed under representative mission conditions to provide additional quantitative data. The NESC also assisted with state-of-the-art NDE techniques to better evaluate the epoxy bond integrity.

WSTF engineer Tim Gallus measures electrostatic build-up during testing of the TPC. The cartridge is shown installed on the shaker table at the New Mexico State University for vibration testing.

Results: Neutron computed tomography and focused immersion ultrasonic (UT) scanning techniques were used. These methods effectively imaged the bonded area, and provided a comparison to the Ares I Project's handheld UT method. The propellant impact test matrix included 1 to ~100 grains of propellant, and drop energies ~100 times the anticipated worst-case energy input. Propellant grains tested in a high fidelity TPC configuration did not ignite at impact energies ~100 times greater than the mission scenario. To evaluate the ESD concern, a representative TPC simulator was fabricated, but used polymers with greater triboelectric charging potential. Charging during a predicted three sigma Ares I-X launch vibration profile was less than 0.001 of the required ignition energy, leading to a conclusion that launch vibration would not initiate the TPC.

Lessons Learned: High fidelity testing is often required to understand true safety margins.



Concept of a mechanical strut that would minimize the loads to the crew through all phases of flight.

Concept of Orion six-person seats (left) on an isolation pallet (right) to provide crew safety over all phases of flight.

Orion Crew Seat Energy Attenuation Mechanism Concepts Developed for Occupant Protection

Problem: The Orion Project requested alternate seat attenuation designs be developed and analyzed for occupant protection in the Orion crew module (CM) with primary focus on providing improved crew survivability for nominal and contingency land landing (CLL). Emphasis was placed on the Project-directed goals of improving robustness and maximizing crew protection from acceleration forces. Due to the team's in-depth knowledge of the problem and work with isolation systems, the NESC was later asked to evaluate design options in the crew seat area to mitigate the Ares I thrust oscillation (TO) environment and evaluate any effect on crew response to landing loads.

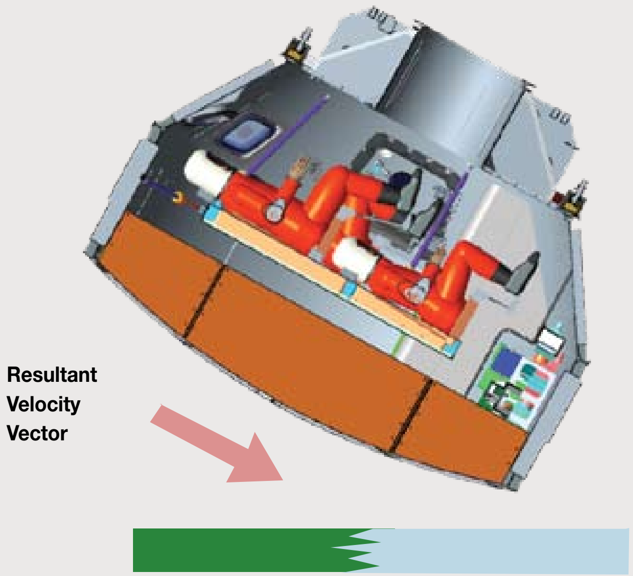
NESC Contributions: The assessment team consisted of designers and analysts from multiple Centers (including GSFC, JSC, JPL and LaRC), contractors, and academia.

The Orion CM landing approach orients the module such that the reclined crew impacts the Earth's surface (water or land) "feet first." The result is that a major portion of the crew impact force vector is along the axis of the crew's spines and the maximum energy absorbing stroke would be required in this direction. Alternate designs for CLL considered a variety of concepts with different approaches to improve the interface between the attenuating struts and the pallet, between the pallet and the seat, and between the seat and the crew.

Analysis performed by another NESC team assessing Orion occupant injuries found that improving the lateral restraint of the crew, as well as holding the crew tighter in a conformed seat, reduced injury risks. A NESC seat design expert developed and tested mockups of improved harnessing techniques to achieve these results.

Based on the Orion Project's review of the alternate concepts, the NESC team focused detailed design and analysis effort on investigating the effectiveness of incorporating an isolation system between the seat pallet and the CM pressure vessel structure. Two concepts for a new pallet interface emerged. The first tilted the crew pallet during landing to provide a greater stroking distance to absorb more energy in the spine axis direction. The second concept focused on providing isolation at the strut-pallet interface.

The NESC team developed simplified dynamic response models and utilized the Orion baseline models to examine a range of pallet isolation properties for crew landing attenuation. The analytical tool development and the pallet isolation analysis were also used to examine mitigating the effects of TO from the Ares I first-stage solid rocket booster on the crew using isolation concepts. Coupled loads models for launch and landing models using LS-DYNA and Adams multibody dynamics software were used to examine the optimal TO isolation frequency that would minimize crew loads during all phases of the Orion flight. In addition, hardware design concepts for implementation of this feature have been generated.



Current Orion landing concept for water or land orients the crew where the majority of the impact energy is along the crew spine, requiring maximum energy absorption of the seat isolation system in this direction. Alternate methods are being explored.

The NESC team continues to evaluate the effect of passive pallet isolation on the crew for landing impact.

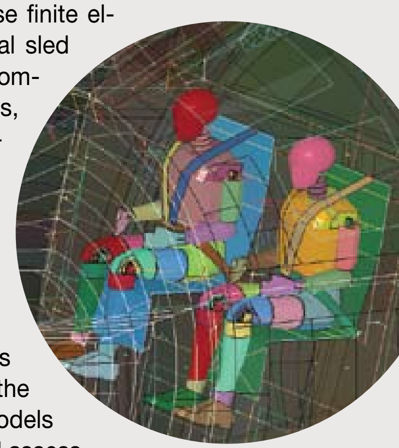
Results: Modeling of NESC isolation concepts versus the baseline design showed improvement in the impact acceleration forces experienced by the seat occupant in all three axes for most load cases by reducing the dynamic amplification portion of the load. Other load cases did not show significant impact acceleration improvement with isolation but did show increased stroke in some instances. The NESC team is evaluating active systems to improve the strut performance over the baseline for all landing cases.

Results from the TO study confirmed the optimal crew isolation frequency and revealed a potential problem with a rocking mode of the crew seat should isolation be implemented at that location. The NESC team also examined pallet isolation and found that approach to be more appealing from a load mitigation perspective. Isolating in series with the pallet struts has a lower effect on crew landing loads than seat isolation and a higher probability of successful implementation. The NESC team continues to evaluate updated load cases and refine the hardware design concept. Engineering evaluation tests are planned for late 2009 into early 2010. These tests will be focused on determining the effectiveness of the isolation frequency for crew performance during the TO event as well as the isolators contribution to landing impact loads on the crew.

Evaluation of Orion Occupant Protection through LS-DYNA Modeling

Problem: The Orion crew module (CM) is being designed with the capability of a primary water landing as well as contingency land landings. Reliable injury predictive tools and injury criteria are required to ensure that the Orion CM is designed with the appropriate level of occupant protection, and to define acceptable injury criteria associated with seat restraint and attenuation systems. While conventional tools used in the aerospace community typically lead to safe designs, they may be overly conservative resulting in additional complexity and increased system mass. Alternate approaches, such as those used in the automotive industry, may provide more fidelity; however, their application to the Orion Project requires modification and study.

NESC Contribution: The NESC has developed finite element models (LS-DYNA) of Hybrid III anthropomorphic testing devices (ATDs) to assess potential crew injuries during Orion landings. Results from these finite element models (FEMs) and physical sled tests with the ATDs are being compared to whole-body injury models, commonly referred to as the Brinkley criteria, which have been typically used for aerospace applications. The ATD models allow for assessing the occupant restraint systems, cushion materials, side constraints, flailing of limbs, and detailed seat/occupant interactions to minimize landing injuries to the crew, whereas the whole-body models do not provide this level of detailed assessment. Predicted crew member response is obtained by loading the ATD using accelerations derived from vehicle landing simulations. The landing load accelerations, combinations of vertical, horizontal, lateral and rotational accelerations, are applied to the numerical Hybrid III FEMs properly positioned in models of the current Orion seat design. Injury criteria is then extracted from the simulations (e.g., neck forces, head accelerations, pelvic motion) and compared to recommended injury criteria established in the Human Systems Integration Requirements (HSIR).



Results: While this work is ongoing, results thus far indicate numerical Hybrid III finite element models used in conjunction with the Brinkley criteria provide a useful set of tools for predicting and eliminating potential crew injuries. The FEM models developed in support of this task have also been used to evaluate proposed designs by the NESC team investigating alternate landing attenuation and isolation systems. This information will be used to understand trends in occupant protection and to define acceptable injury criteria associated with seat restraint and attenuation systems.

Independent Review of the CEV Parachute Assembly Subsystem for Orion Crew Module

Problem: A reliability assessment of the Crew Exploration Vehicle (CEV) Parachute Assembly System (CPAS) showed it to be the top contributor to the overall probability of loss of crew (LOC) for the Orion crew module (CM). The NESC was requested to perform an independent assessment of the Orion Project's reliability assessment methods, the various design options under consideration and the ability of the draft development and certification programs to effectively and efficiently uncover, characterize and retire reliability risks.

NESC Contribution: The NESC formed a diverse team of experts in parachute design, design-development and testing from LaRC, MSFC, the Naval Air Warfare Center, and Sandia National Laboratories. Experts in avionics, materials, testing, statistics, reliability, and design of experiments (DoE) were added from LaRC, GRC, GSFC, SSC, and five contractors. Two heritage-Apollo parachute and safety experts were also included to provide historical perspective on the development of recovery parachute systems for crewed space vehicles.

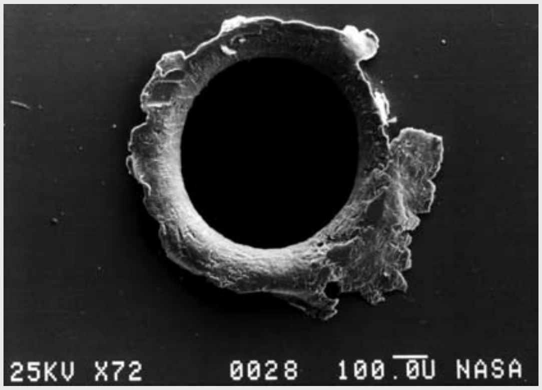
Results: The NESC team provided the Orion Project with early interim recommendations on design options and design development practices related to reliability. The team later provided additional recommendations on effective development testing and on comprehensive, resource-efficient verification activity planning using DoE techniques. The team's innovative recommendations, made possible by the diversity of its members' perspectives, will help the Orion parachute team define a robust and reliable design in time for their Preliminary Design Review.

Mike Herr (left), Senior System Engineer with the Naval Air Warfare Center, and Bob West, retired Test Manager of the Apollo Earth Landing System, examine an Orion drogue parachute at Airborne Systems North America.

Independent Review of Orion Micrometeoroid and Orbital Debris Risk Assessment

Problem: One of the greatest recognized risks the Orion crew module will face is that posed by micrometeoroid and orbital debris (MMOD), and protecting the spacecraft from MMOD damage influences many of the design decisions made by the Orion Project.

NESC Contribution: The NESC performed a review of Orion's MMOD risk assessment process. This included evaluating the MMOD environment models, hypervelocity testing programs, and the software tools used to compute the risk due to MMOD. The NESC team also produced their own MMOD risk assessment using a software application parallel in function to the tool (Bumper II) used by the Orion Project. With this alternative tool the NESC team successfully verified the gross assumptions and computations of Bumper II. The NESC team included some of the country's leading experts on MMOD from JPL, GSFC, and JSC, as well as from the Institute for Defense Analysis, The Aerospace Corporation, and the Missouri University of Science and Technology.



MMOD impact on satellite component retrieved during the STS-41C Solar Max repair mission. The hole is 500 microns – about the size of the period at the end of this sentence.

Results: The team identified several areas in the Orion Project's risk assessment that either over-predicted or under-predicted risk, and offered recommendations that could lead to a better estimation of actual MMOD risk.

Smart and Intelligent Sensor Payload Technology Advancement and Demonstration

Problem: Sensors are ubiquitous system elements for applications ranging from monitoring to closed-loop control in ground-based and space-based platforms. Methods are sought to simplify sensor configuration and maintenance, and contribute positively to systems engineering trades involving wiring, power consumption, and reliability. Promising sensor technologies require application in a relevant environment to advance the technology readiness level to 6/7.

NESC Contribution: A project was proposed to demonstrate sensor system advances including: (1) smart sensors adhering to defined standards, (2) small reconfigurable commercial-off-the-shelf (COTS) data acquisition system, (3) integration of radio frequency identification (RFID) technology for tracking system elements and to link to EEE1451.4 transducer electronic data sheets (TEDS), (4) power distributed over ethernet (POE), (5) wireless sensors, and (6) intelligent sensors that embed health assessment. SSC proposed the Smart & Intelligent Sensor Payload (SiSP) Project, which was approved for ground operations associated with the MLAS launch.

The SiSP development approach adopted the MLAS Resident Engineer model; where two junior-level engineers at SSC were selected as the electrical and mechanical leads. The SiSP Project involved several collaborations. KSC contributed their smart networked element (SNE) intelligent sensor, GRC defined pressure measurement requirements, and MSFC coordinated acoustic measurements.

Results: The SiSP was installed at the WFF launch pad in advance of the MLAS launch. External SiSP sensors included four pressure transducers on the launch stool to collect ignition overpressure measurements, two radiometers on the blast wall, and a microphone near the launch pad. Internal SiSP sensors, including thermocouples and a tri-axial accelerometer with RFID tags, were attached to selected modules to demonstrate automated inventory verification. RFID tagged transducers were also used to access virtual TEDS parameters. The proximity of the rocket plumes destroyed much of the interconnect cabling, preventing communication with the SNE. Fortunately the health detection capabilities of this sensor had been previously demonstrated in another project. Review of the data that resulted from the SiSP experiment showed that it achieved its primary objectives.

Lessons Learned: The availability of sensor standards provides the ability to simplify sensor installation and maintenance, moving toward plug-and-play capability. In particular, TEDS provides key benefits that reduce labor associated with configuration. The SiSP Project showed that a cost-effective method of retrofitting TEDS capability into existing sensors can be accomplished using RFID and simplified interconnections can be achieved using POE. The advantage of flexible COTS data acquisition systems has been demonstrated by the reuse of SiSP components to achieve rapid turnaround development of several follow-on systems.

(Above, from left) John Schmalzel, Andrew Bracey, and Stephen Rawls prepare the SiSP sensor package for the MLAS launch. (Right) MLAS Flight Test Vehicle is shown on the launch stool during sensor installation.

Final check out of the MLAS FTV in the high bay of the WFF Payload Processing Facility prior to transport to the launch pad.

Max Launch Abort System Risk Reduction Test Completed Successfully

Problem: The Launch Abort System (LAS) for the Orion Crew Exploration Vehicle will provide a means of separating the crew module (CM) from the Ares I in the case of a launch vehicle malfunction occurring from the time the crew enters the CM through ascent to orbit. As a risk mitigation effort for the technical development of the Orion LAS, the NESC designed, built, and tested an alternative concept, independent of the Orion Project.

NESC Contribution: Conceptually, the Max Launch Abort System (MLAS) extracts the Orion CM from the launch vehicle using alternative methods for providing propulsion, stabilization, and parachute deployment compared to the current Orion baseline design. The MLAS flight test was a full-scale unmanned pad abort test demonstrating the viability of this alternative design.

The flight test vehicle (FTV) was assembled, tested and launched from the Wallops Flight Facility (WFF) to take advantage of decades of sounding rocket development and flight experience. Over 150 people from across the Agency and industry participated in the MLAS Project. This was an accelerated project lasting approximately two years and was intended to run independently of, but parallel to, the Orion Project's own LAS development. To meet cost and schedule goals, off-the-shelf hardware and existing technologies were used wherever possible. The team also adopted a rapid prototyping approach wherein testing was performed on those subsystems and components that were deemed high risk and/or priorities in ensuring the success of the mission objectives. Testing included wind tunnel exposures to validate the aerodynamic design, a booster motor firing, vibration exposures of selected avionics boxes, and firing of frangible release ordnance. In addition, the landing system was extensively tested including a parachute mortar firing, several ground deployment tests, and a helicopter-initiated drop test demonstrating a portion of the parachute deployment sequence.

A CH-53 from the HX-21 Air Test and Evaluation Squadron was used to successfully release the MLAS forward bay cover drop test payload.

To reach the coast phase of flight, the FTV was staged with a boost skirt containing four MK 70 solid rocket motors, which launched the


Dr. Charles Schafer, NESC Chief Engineer at MSFC, monitors MLAS propulsion system sensors moments before liftoff.


The forward fairing and coast skirt (left) integrated for fit check prior to encapsulation of the crew module (right).

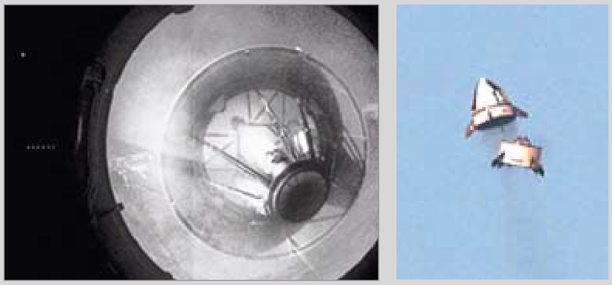
FTV and placed it at the proper altitude and velocity for the testing phases. After the boost skirt was released, the FTV coasted, stabilized by fins on the coast skirt, demonstrating passive coast stabilization. To transition from the coast phase to the landing phase, parachutes were used to reorient the vehicle to a vertical attitude. At that point, the forward fairing released the CM simulator and the landing demonstration began. All of the components landed in the ocean. The 88-second flight test accomplished all MLAS Project objectives.

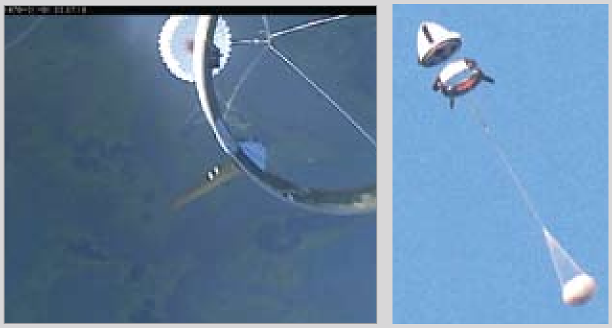
Results: The flight test of the MLAS FTV was successful and will provide NASA, and specifically the Orion Project, with a dataset to be used as needed with the development of the final Orion design. The major objectives of demonstrating passively stable coast, passive reorientation, and the landing parachute deployment were met. The MLAS Project also provided a unique opportunity for NASA engineers and analysts to design, build, and test a full-scale prototype vehicle, expanding NASA's experience base in accelerated design and development projects. The interaction between NESC technical leaders, Apollo veterans, and early-career Resident Engineers also created a learning opportunity for everyone. The NESC Resident Engineer Program, where junior-level engineers are detailed to the NESC for one year, has since been spun off as an NESC program of its own.

On-Board and Range Flight Video Imagery


Liftoff of the MLAS FTV from the WFF test range.

ON-BOARD IMAGES | RANGE IMAGES


Boost skirt separation viewed from the CM heatshield.


Coast skirt separation viewed from the FTV outer mold line.


CM release viewed from inside of the forward fairing.

Robert Browning (left) from WSTF and Curtis Banks from MSFC, install conventional and Fiber Bragg Grating strain gauges on a Composite Overwrapped Pressure Vessel for testing.

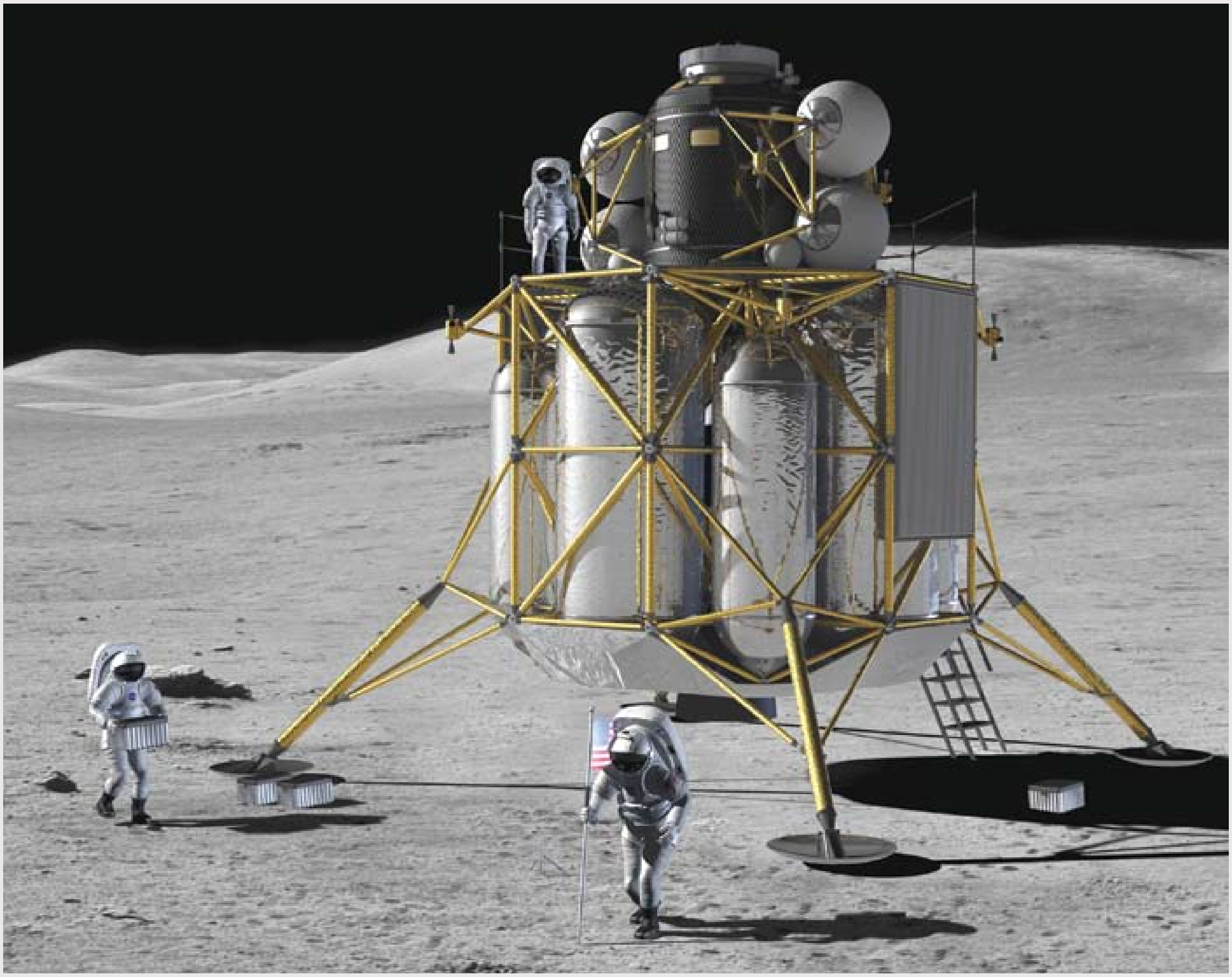
Launch Vehicle Shell Buckling Knockdown Factors Testing Underway

Problem: The NESC Shell Buckling Knockdown Factor (SBKF) Project was established in March 2007 to develop and validate new analysis-based shell buckling design factors (i.e. knockdown factors) for Ares I and V metallic and composite launch vehicle structures. Refined knockdown factors will enable significant weight savings in these vehicles and will help mitigate launch vehicle development and performance risks.

NESC Contribution: The NESC has supported a significant portion of the SBKF Project, including funding for the design and fabrication of a large-scale test facility, the first series of large-scale buckling test articles, programmatic and technical support, peer reviews, and advocacy.

Results: In FY09, the SBKF Project made significant progress in several key work areas including sub-component and component testing and analysis, Ares V structures trade studies and associated mass savings estimates, and testing of an alternate aluminum-lithium (Al-Li) alloy for Ares V core stage. Some of the highlights for this year include successful testing of two 8-foot-diameter Al-Li orthogrid barrel test articles one of which was representative of a 45 percent-scale Ares I upper stage liquid hydrogen tank barrel section. The high-fidelity analysis predictions of these large-scale tests continue to correlate well with the test result and, once fully validated, will become the basis of new analysis-based design factors. The subcomponent analysis and test activity within the SBKF Project completed its first set of path-finding stiffened panel crippling tests at LaRC. These tests were used to integrate a typical local stiffener failure mode that is not well understood and is not accounted for explicitly in current Agency design practice. Analysis tools and nonlinear orthotropic material models are being developed to aid in the design of these important detail features. The Advance Aluminum Alloy Development activity and the Structures Trade Study activity worked together to identify the benefits of other Al-Li alloy materials on the design of several Ares V vehicle concepts. The results of the study indicated thicker Al-Li material would enable more structurally efficient orthogrid barrel components by increasing the height of the machined stiffeners. To this end, Al-Li 2050 was identified as a candidate replacement material for Al-Li 2195 in the Ares V core stage because it is available in thick plate material, has similar material properties to 2195, and is currently being used in commercial aircraft. The NESC supported the purchase of a large plate of 4-inch-thick 2050 material for preliminary material property and subcomponent screening tests to assess the performance of the material in typical launch-vehicle specific environments. The SBKF Project was peer reviewed in March 2009, and has published 13 technical reports summarizing trade studies, testing, analysis, and design activities and results.

Andrew Lovejoy (seated) Stress Analyst, and Dr. Mark Hilburger, (center) Principal Investigator from LaRC; and Mike Roberts, Test Engineer, MSFC discuss real time data from an Ares V-style shell under test at MSFC (right).



Probabilistic design methods for the Lunar Surface Access Module, Altair, may lead to designs that decrease weight while increasing performance.

Increasing the Use of Physics-Based Probabilistic Analysis and Design within the Agency

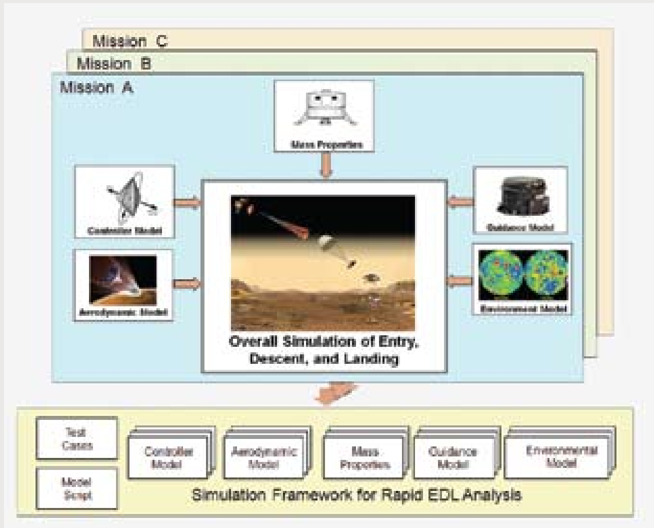
Problem: The NESC was asked by the NASA Engineering Management Board to identify candidate design problems to highlight the potential of probabilistic design methods, an alternative approach to the more traditional factor-of-safety paradigm commonly used in aerospace structural design. Probabilistic design methods incorporate aleatory (random) and epistemic (manufacturing, tolerance, etc.) uncertainty models as well as material and load variability probability distributions to obtain quantitative sensitivity and probability-of-failure information about the design. This information can be used to make informed judgments about critical system testing needs, manufacturing controls, the relative reliability of design options, and the balancing of reliability and performance of integrated system components. Tailoring of the overall system reliability to the operational scenario may then allow, for example, lighter launch vehicle structural designs than would be obtained by using factor-of-safety or worst-on-worst case load combinations.

NESC Contribution: The NESC formed a team of probabilistic design methods experts from LaRC, GRC, and MSFC, safety and reliability experts from HQ, and discipline experts in structures, loads and dynamics, and controls from various Centers, industry and academia. The team met with key engineering personnel from the Ares V and Altair Projects, identified over 30 candidate problems, and developed ranking criteria to reduce the final number of candidate problems to six.

Results: These candidate problems, along with recommendations for increasing the awareness and use of physics-based probabilistic analysis and design methods, were provided to Agency senior management.

Developing a Simulation Framework for Rapid Entry, Descent, and Landing Analysis

Problem: Entry, descent, and landing (EDL) flight simulations are typically developed for specific tasks and in many cases once the effort is completed, the simulation models are not adequately documented or retained. Many projects or studies requiring EDL would benefit from high-fidelity simulations with a library of validated and documented models.



Models used to simulate successful EDL missions are being collected and stored in a secure repository to facilitate rapid prototyping of future missions.

NESC Contribution: An NESC team is converting and archiving relevant EDL models and scripts into a secure user library with appropriate user documentation and test cases. These models include: mass and aerodynamic models, and atmospheric models; guidance and control algorithms from a number of past and current Earth and planetary flight projects; and new simulation models (ellipsed aeroshell, inflatable decelerators, and supersonic retro propulsion) under development by an Agency-wide EDL systems analysis study team.

Results: It is expected the products of this assessment will help define the required architectures and investment strategies to enable a wide range of future robotic and human exploration missions. Additionally, it will increase the ability of the Agency to provide rapid evaluation of EDL characteristics in systems analysis studies, preliminary design, mission development and execution, and to respond to time-critical assessments.

NASA Technical Fellows Sponsor Entry, Descent, and Landing Engineering Workshop

Problem: For missions requiring entry into an atmosphere, the entry, descent, and landing (EDL) system is a key driver of the mission architecture. The Orion and Mars Science Laboratory (MSL) Projects have many EDL similarities, as they both use a guided and lifting atmospheric entry of a blunt capsule. In the past, there had been limited collaboration between these two Projects, mostly in the areas of aerothermodynamics and thermal protection systems, but they were otherwise developing independent engineering solutions to this critical mission phase.


Brian Hoelscher, Subsystem Manager for Orion Entry Flight Control, discusses control of the Orion spacecraft during entry at the EDL Workshop.

NESC Contribution: The NESC organized a workshop in April 2009 to provide an opportunity for the Orion and MSL Projects to exchange and compare their EDL design requirements, technical approaches, testing strategies, top concerns, and lessons learned, as well as to extend their collaboration to other technical areas. Approximately 50 people from NASA and industry attended the workshop representing the Orion and MSL EDL teams and several NESC Technical Discipline Teams.

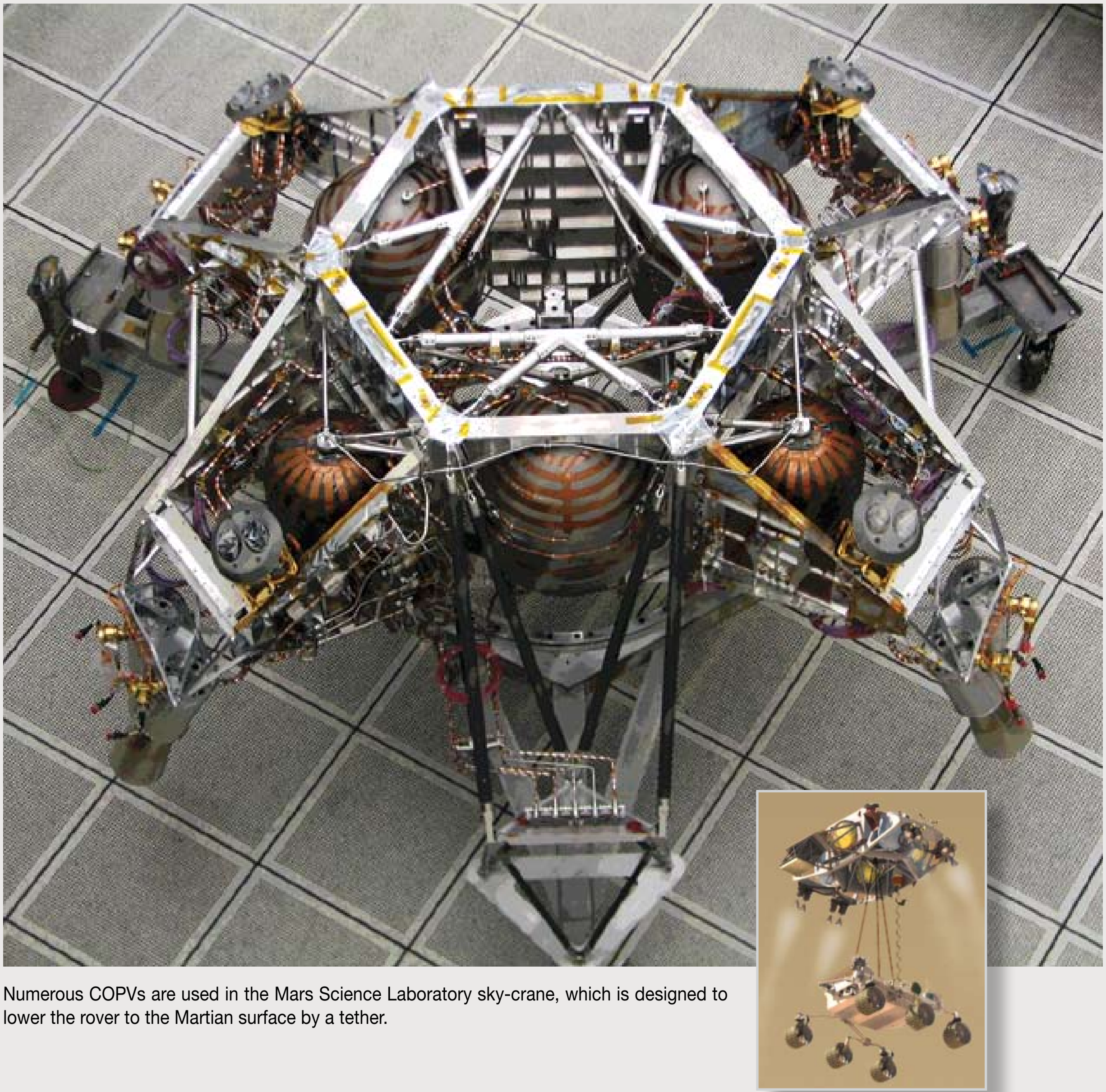
Results: Technical discussions took place in the areas of aerodynamics, reaction control system jet interactions, guidance and control, uncertainties, modeling and simulation, decelerators, event triggers, and verification and validation. In general, the workshop participants built a shared understanding of their EDL engineering challenges, technical approaches, risks, lessons learned, and developed improved communication channels between the teams. The workshop products included a summary of key findings and recommendations, desired topics for future technical interactions, and identification of the best opportunities to leverage their engineering experience to improve EDL solutions and reduce risk to the Orion and MSL missions. The participants also made recommendations for future NESC-sponsored engineering studies that could address EDL challenges outside the scope of these Projects.

Composite Overwrapped Pressure Vessel Life Prediction Model Development

Problem: Stress rupture of composite overwrapped pressure vessels (COPVs) is a time-dependent failure mode of the composite material that can occur at operating pressures and temperatures resulting in a burst of a COPV below the ultimate strength. In previous assessments of COPV stress rupture risk, deficiencies were identified in the parameters and structure of modeling approaches used to predict the stress rupture lifetime of COPVs.

NESC Contribution: To address this Agency-wide problem, the NESC assembled a team of both analytical and test experts from JPL, LaRC, GRC, and MSFC with backgrounds in composite modeling, statistical methods and uncertainty, COPV fabrication, and strand material property testing. The analytical team will identify a model that will include the effects of proof testing and uncertainty treatment.

Results: Analysis and testing is planned to be conducted over several years. The NESC team will publish the strand and subscale COPV empirical data, updated or new reliability estimation models, findings and recommendations, and a list of underlying assumptions. This will be packaged for presentation to NASA projects and programs. In addition, testing methods and lessons learned during the testing phases will be compiled along with any recommended follow-on testing.



Numerous COPVs are used in the Mars Science Laboratory sky-crane, which is designed to lower the rover to the Martian surface by a tether.

Applying Acoustic Emission to Characterization of COPV Progressive Damage

Problem: NASA faces recertification and life extension issues for Kevlar® epoxy composite overwrapped pressure vessels (COPVs) used on the Space Shuttle orbiter. Of particular concern is a catastrophic "burst-before-leak" failure mode caused by stress rupture. Reliability issues also exist for International Space Station carbon-epoxy COPVs, which are susceptible to impact damage, resulting in a reduction of the burst strength.

WSTF Project Leader Ralph Lucero (left), Jacobs Technology, and Dr. Valery Godinez, Mistras NDE Solutions, check Acoustic Emission (AE) sensors prior to test.

NASA is actively developing sensitive nondestructive evaluation (NDE) methods for use during the COPV life cycle. Acoustic emission (AE) has shown particular promise for real-time detecting and monitoring of the stress-wave propagation produced by actively growing defects in composite overwraps of COPVs.

NESC Contribution: The NESC team implemented voluntary consensus standards used by industry for AE characterization of damage progression using intermittent load hold stress. The team gained insight into progressive damage by monitoring AE event rate and energy. Source location data helped discern between AE due to microstructural damage and background noise.

Results: When stressing (pressurizing) a COPV, usually no AE from the overwrap is observed upon reloading until the previous load has been exceeded. This is classically known as the Kaiser effect. A corresponding numerical value known as the Felicity ratio, which is the applied stress at which significant AE begins during loading divided by the applied stress during the previous cycle, is used to determine if the Kaiser effect holds or is violated. At Felicity ratio ≤ 1.0, the Kaiser effect is violated, which is indicative of irreversible, accumulated damage in the overwrap. Waveform analysis of the AE events and corresponding microscopic indications associated with violation of the Kaiser effect could lead to robust pass-fail acceptance criteria for COPVs.

Lessons Learned: Application of voluntary consensus standards used by industry can help solve difficult technological problems that confront NASA.

Modeling of Carbon Composite Overwrapped Pressure Vessel for Autofrettage Response

Problem: Long-term reliability of composite overwrapped pressure vessels (COPVs) is still uncertain. Although design, test, and manufacturing procedures are well developed, additional data are needed to verify reliability predictions. Complex COPV structures require high-precision analytical models to predict safety and reliability.

NESC Contribution: A joint NESC, GRC and WSTF effort developed numerical modeling of COPVs to increase predictive capabilities. A building-block approach, with evaluation of finite element analysis techniques, has improved NASA COPV life prediction capabilities. One focus was accurate modeling of manufacturing autofrettage processes to capture and quantify the resulting mechanical response. Autofrettage pressurizes the COPV metal liner past its yield stress to plastically deform it while constrained by the overwrap, resulting in a compressive state at ambient pressure conditions.

Technician Don Saunders installs a COPV autofrettage test article into the WSTF 860 test system as Project Leader Ralph Lucero (left), Jacobs Technology, looks on.

Physical measurement data from pressurized COPV testing are factored into the numerical simulation models. Preliminary data analysis quantifies the level of permanent liner deformation.

Results: While initial understanding of the base components' material properties and structure was critical to accurately predict stress states, COPVs could be accurately modeled with numerical simulation techniques, which improve as mechanical results of autofrettage are better understood. The latest models provided insight into critical areas within a specific COPV structure. Numerical simulation information, coupled with physical testing, enhanced the in-situ monitoring of vessels for life time assessment and guided designers to improve processes for safety and reliability.

Mobile Aerospace Reconnaissance System Performs MLAS Visual Imagery Demonstration

Problem: The Max Launch Abort System (MLAS) flight test demonstrated an alternate launch abort system for the Orion spacecraft. The flight demonstration involved a number of separation and parachute deployment events critical to the operation of the vehicle. Detailed visual imagery of these events was necessary for accurate post-flight assessments.

NESC Contribution: Under NESC sponsorship, the Hypersonic Thermodynamic Infrared Measurements (HYTHIRM) team identified a ground-based visual and infrared camera system of high resolution and frame rate that would be capable of capturing the details of the MLAS flight. This camera system, known as the Mobile Aerospace Reconnaissance System (MARS), was used to image the MLAS flight and capture the details of the separation and parachute recovery events required to successfully deliver the Orion Crew Module (CM) Simulator safely to the Atlantic Ocean.

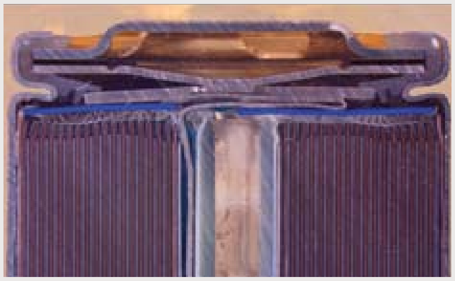
Results: The imaging of the MLAS flight demonstrated the advanced capability of the MARS camera system to provide detailed, high-resolution video of complex flight events and processes. Images captured from a distance of over 2.5 miles are sharp and detailed enough to capture details of the CM separating from the forward fairing, parachute extraction and deployment, and splashdown dynamics as the CM entered the ocean.

The MARS system successfully captured all CM separation and parachute deployment events. Detailed processing of the CM separation from the forward fairing has been used to better determine and understand the mechanics of the CM separation, which was also captured by on-board inertial measurement unit instrumentation. Time synchronization of the images provided the ability to post-process the imagery to determine overall vehicle and component trajectories. Simultaneous imaging in both the visual and infrared spectrums provided additional contrast and definition that could not be obtained by either method alone.

Application of Lithium-Ion Long Life Battery in the ISS EMU Being Studied

Problem: The Chief of the Energy Systems Branch at JSC requested an NESC assessment of the ISS Extravehicular Maneuvering Unit (EMU) Long Life Battery (LLB). The LLB had been identified as an ideal candidate for redesign in order to use the longer cycle life and higher specific energy densities associated with Lithium-Ion (Li-Ion) cells when compared to its current silver-zinc-based batteries. Li-Ion batteries are increasingly used in space programs in an effort to minimize launch mass. The issue of addressing electrode thermal instability and flammability of the electrolyte in Li-Ion cells that make them prone to catastrophic thermal runaway was necessary in order to consider them safe for use in spacecraft or spacesuit environments. It was essential that the risk of using these batteries be thoroughly understood and potential modifications to the design or testing/screening of the cells and batteries required examination to reduce the probability of failure and increase the reliability and safety.

NESC Contribution: The NESC organized and led a team of Li-Ion battery experts from GRC, GSFC, JPL, JSC, MSFC, The Aerospace Corporation, and other government agencies. The team was tasked with identifying known causes of internal electrical shorting mechanisms in 18650 size Li-Ion cells as well as providing a technical review of the preliminary thermal and electrical design application for the LLB. The NESC team provided expert opinion, probabilistic failure occurrence analyses, and an examination of the basic safety features currently implemented in commercial charger and battery designs for applicability to the LLB.



Cross-section view of a Li-Ion battery cell showing crimp and electrode design features.

Results: The results of the assessment included a comprehensive set of recommendations for screening battery cell lots and performing worst case thermal analysis to minimize the chances of a Li-Ion cell short in the proposed LLB design. These findings were realized in time to support the Project scheduled Critical Design Review.

High-resolution MARS video of the MLAS CM simulator separation demonstrates that both qualitative and quantitative data can be extracted from a land-based imaging system operating at a range of over 2.5 miles.

Both visual (left) and infrared (right) imaging of the CM main parachutes provide sufficient detail to assess parachute damage or other operational anomalies.

Independent Review of Research Flight Control System Software/Hardware

Problem: The Integrated Resilient Aircraft Control (IRAC) Project requested the NESC review software plans to host both level A (safety critical) and level B (non-safety critical) software on the same Research Flight Control System (RFCS). This is a critical part of the development of a new F-18 testbed aircraft with a full array of capabilities supporting the Aviation Safety Program. The goal was to ensure that the new testbed is at least as safe as previous flight-control testbeds flown at DFRC.

NESC Contribution: NESC technical experts reviewed the design approach that had been developed by the IRAC Project and its contractor. This was done through a review of contractor documentation and presentations, and a series of discussions with the project team and contractor. The NESC team assessed the application software approach, the level of testing, the methods used to separate the software, and other mitigation factors.

Results: The NESC review concluded the software design and testing methods the IRAC Project was using, combined with the limited flight envelope enabling the pilot to recover from any control system induced problem, will allow a satisfactory level of safety with no additional modifications required. In addition, future design improvements were identified that could be implemented by the IRAC Project to meet future testbed requirements at a later date.

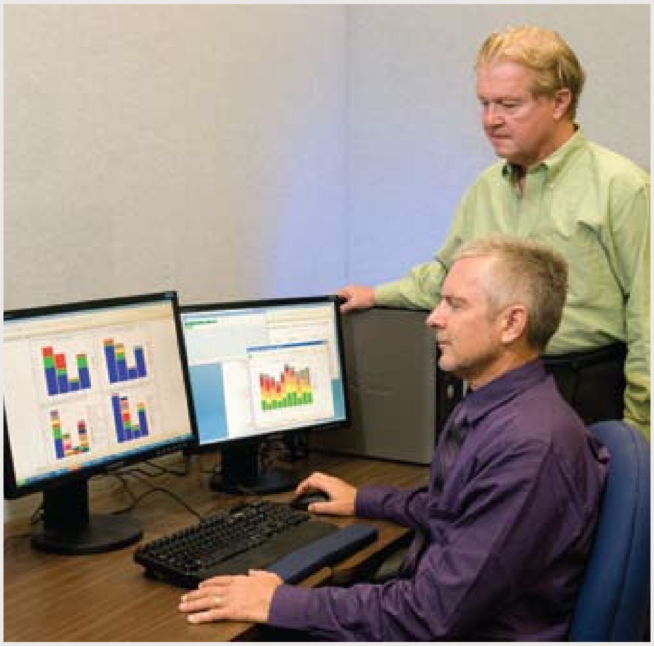
(From left) Dr. James Lee, IRAC Chief Engineer; Jerry Budd, IRAC Project Manager; and Dr. James Stewart, the NESC Chief Engineer at Dryden discuss the IRAC F-18 Testbed Aircraft software and hardware.

Data Mining and Trending Working Group Continues Efforts to Expand Trending

Problem: The Agency requires improved capability to trend technical issues encountered in NASA programs.

NESC Contribution: The NESC is leading the Agency-level Data Mining and Trending Working Group (DMTWG) whose purpose is to assist in formulation and implementation of capability to strengthen trending of NASA programs and projects and to ensure appropriate visibility of data mining and trending. Through workshops, monthly meetings, and training, the NESC has developed working relationships with data mining and statistical experts within academia, industry, and other government agencies.

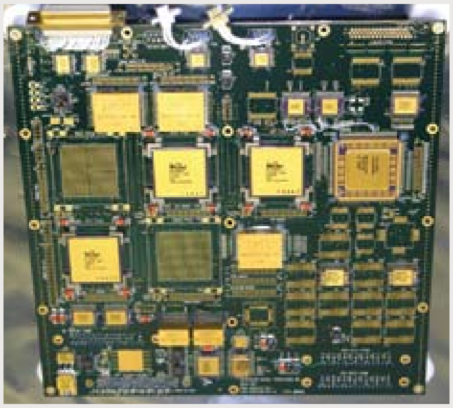
Results: The DMTWG assisted NASA organizations by providing data mining experts to NESC assessments, such as the orbiter's main propulsion system gaseous hydrogen flow control valve poppet failure. The DMTWG team also aided the development and implementation of linguistic data mining approach meant to ameliorate terminology inconsistencies in problem reporting under joint development by the JSC Engineering Directorate and the University of Central Florida. This group provided a forum to enhance communications across the Agency in the areas of data mining and trending by sharing ideas, methods, technologies, processes, tools, and lessons learned.



Roger Schwarz (seated) Engineering Discrepancy Report Analyst, and David Throop of Boeing, a developer of the NASA Semantic Trend Analysis Tool prototype, view results from text mining.

RTAX-S Field Programmable Gate Arrays Risk Reduction Testing Continues

Problem: Multiple projects across NASA desire using the latest Actel RTAX-S series Field Programmable Gate Arrays (FPGAs). These parts offer significant advantages over the use of previous FPGA versions (RTSX-S or RTSX-SU) with regard to maintenance of signal integrity, capacity, capability, speed, and electrostatic discharge tolerance. Reported user application related failures in the previous generation of FPGAs (RTSX-S) precipitated concerns late in the hardware design cycle for several NASA projects, causing significant cost impacts and higher mission risks.



Circuit board using multiple RTAX2000S parts.

NESC Contribution: The NESC conducted a 6,000-hour test of 80 units (two lots) of RTAX250S and 80 units (two lots) of RTAX2000S programmed with an algorithm designed to emulate expected space flight applications. The test series subjected the parts to the voltage specification limit and temperature specification limit conditions. The selected representative space flight designs include multiple copies of a Military Specification 1553 Remote Terminal interface, an eight-bit microprocessor (PIC 16F84), Embedded Block Random Access Memory, an Error Detection and Correction algorithm, a Memory Controller, and a Universal Asynchronous Receiver/Transmitter.

Results: Following completion of the planned 6,000-hour test in the second quarter of calendar year 2009, the preliminary results indicated no part failures or part "out of specification" conditions. There was observable parametric trending which is still being analyzed. The parts will be transferred to Actel for additional Actel-funded radiation testing.

Improving Spacecraft Connector Selection to Reduce Failure Rates

Problem: The Agency recently experienced "high profile" connector problems, the most visible and publicized of these being the problem with the Space Shuttle's main engine cut-off system (specifically the cryogenic feed-through connector). This problem had similarities to an Atlas expendable launch vehicle issue experienced and resolved some years earlier. These occurrences pointed to the need for a broader Agency review of the electrical connector selection and application processes for space flight applications and how lessons learned and past problem records are fed back into the processes to avoid recurrences.

NESC Contribution: An NESC team which included members from all Centers, reviewed spacecraft electrical connector selection and application processes at each Center on specific projects. This included reviewing how lessons learned are incorporated and disseminated. Each Center's controlling documentation for spacecraft connector selection and application, including the roles of government and contractors, was also examined. In December 2008, the team participated in a Government Inter-Agency Science and Technology Wiring Working Group Meeting and surveyed the Society of Automotive Engineers Connector Committee members regarding their experience relative to NASA connector concerns. For this assessment, the NESC team attempted to determine whether spacecraft electrical connector selection and application processes could be improved, and if so, whether the NESC could provide assistance in furthering that goal.

Bob Arp, an aerospace technician with the United Launch Alliance, repairs a replacement feed-through connector installed in the external fuel tank on STS-122.

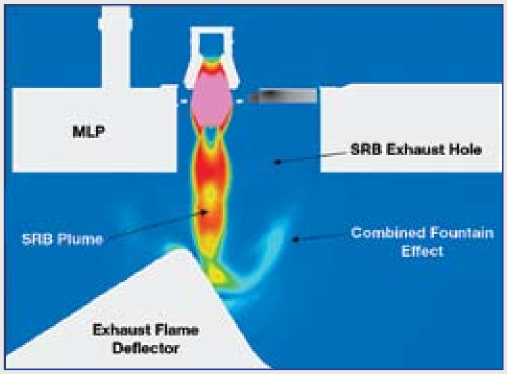
Results: While the number of documented operational failures is not large when the scope of use is considered, the majority of spacecraft electrical connector issues are application-related and tend to reoccur with potentially serious consequences to mission success and safety. Connector failures occur throughout the life-cycle (from design to field usage), but analysis on two data samples still suggests that the majority of connector issues are application related. The team recommended several targeted adjustments to improve the effectiveness of the existing Lessons Learned Information System and community.

Launch of STS-124 which carried the module to complete the Japan Aerospace Exploration Agency's Kibo laboratory.

STS-124 launch resulted in over 3,000 fire bricks being stripped from the east wall of KSC Launch Pad 39-A.

Computational Fluid Dynamics Used to Characterize STS-124 Launch Pad 39-A Damage

Problem: During the launch of STS-124, the flame trench on Pad 39-A sustained significant damage. Blast impact and subsequent flow from the firing of the Solid Rocket Boosters (SRBs) dislodged more than 3,000 20-lb. ceramic fire bricks from the wall of the flame trench, breaking many into pieces and ejecting them from the trench at velocities as high as 1000 ft/sec. The vast majority of these bricks and fragments were driven well clear of the launch pad and posed no threat to the Space Shuttle or pad facilities during liftoff and no damage due to this event was recorded on the orbiter. However, the question was raised as to whether a brick or one of its fragments could be entrained in the Space Shuttle engine exhaust flow or ricochet off pad structure and damage the orbiter during liftoff.



Detailed CFD was used by MSFC engineers to predict the KSC Pad 39-A flame trench flowfield resulting from firing of the Space Shuttle SRBs.

NESC Contribution: Engineers from MSFC employed highly detailed Computational Fluid Dynamics (CFD) techniques to predict the velocities and pressures in the flame trench during the liftoff event. Data from these simulations were then used by engineers at both MSFC and JSC to predict debris tracks and ultimately clear future Space Shuttle missions for the possibility of similar events. Since the Orbiter Project analysis employed advanced CFD technology that had extremely limited application to flight problems of this type, the NESC was requested to perform a peer review of the Project's analysis. To perform this review, the NESC assembled a panel of leading experts in the theory and development of these CFD techniques from LaRC and ARC. Ultimately, the panel was expanded and used to review and consult on the resulting debris transport analysis performed by the Orbiter Project and used as flight rationale for future shuttle missions.

Results: The NESC team found no credible fault or shortcoming in the Project's fundamental approach to the problem and was supportive of their willingness to employ high fidelity analyses despite the limited validation and testing available for the methods employed. The panel did note some geometric modeling simplifications incorporated by the Project that could play a role in the analysis and recommended sensitivity analyses to determine which of these might most impact their results. One of the most significant results of the review identified a technology gap: the inability to accurately model the impact of the water deluge system employed on the pad to the resulting aerodynamic predictions. Both the reviewers and the Project felt that the water deluge could play a role in the aerothermodynamic development of the flow in the trench, but there was no methodology available to effectively predict this effect.

Lessons Learned: With appropriate technical expert review and consultation, complex analysis techniques with limited validation and/or application to the specific problem at hand can be effectively employed to predict and simulate complex physical problems resulting from ongoing flight operations. Also, exposure of the research and development community to the real-world problems of operational vehicles often uncovers shortcomings of existing technology and is useful in guiding future research and development efforts.

KSC workers repair east wall of Launch Pad 39-A damaged by STS-124 SRB ignition.

Independent Review of Pad 39-A Flame Trench Repair

Problem: Post-launch inspection of the Mobile Launch Platform-3, Pad 39-A Fixed Service Structure and Pad 39-A apron was conducted after the launch of STS-124. The inspection showed excessive Solid Rocket Booster (SRB) flame trench retention wall debris. Excessive liberation of bricks from the east retention wall was also observed. Extensive repair of the flame trench was performed. A region of 25x100 ft. of the east wall and a region of 25x80 ft. of the west wall were cleared of bricks. All around the cleared regions steel lintels were installed. A Fondue Fyre (FF) refractory concrete system was installed in the cleared regions. Anchor plates on brick walls above the lintels and near control joints were installed.

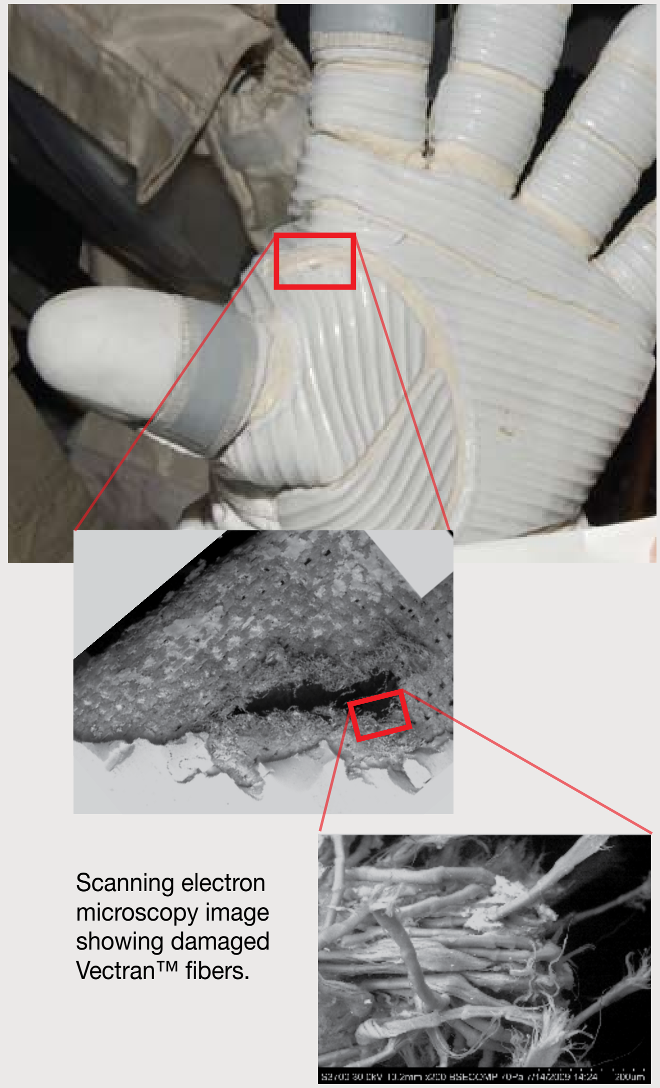
KSC inspectors test repairs on the Fondue Fyre refractory concrete system on the flame trench walls. Fondue Fyre was developed during Apollo.

NESC Contribution: An NESC debris transport team was formed to conduct a review of the design and analysis of the flame trench retention wall repair. The team did not perform any new analyses or tests, but reviewed all the materials, data, and analysis that pertained to the wall repair.

Results: The team found the flame trench wall repair design and analysis to be well documented and found that repair analysis showed all stresses were within the current allowable environmental requirements. Also, it was confirmed that design and sizing of all elements were performed according to current engineering practices.

The team concluded that analysis of the FF system resulted in large positive margins demonstrating a safe and satisfactory design, although current Nondestructive Evaluation (NDE) techniques have not been validated to determine wall integrity. Qualitative tap-testing showed promise for detection of disbonds and voids in FF and debris liberation from brick wall and FF repair area appeared to be unlikely.

The NESC team suggested that debris transport to the vehicle is unlikely. It recommended collecting sufficient vibroacoustic data to accurately determine the environment of the flame trench, validate the assumptions made in the vibroacoustic analyses, and continue the development and validation of NDE methods to assess the integrity of FF panels, bricks and control joints.



Scanning electron microscopy image showing damaged Vectran™ fibers.

Root Cause Determination of Extravehicular Mobility Unit Glove Damage Modes

Problem: The number of Extravehicular Mobility Unit (EMU) gloves damaged during extravehicular activities (EVAs) has increased. The NESC assisted a JSC Materials and Processes team to identify glove damage modes.

NESC Contribution: The NESC assembled materials experts from LaRC, GRC, JSC, the US Army and SRI International. The team reviewed glove materials, manufacturing processes, and testing; examined damaged outermost Thermal Micrometeoroid Garment (TMG) gloves using a unique NASA scanning electron microscope facility with enhanced capabilities; and conducted laboratory tests to duplicate observed microscopic damage modes where different off-nominal surfaces were used to replicate glove damage.

Results: Detailed microscopy of eleven gloves confirmed that damage is the likely result of five damage modes. Ten gloves exhibited damage confined to the thumb region and a single glove exhibited damage in the palm region. In all cases, the exterior glove protective pad was damaged, exposing the glove fabric to damage and ultimately resulted in severed fabric yarn. Laboratory tests were conducted to reproduce TMG glove damage morphologies wherein comparisons of the test results to glove microscopy data confirmed glove damage modes and eliminated other proposed damage modes. Laboratory test results also revealed that glove damage is likely the result of contact with off-nominal (sharp and rough) surfaces during EVAs; such off-nominal surfaces may be produced by micrometeorite impacts. The investigation's results also suggest that other multiple factors contribute to the damage processes, including fabric material properties, fabric architecture, protective pad-to-fabric adhesion, and EVA environments. In an attempt to mitigate future glove damage, understanding gained from this study has been applied to a TMG glove redesign.

Assessment of the Orbiter Gaseous Hydrogen Flow Control Valve Poppet Cracking

Problem: During STS-126 ascent, an orbiter main propulsion system Gaseous Hydrogen (GH2) flow control valve (FCV) appeared to transition from low to high flow position without being commanded. Upon removal post-flight, the FCV poppet was found to have approximately 20 percent of the upper flange fractured. Flight concerns from a poppet fracture include excessive ullage pressure causing the External Tank to vent during ascent and/or debris penetrating the downstream line producing GH2 leakage into the orbiter aft compartment.

STS-126 orbiter main propulsion system flow control valve poppet fracture showing 20 percent loss of upper flange.

NESC Contribution: The NESC augmented the Orbiter Project with subject matter expertise from Pratt & Whitney and seven Centers in the areas of high-pressure hydrogen fractography, nondestructive evaluation (NDE), materials characterization, reliability prediction, and computational fluid dynamics and structural analyses. These team members provided crucial STS-126 fracture analysis, low-stress polishing procedures, and eddy current (EC) NDE inspection standards.

Results: The FCV poppets are EC inspected for crack indications after each ground test and flight. The Orbiter Project is evaluating alternate poppet materials and FCV designs to preclude cracking, and methods for downstream line hardening for debris protection.

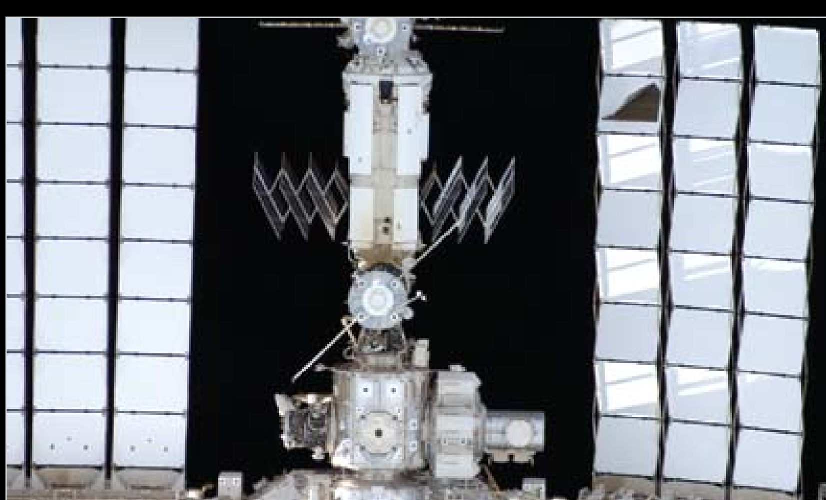
Modeling of International Space Station Radiator Face Sheet Damage

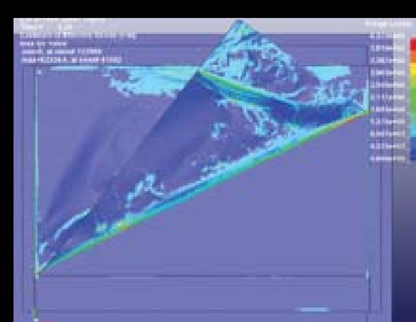
Problem: In September 2008, a damaged International Space Station (ISS) Active Thermal Control System radiator panel face sheet was discovered while inspecting for damage as a result of a possible Service Module thruster cover impact.

NESC Contribution: The NESC became involved at the request of the JSC Engineering Directorate. Initial activities included review of design, flight and micrometeoroid test data. NESC engaged LaRC expertise for infrared (IR) software operations and assisted in analyzing the radiator IR imagery.

As part of the failure investigation, the NESC chartered a dynamic analysis of a panel failure scenario using the LS-DYNA software leveraging expertise from the JSC Structural Engineering Division. The model used a physics-based approach to simulate failure by a pressure event and reproduced many of the observed damage features.

Results: By performing numerous sensitivity analyses, the team was able to characterize the failure mode and establish an estimate of the pressure required to induce the observed failure. Additionally, the NESC performed thermal radiation view factor analysis which corroborated panel-to-panel temperature trends which accounted for various radiator, solar array, and beta gimbal angles. The team arrived at a preliminary conclusion that the face sheet failure was a pressure event. NESC support will continue through the conclusion of the investigation.





(Left) On orbit photo depicting radiator face sheet damage. (Above) LS-DYNA analysis depicting predicted damage due to a pressure event.

Analysis of Solid Rocket Booster PBIS Transformers Reliability

Problem: Destructive physical analysis of a failed flight T2 transformer from a Solid Rocket Booster (SRB) Power Bus Isolation Supply (PBIS) revealed one broken wire on a soldered pin resulting in a persistent open circuit. This failure had been seen in another T2 transformer and there was evidence of fatigue and insufficient strain relief. Such a failure, should it occur in one of five critical T2 leads, is a precursor to multiple failure modes for the SRB, including loss of hydraulic pressure to the thrust vector control actuators and subsequent SRB loss of control. The Office of Chief Engineer requested an NESC independent review to assess PBIS system failure risk.

Launch of the STS-125 Mission which successfully repaired the Hubble Space Telescope.

NESC Contribution: The NESC team comprised of members from GSFC, JSC and MSFC systematically assessed the physics of the failure and the probability of the events which, if occur in sequence, lead to a critical failure. It was noted that the wires soldered to the T2 transformer pins had a 90-degree bend near the pin.

Results: Wire bending experiments at GSFC demonstrated that straight wires repeatedly bent through small angles failed at large numbers of cycles and had the characteristics of "wear out" failures. But wires that were pre-bent to a 90-degree angle then bent repeatedly through small angles failed at many fewer cycles, and exhibited "random failures" behavior. Additionally, a mechanical break in a T2 wire would not necessarily lead to a persistent electrically open circuit. The NESC team concluded the PBIS units with less flight time should be given preference in flight assignment, or preferably, that a fix should be developed. The SRB contractor, the SRB Project, and MSFC Engineering proposed a simple and effective fix through the use of protective fuses. The NESC team endorsed this approach which was implemented on STS-127.

STS-125 Aerosurface Servo Amplifier Anomaly Investigation Support

Problem: Approximately three seconds before the STS-125 launch, the orbiter encountered an anomaly associated with the Aerosurface Servo Amplifier (ASA)-1 indicated by a distorted, 400Hz sinusoidal wave injected onto the M/DM FA1 and OA1 signal return buses, which in turn affected several open ended telemetry signals. While the ASA-1 function is redundant, understanding the cause and implications of the failure in a timely fashion was critical in order to maintain both the safety of the STS-125 crew as well as preserving the mission to service the Hubble Space Telescope. The JSC NESC Chief Engineer requested independent power and avionics technical expertise for evaluation of the anomaly and assistance in determining the likely cause and impact to the mission.

NESC Contribution: Several NESC Electrical Power Technical Discipline Team members supported Orbiter Project personnel in examining the anomaly signatures. The team also provided assistance in evaluating the likely root cause as well as recommendations related to safely preparing the orbiter for re-entry. Real-time detailed review of ASA schematics identified two possible sources for the anomaly: one being similar in nature to the anomaly experienced during ground testing with STS-37 and the other being a less likely scenario caused by an internal short circuit failure within the ASA itself.

Results: In real-time, the most likely cause of the ASA-1 anomaly was isolated to a 26V 400 Hz AC output signal short to ground. This condition resulted in the distorted excitation signal corrupting multiple telemetry signals sharing the common M/DM that persisted until the ASA power supply was isolated by the Remote Power Controller trip. Mission Control was able to revise the on-orbit checkout preparations to avoid the ASA involved to allow the orbiters's safe return. Follow-up inspections confirmed a wire short on the suspect signal. The ASA involved was removed for failure analysis and repair.

Assessments of the Mars Science Laboratory Actuator Status-Tribomechanical Capabilities

Problem: The Mars Science Laboratory (MSL) is a multi-functional exploration rover that uses a number of similarly designed actuators for mobility and mechanical investigations. These actuators are located at each drive wheel, the front steering knuckles, the sensing mast and antenna, and in several robotic arm locations.

The MSL actuators are made of two major components: a gearbox and motor that bolt together as a unit. Due to the mission requirement of operation with minimal electrical power over a wide range of temperatures (-70 C to 70 C), unconventional lubricants and bearing designs must be employed. The design features include minimal bearing preloads, solid lubricants, fluorocarbon greases, seal-less bearings, and ball bearing cages with high levels of clearance.

During system level tests, several undesirable performance issues were observed that have no readily identifiable cause(s). These issues include high levels of drag torque and unstable and high levels of drive motor current required to achieve minimum output torque levels. Because of these issues, the NESC was asked to perform an independent assessment of the actuators.

NESC Contribution: The NESC team was comprised of personnel from GRC, GSFC and JPL with expertise in materials, tribology, mechanical systems, and spacecraft design.

Results: The NESC team identified three primary areas of concern: inconsistent bearing preload, poorly quantified motor shaft rotordynamics, and bearing cage instability. The rotordynamics modeling effort corroborated the contractor's approach to forgo rotor balancing provided the bearing stiffness was maintained through adequate preload. Further, the analysis eliminated other potential sources of vibration except cage instability; this helped to determine the cause for the large amplitude current instabilities observed. These appear to have been traced to interference between the cage and improperly placed bearing preload shims in the motors. The enhanced preload methods, improved shimming, and subsequent testing resulted in improved actuator performance. Torque levels were manageable and every indication is that the life testing had a successful outcome.

The Mars Science Laboratory rover during assembly at the Jet Propulsion Laboratory.

WSTF Project Leader Luis Hernandez (right) and NASA WSTF Project Manager Regor Saulsberry discuss composite overwrapped pressure vessels test system assembly status.

AMES RESEARCH CENTER

During 2009, Ames Research Center (ARC) continued to provide a wide variety of expertise to NESC activities. Approximately 50 ARC civil servants and contractors provided support to the NESC. ARC provided expertise over a range of disciplines including human factors, wireless avionics, digital archives, composites, reentry systems, aerodynamics, nondestructive evaluation and flight dynamics. The NASA Technical Fellow for Human Factors is resident at ARC.

Nans Kunz
NESC Chief Engineer at ARC

Dr. Tina Panontin
Former NESC Chief Engineer at ARC

Exploration Systems

Composite Crew Module (CCM): ARC provided ProEngineer support and testing of the CCM composite Pi preform joints. ARC personnel continued integrated assistance to the CCM team at Alliant Techsystems (ATK), to enhance cross-disciplinary knowledge and understanding of space structures fabrication processes. Specifically, this included lamination of the lower pressure shell and bonding of the backbone structure with Pi preform technology. Small areas of those joints were disbonded, so repair fittings were designed and machined at ARC, then sent to ATK for installation.

Wireless Connections in Space (WCIS): In support of the NESC initiative to develop and demonstrate a highly reliable wireless architecture capable of being implemented in radiation tolerant devices, the ARC team is conducting wireless sensor web and mesh fault tolerance testing of Zigbee and 801.11n products. The Wireless Fault Tolerance Testbed has been initiated, with the Zigbee Evaluation Kit and Daintree network analyzer. Initial experiments, protocol development, and test reports are in progress. ARC also contributed to the SSC Wireless Intelligent Sensor Module effort used on the MLAS flight test, which integrated IEEE 1451 standard sensor information structures, and led to a plug and play capability. The project will conduct an Ares V wireless instrumentation case study, applying the results of these evaluation efforts.

Entry, Descent, and Landing Data Repository (EDL-R): ARC is supporting the NESC EDL initiative by supporting the development, testing and populating of the EDL-R currently located at JPL. This includes significant contributions of Space Shuttle EDL data and software, and digital archive expertise.

EDL Systems Analysis (EDL-SA): ARC is providing aerodynamic, aerothermal, and thermal protection system (TPS) models to the NESC's EDL-SA Project, and will develop a simulation framework and a set of validated sub-system models and scripts to allow rapid EDL evaluation. Numerous tools were used to generate the aerodynamic, aerothermal, and TPS models for both a rigid, mid lift/drag (L/D), ellipse sled configuration and for a flexible, low L/D, inflatable concept. The predictions provided by ARC will aid in the evaluation of capable EDL technologies for future Mars missions.

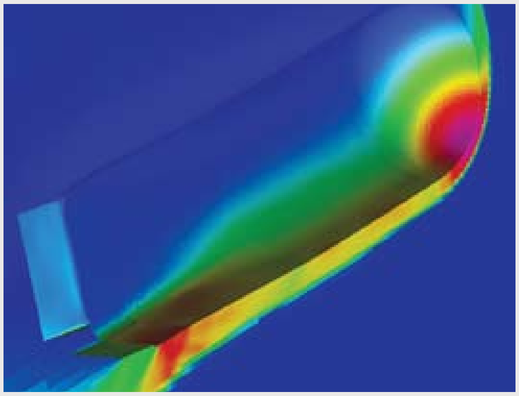
General

Flight Critical Hardware Test Facilities Human Factors Review: NASA operates test facilities for the development of cutting-edge aerospace technologies. These facilities often test one-of-a-kind flight critical hardware under extreme conditions, creating an unforgiving working environment. Although strict safety procedures are implemented, close calls and mishaps still may occur.

An NESC-sponsored, ARC-led review of NASA test facilities operations indicated that close calls and mishaps may often be explained by predictable factors that affect human performance. Human factors assessments at NASA Centers revealed common underlying patterns in management, scheduling, maintenance, human system interfaces, procedures, training, and abnormal operation. A review of mishap reports and lessons learned indicated that prior assessments have revealed subsets of these same underlying issues. However, the identified best practices have not been suitably applied to prevent recurring close calls and mishaps. A report is in development to provide guidance on how to appropriately apply lessons learned to help predict and preclude potential failures during test operations. These methods may be easily integrated into NASA test facilities' daily operations.

Dr. Ethiraj Venkatapathy (left) Flight Systems Lead for the CEV TPS Advanced Development Project and Dr. James Arnold, NESC Aeroscience Team member and reviewer, discuss the Avcoat heat shield manufacturing demonstration unit built by Textron.

(Right) CFD solution for the 30-meter Long Ellipse Sled Configuration at Mach 6, 50-Degree Angle of Attack.



DRYDEN FLIGHT RESEARCH CENTER

Dryden Flight Research Center (DFRC) scientists and engineers have contributed to the NESC's multi-disciplinary teams in addressing the Agency's toughest problems. DFRC engineers supported NESC in the areas of rapid entry, descent, and landing (EDL) analysis simulations, in development of the Loads and Dynamics Technical Discipline Team (TDT) Community of Practice (CoP) website supporting vibroacoustics best practices, and continue to support Composite Crew Module structural tests. In addition, the NESC technical experts have supported DFRC by independently assessing the safety of a new testbed's aircraft flight control system hardware/software.

Dr. James Stewart
NESC Chief Engineer at DFRC

Exploration Systems

Composite Crew Module (CCM) Structural Testing: Building on last year's structural testing, DFRC engineers, through support of NESC's Nondestructive Evaluation TDT, are continuing to support NESC's full-scale CCM Project. The team is currently preparing to support full-scale testing in early FY10. This task includes using NASA-developed fiber-optic sensor technology to monitor the structural strains at hundreds of locations around the windows, along the splice joint and on the backbone of the full-scale CCM. Each fiber is approximately the diameter of a human hair and can be placed in geometrically-complex regions where conventional sensors cannot be installed. The 0.5-inch spatial resolution also provides significantly higher measurement fidelity than conventional sensors. This feature is especially important for the areas of highly non-uniform strain gradients that are expected during testing. The fiber optic system, which was tested on the Ikhana aircraft this year, can monitor strains at rates that surpass commercially-available systems.

Space Operations

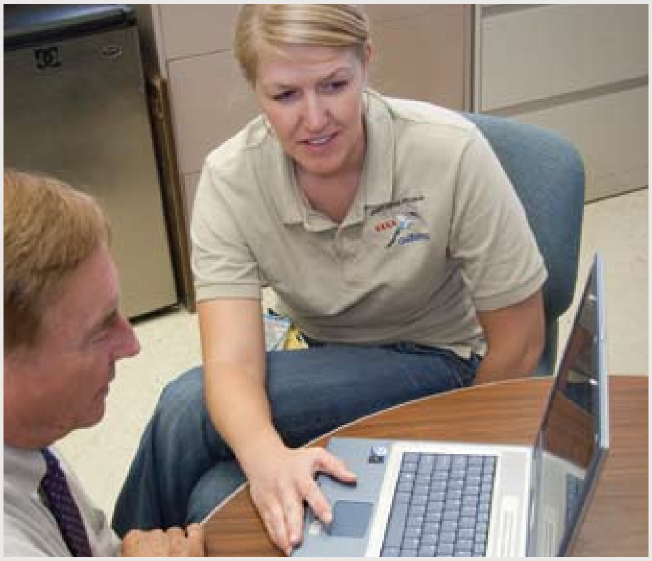
Simulation Modeling for Rapid Entry, Descent, and Landing: DFRC supported a multi-Center NESC team that is collecting and documenting EDL system architecture validating EDL models used to support various NASA missions (Genesis and Huygens). The team will utilize software developed at LaRC known as Program to Optimize Simulated Trajectories (POST2). This widely-used trajectory software, originally used to complete Space Shuttle re-entry guidance profiles, has been used on recent Mars missions to assist in successful landings.

General

Loads and Dynamics Community of Practice Website Development: DFRC engineers assisted in development of the Loads and Dynamics CoP website hosted by the NASA Engineering Network (NEN). The site was developed with the purpose of providing an easy resource for lessons learned, available relevant training, best practices, policies, and procedures while promoting collaboration among NASA's structural dynamics and flight loads engineers. DFRC participation helped give the website an aeronautical perspective. Aeronautical-associated material, including documents on aircraft flight and ground testing, conferences, model development, and commonly used software were provided.

Aeronautics

NESC supported a DFRC request to independently assess the hardware/software configuration of the Research Flight Control System (RFCS), which is a critical part of the development of a new test bed aircraft for the Integrated Resilient Aircraft Control (IRAC) Project in the Aeronautics Mission Directorate.

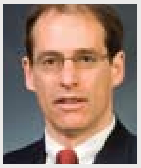


Kia Davidson, a Dryden engineer and member of the NESC Loads and Dynamics TDT, demonstrates to Dr. James Stewart the features of the Loads and Dynamics CoP website that she helped develop.

(From left) Anthony Piazza, Allen Parker, and Dr. Lance Richards (Group Lead) of the Advanced Structures and Measurement Technology Group preparing the NASA developed fiber optic sensor equipment for use in the CCM structural tests at LaRC.

GLENN RESEARCH CENTER

During 2009, the Glenn Research Center (GRC) engineers, scientists and technicians provided a broad range of unique skills to NESC assessments, technical discipline teams and special projects.



Bryan Smith
NESC Chief Engineer at GRC

Exploration Systems

GRC personnel performed a combination of numerical simulations in connection with sled tests that were conducted at the Wright Patterson Air Force Base for the Orion Occupant Protection Modeling study. The NESC investigated potential crew injuries using experimental data and numerical finite element models. The simulations were compared to test data generated for frontal, rearward, spinal, and lateral impact loadings. The results indicated that the Orion seat designs were progressing towards providing the necessary crew protection for landings.

GRC engineers and the NESC Resident Engineers supported engineering and flight activities for the Max Launch Abort System (MLAS). GRC technicians played an integral role in the fabrication and assembly of MLAS at the Wallops Flight Facility. Different specialized manufacturing teams served rotational assignments at the assembly facility to complete fabrication, assembly, and test operations for the flight article.

Space Operations

GRC contributed to the orbiter reinforced carbon-carbon Coating Adherence Investigation by leading the microscopy and high temperature chemistry efforts, which required specialized skills in machining, polishing and metallography. Activities were focused on understanding the root cause for coating defect formation and spallation at wing leading edge joggle locations. GRC worked to develop nondestructive procedures to detect and characterize the subsurface defects on-vehicle and to develop criteria for flight safety.

GRC support to the International Space Station (ISS) Solar Alpha Rotary Joint (SARJ) anomaly included experimental work to mimic the existing conditions of the degraded SARJ on-orbit. The unique GRC Vacuum Roller Rig tested rollers operating under degraded conditions using the same lubricant that was applied to the ISS SARJ during STS-126. This testing provided a durability assessment and established on-orbit maintenance schedules.

Science

GRC investigated potential failure mechanisms for Reaction Wheel Assemblies (RWAs) that provide stability and attitude control for space vehicles. The testing characterized the metal-to-metal contact in bearings of the Kepler and Fermi spacecraft RWAs as a function of speed and temperature. A review of the designs suggested the transition from the mixed lubrication to the elastohydrodynamic regime might occur at higher bearing speeds than previously predicted. The RWA manufacturer implemented a number of design changes as a result of the investigation.

GRC personnel experienced in tribology and rotordynamics were asked to determine root causes of an anomalous vibration encountered during development testing of the motor drive systems for the Mars Science Laboratory. GRC analysis and modeling techniques identified the most probable contributions and provided recommendations to the manufacturer on methods to alleviate the vibration.

Technical Discipline Teams

GRC supports several Technical Discipline Teams (TDTs) and working groups including the Composite Pressure Vessel Working Group, which initiated a composite overwrapped pressure vessel stress rupture test program that will provide a better understanding of carbon fiber/epoxy stress rupture testing and refine current stress rupture reliability models. Also supported was the NESC Computational Nondestructive Evaluation (NDE) team including evaluation and use of computational NDE tools to perform “virtual” inspections of stiffeners and weld configurations used in aerospace structures. Support to the Battery Working Group focused on the establishment of manufacturing processes and facilities to produce materials in Li-Ion cells suitable for long life, low-earth orbit missions. Support to the Structures TDT is to provide recommendations for Orion vibroacoustics test and analysis.

Kenneth Street of the Tribology and Mechanical Components Branch checks initial test conditions for the RWA bearing tests.

Beth Opila of the Durability and Protective Coatings Branch investigates orbiter reinforced carbon-carbon coatings.

GODDARD SPACE FLIGHT CENTER

During 2009, more than 130 Goddard Space Flight Center (GSFC) specialists supported more than 40 NESC tasks contributing Electronic, Electrical, and Electromechanical parts; spacecraft electronics; guidance, navigation and control (GNC); materials; mechanical and power components and systems; reliability; software; and systems engineering expertise. GSFC's Express Logistics Carrier (ELC), Hubble Space Telescope (HST), James Webb Space Telescope (JWST), National Oceanic and Atmospheric Administration NPrime and National Polar-orbiting Operational Environmental Satellite System (NPOESS) programs benefited from NESC support. GSFC is home for the NASA Technical Fellows for Avionics, Electrical Power, GNC, Mechanical Systems, and Software.

Timothy Trenkle
NESC Chief Engineer at GSFC

Steven Scott
Former NESC Chief Engineer at GSFC

Exploration Systems

GSFC supported several Constellation Program NESC tasks addressing prominent issues such as launch pad abort environments, vehicle seat attenuation designs for assuring crew safety and survivability, and the parachute landing system. GSFC and the Wallops Flight Facility provided extensive support to NESC's Max Launch Abort System (MLAS) Project, which was successfully demonstrated in July 2009.

Space Operations

Space Shuttle Program support included Ground Umbilical Carrier Plate, Aerosurface ServoAmplifier, Power Contactor Assembly, Orbiter Flow Control Valve cracking investigations, and assessing Li-Ion battery risks for astronaut extravehicular activities. International Space Station contributions included "fixes" to solve the solar array "steering" joint degradation, assessing plasma contactor unit utilization, and support for the carbon dioxide removal assembly investigation.

Science

GSFC contributed to NESC science mission assessments including Kepler reaction wheel usage, HST Science Instrument Command and Data Handling anomaly board and Science Data Formatter spare review, ELC avionics review, NPOESS Visible Infrared Imager Radiometer Suite mechanism, and JWST composite joint failure.

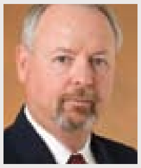
General

The NESC initiates tasks to address NASA-wide problems or potential issues before they create significant impacts. Key support was provided by GSFC to the NASA Aerospace Battery Working Group, a NASA-wide electrical connector study, a study of the design, development, test and evaluation of field programmable microelectronic devices, and multi-layer ceramic capacitor low voltage failure phenomena.

Wallops Flight Facility engineers and technicians assemble the MLAS avionics shown installed in the crew module (shown above).

JET PROPULSION LABORATORY

In 2009, the Jet Propulsion Laboratory (JPL) participated in numerous NESC assessments for the Science, Exploration Systems and Space Operations Mission Directorates.



Lloyd Keith
NESC Chief Engineer at JPL

Exploration Systems

JPL is leading the assessment for the NESC Orion hydrazine landing roll control assessment. The team is evaluating different options for using hydrazine to orient the Orion capsule for landing.

The NESC Composite Pressure Vessel Working Group (CPVWG) has recently developed a test plan for stress rupture (a Composite Overwrapped Pressure Vessel (COPV) failure mode) based on needs identified in previous NESC assessments. Based on this plan, the NESC has proceeded with a stress rupture model development program for which JPL provides technical leadership. This effort will require testing of both strands and subscale COPVs to provide adequate data and a significant analytical effort that will provide an approach that can be used across all NASA programs and projects.

Space Operations

An NESC team used JPL's 25-foot Space Simulator to create conditions that could cause buckling of the International Space Station (ISS) solar array masts. Tests were completed in October 2008 and data analysis is underway.

Science

JPL provides leadership and is the host for the NESC CPVWG, which is responsible for understanding and communicating issues and risks associated with the current state-of-the-art and emerging composite pressure vessel technology. The CPVWG is tasked with the development of appropriate strategies, approaches, and methodologies to minimize technical risk associated with composite pressure vessels and to create/revise technical requirements to mitigate this risk for future human and robotic space missions.

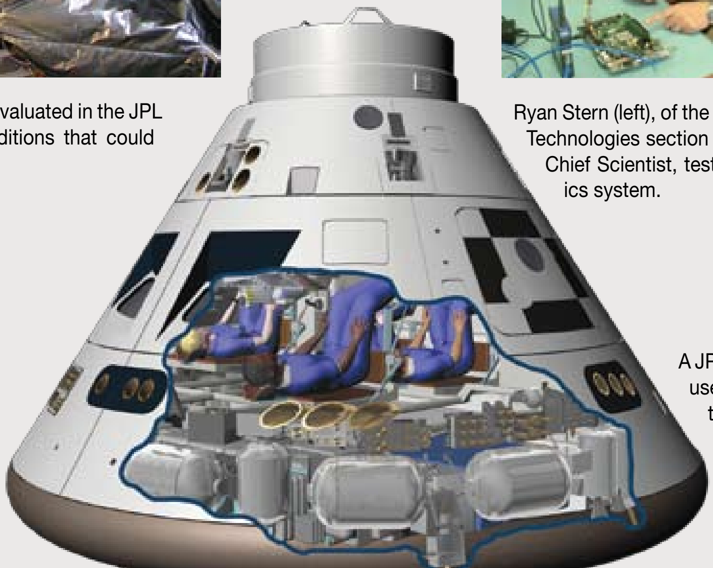
The CPVWG coordinates with programs and projects throughout NASA, and has been working proactively to address COPV mechanical modeling concerns, nondestructive testing, lifetime assessment issues and standards development. While COPVs have been a priority, the CPVWG is also reviewing the state-of-the-art of cryogenic propellant tanks to understand the technology limitations and path forward to developing the technology.

Robotics Technical Discipline Team (TDT)

The Robotics Operations TDT, led by JPL, is working several tasks to advance robotic exploration. The entry, descent and landing (EDL) task developed a database that is capturing at-risk EDL data to benefit future spacecraft designs. EDL experts from GSFC, JPL, JSC, and LaRC are populating the database with at-risk EDL data and expanding the base of users. The Wireless Avionics task developed a set of long-term requirements, an architectural approach, and a preliminary prototype to prove out the concepts. ARC, GSFC, JPL and JSC avionics engineers are cooperatively working this task.

A section of ISS solar array mast was evaluated in the JPL 25-ft Space Simulator to create conditions that could cause buckling of the masts.

Ryan Stern (left), of the Advanced Computer Systems and Technologies section and Dr. Daniel Winterhalter, NESC Chief Scientist, test components of a wireless avionics system.



A JPL-led NESC team is evaluating the use of hydrazine roll control to orient the Orion capsule for landing.

JOHNSON SPACE CENTER

Dr. Nancy Currie
NESC Chief Engineer at JSC

NESC personnel at Johnson Space Center (JSC) support the safe and successful execution of the Space Shuttle Program (SSP), the continuous operation of the International Space Station (ISS), and the development of the human-tended spacecraft in the Constellation Program (CxP). The NESC provides real-time mission support as a member of the SSP and ISS Mission Management Teams. Throughout 2009, NESC personnel were also actively involved in technical assessments for SSP, ISS and Constellation and served as non-voting members on major technical boards for these Programs. In 2009, the JSC office welcomed the NASA Technical Fellow for Passive Thermal and the new NESC Deputy Director for Safety. They joined the NASA Technical Fellows for Loads and Dynamics and Life Support/Active Thermal.

Exploration Systems

The NESC is actively engaged in providing independent assessment at all levels of the CxP. Independent assessments of critical issues affecting the Crew Exploration Vehicle (CEV), Orion, include reliability of the parachute system, use of hydrazine for roll control during landing, and wave models used in the prediction of water landing accelerations. NESC personnel were also involved in activities associated with occupant protection during dynamic flight phases of the Orion spacecraft. The NESC Orion seat attenuation team, led by the Mechanical Systems NASA Technical Fellow, refined seat/pallet isolation design concepts developed in 2008. This system can be used to mitigate the effects of thrust oscillation and landing accelerations on the crew. A team led by the JSC NESC Chief Engineer continued test and analysis efforts to improve the capability to model human response to accelerations to determine the potential risk of crew injury during landing scenarios. The NASA Technical Fellow for Loads and Dynamics led an effort to review and provide recommendations associated with the Orion ascent abort loads and supported review of Orion pad abort environments. The Life Support/Active Thermal NASA Technical Fellow led studies of lunar dust control designs for Altair and Orion. The NASA Technical Fellows supported the Orion Subsystem Design Reviews and the System and Module Review providing comments and observations regarding Orion subsystem designs and evaluated the integrated vehicle design to support the Preliminary Design Review milestone. NESC personnel also supported development of the Ares I launch assessing liftoff acoustics and thrust oscillations and issues affecting the Ares I-X test vehicle including structural loads, drift into ground support systems at launch, and mobile launch platform stabilization.

Space Operations

NESC experts supported the anomaly investigation associated with gaseous hydrogen flow control valve poppet cracking including evaluation of component material to determine potential failure modes, nondestructive evaluation techniques for screening poppets prior to and following flight, and computational fluid dynamics analysis of a liberated particle. NESC personnel also supported an SSP anomaly resolution team to troubleshoot and perform root cause investigation of the H2 leaks at the ground umbilical carrier plate in support of STS-127. A team of NESC personnel and consultants supported the External Tank Project for the investigation of causes of foam losses from the Intertank, Bipod, and liquid oxygen (LO2) Ice Frost Ramps during STS-127. Avionics and electrical experts provided real-time support during STS-125 for the Aerosurface Servo Amplifier anomaly investigation. The Passive Thermal NASA Technical Fellow supported the SSP thermal protection system damage assessment process during each Space Shuttle mission.

NESC discipline experts from Guidance, Navigation and Control, Thermal, and Mechanical Loads and Structural Integrity provided a detailed technical review of the impacts from an anomalous reboost of the ISS. The NASA Technical Fellows for Life Support/Active Thermal and Passive Thermal provided a recommended course of action to fully determine the cause and effects of face sheet damage to one of the ISS radiators. The NESC also assessed the readiness for the ISS to support a 6-person crew and provided technical support for anomalies with the Urine Processing Assembly, Water Dispenser, Oxygen Generation Assembly, Waste and Hygiene Compartment, and the Carbon Dioxide Removal Assembly. In support of ISS hardware development, NESC avionics experts conducted an independent review of the GSFC-developed ExPRESS Logistics Carrier Avionics built for the ISS. Composite Pressure Vessel experts provided independent feedback on the ISS Nitrogen/Oxygen Recharge System Composite Overwrapped Pressure Vessel concept.

KENNEDY SPACE CENTER

The NESC is involved in multiple activities and projects at the Kennedy Space Center (KSC). Likewise, KSC continues to provide support and expertise to a wide variety of NESC assessments and testing across the Agency. More than 20 KSC civil servants and contractors of various disciplines were active in NESC assessments and studies this year. Also, 25 NASA personnel at KSC are members of the NESC's Technical Discipline Teams (TDTs). These discipline expert teams are the primary workforce the NESC calls upon when performing assessments and studies.

Stephen Minute
NESC Chief Engineer at KSC

Exploration Systems

Max Launch Abort System (MLAS): KSC engineers and researchers worked with the NESC on the MLAS Project. The MLAS Project, focused on alternate launch abort techniques as risk mitigation for Constellation's Orion Project, was successfully flown at Wallops Island. A unique aspect of the MLAS Project is the Resident Engineer (RE) Program. Engineers that are relatively early in their career were paired up with NASA Technical Fellows and Apollo design engineers to get "hands-on" experience in designing, developing, building, and launching a full scale launch abort system. KSC had two RE's assigned to this Project. Because of the success of the RE Program, the NESC is continuing the Program for another year on additional NESC projects.

Ares I-X: KSC engineers were integrally involved in several NESC assessments, including Ares I-X lift-off acoustics, rollout loads, and drift and plume impingement analysis.

Dr. Chris Iannello (left) and Hung Nguyen of NASA discuss connector issues as part of the spacecraft connector anomaly database study.

Composite Crew Module (CCM): In addition, KSC is supporting the design team of the NESC CCM Project, developing expertise and techniques for potential composite use on crewed space vehicles.

Space Operations

NESC personnel were engaged in several assessments at KSC, including Space Shuttle flame trench brick wall integrity, External Tank (ET) ground umbilical leak anomaly, STS-127/128 ET foam loss anomaly, and KSC pressure vessel mishap investigation. Likewise, the NESC brought Agency experts together to examine several issues. These included Space Shuttle leading edge structure, spacecraft connector anomaly database, and ExPRESS Logistics Carrier avionics. In addition, NESC partnered with KSC to assess safe operating distances around the Vehicle Assembly Building associated with an anticipated increase in the amount of solid propellant segment processing for the Ares I and Ares V boosters. This study has spurred additional safety studies on the subject.

Science

The NESC was actively involved with the Hubble Space Telescope Science Instruments Command and Data Handling issues. KSC engineers supported the NESC efforts and augmented the team with necessary expertise.

NESC members from KSC participated in NESC assessment teams of various Ares I-X issues over the last 2 years.

LANGLEY RESEARCH CENTER

Langley Research Center (LaRC) continues to support the NESC mission to address the Agency's high risk programs and projects. LaRC has contributed technical expertise in the areas of structures, materials, nondestructive evaluation, flight sciences, fabrication technology, loads and dynamics, computational fluid dynamics, mechanisms, guidance navigation and control, flight mechanics, and avionics. LaRC is the host Center for the NESC Director's Office, Principal Engineers Office, Systems Engineering Office, and the Management and Technical Support Office. LaRC is also home to the NASA Technical Fellows for Materials, nondestructive evaluation, Structures, Aerosciences and Flight Mechanics.

Walter Engelund
NESC Chief Engineer at LaRC

Clayton Turner
Former NESC Chief Engineer at LaRC

Exploration Systems

Shell Buckling Knockdown Factor: LaRC is providing technical leadership and expertise to the NESC team working to develop shell buckling design factors for metallic and composite launch vehicle structures. The NESC Shell Buckling Knockdown Factor (SBKF) Project was established to develop and validate new analysis-based shell buckling design factors for Ares I and Ares V metallic and composite launch vehicle structures. Improved, or less-conservative, knockdown factors will enable significant weight savings in these vehicles and will help mitigate some of NASA's launch vehicle development and performance risks.

Composite Crew Module: The NESC Composite Crew Module (CCM) Project began testing the CCM full-scale test article in the LaRC Combined Loads Test System facility. The plan is to statistically test the assembly to verify that the analysis models predict the response of the structure under load and repeat the tests with internal pressures in the CCM up to 30 psi.

Space Operations

LaRC experts in structures, materials, and NDE supported the NESC investigation of fatigue cracking in the Space Shuttle main propulsion system flow control valve (FCV) poppet. The FCV poppet controls the flow of gaseous hydrogen (GH2) to the External Tank during ascent. A GH2 anomaly was observed during STS-126 in November 2008 and the post-flight inspection discovered that a FCV poppet had a fatigue crack that liberated a small piece of the flange that controls the flow. A fracture investigation was initiated and LaRC developed a polishing procedure and a crack inspection procedure that used a scanning electron microscope to detect cracks as small as 0.001 inches.

General

For missions requiring entry into an atmosphere, the entry, descent, and landing (EDL) system is a key driver of the mission architecture. The NASA Technical Fellow for Flight Mechanics organized and led a workshop in April 2009 to provide an opportunity for the Orion and the Mars Science Laboratory Projects to exchange and compare their EDL design requirements, technical approaches, testing strategies, top concerns, and lessons learned and to extend their collaboration to other technical areas.

Harold Clayton polishes a flow control valve poppet in preparation for inspection.

(Right) CCM test article in the LaRC Combined Loads Test System facility.

MARSHALL SPACE FLIGHT CENTER

NESC personnel at Marshall Space Flight Center (MSFC) continued to support NESC assessments in the areas of Exploration Systems and Space Operations. The NASA Technical Fellow for Propulsion is resident at MSFC.

Dr. Charles Schafer
NESC Chief Engineer at MSFC

Exploration Systems

Composite Crew Module (CCM): Technicians from the MSFC Test Laboratory travelled to Iuka, Mississippi to install strain gauges on the CCM and support its testing. Engineers from the MSFC Materials Laboratory continued their participation in the development and building of the CCM.

Max Launch Abort System (MLAS): The MLAS Project successfully launched its flight test article from the Wallops Flight Facility on July 8, 2009. The MSFC Propulsion Systems Department provided ignition overpressure (IOP) predictions for the MLAS launch and measured the IOP during launch. The worst case prediction for IOP for the MLAS (four motors) had been 2.11 psid, while the values measured at launch showed a maximum value of 0.95 psid. The predictions provided a conservative estimate for design. The measured values indicate that there was significant margin, and there was no indication from launch data that IOP had any significant or unexpected influence on performance. Additionally, the measurements provided information for model validation and upgrade, specifically when multiple motors are present. The MSFC Test Laboratory provided technician support for the installation of strain gauges on the fins which were mounted on the MLAS boost and coast skirts.

Shell Buckling Knockdown Factor (SBKF): The SBKF testing continued to be supported and conducted by the MSFC Test Laboratory during 2009. Significant tests were conducted in September 2009 to measure the response of a composite shell structure with both subcritical loads and a test to failure. Data gathered from this testing is applicable to the Ares I Upper Stage Project and is useful to structural analysts in general to enhance understanding of design margin in metal and composite tanks and other shell structures. The September series of tests were completed successfully.

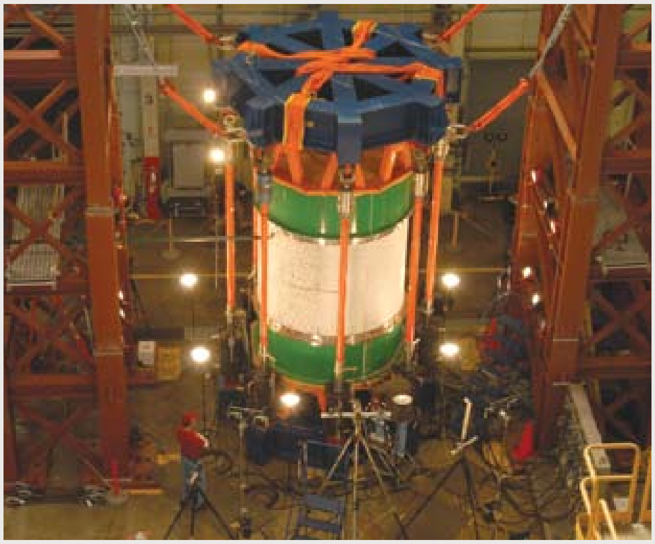
Space Operations

Space Shuttle Program: The NESC office at MSFC continued to participate in readiness reviews for each Space Shuttle flight, including those of the Space Shuttle propulsion projects and the Center Director's review. Some of these resulted in involvement in specific focus areas including External Tank foam loss reviews and an orbiter main propulsion system gaseous hydrogen flow control valve evaluation.

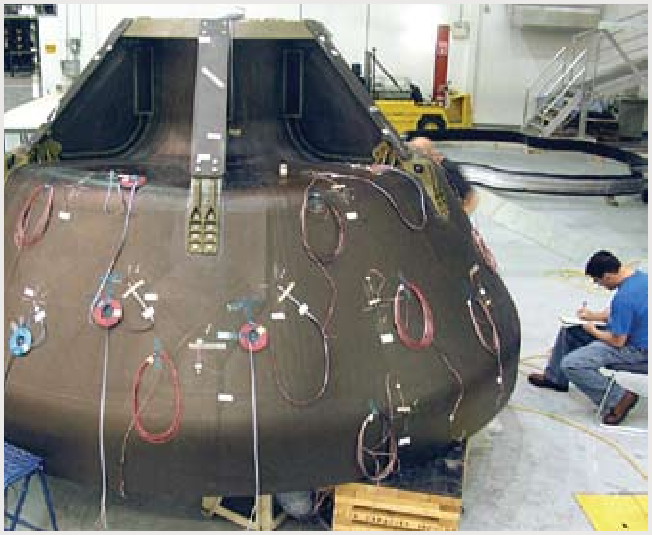
General

MSFC Engineering and the NESC Propulsion Technical Discipline Team are sponsoring work within MSFC Engineering to help enhance the Agency propulsion capabilities in three areas. Propulsion training and knowledge dissemination are being enhanced through the development of a hands-on propulsion learning center. Valve design capability and technology are being improved through a throttling cavitating venturi valve design project. Also, powder metallurgy manufacturing is being used to build a turbopump impeller, which will be tested at MSFC.

Other work within MSFC Engineering that is supported by the NESC includes the Composite Pressure Vessel Working Group, the annual Battery Workshop, and an independent review of wide-range pumps for the Surface Analysis at Mars Instrument.



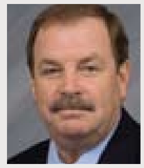
Ares V-style shell undergoing testing at MSFC's Shell Buckling facility.



Technicians from the MSFC Test Laboratory installed strain gauges on the CCM and supported testing.

STENNIS SPACE CENTER

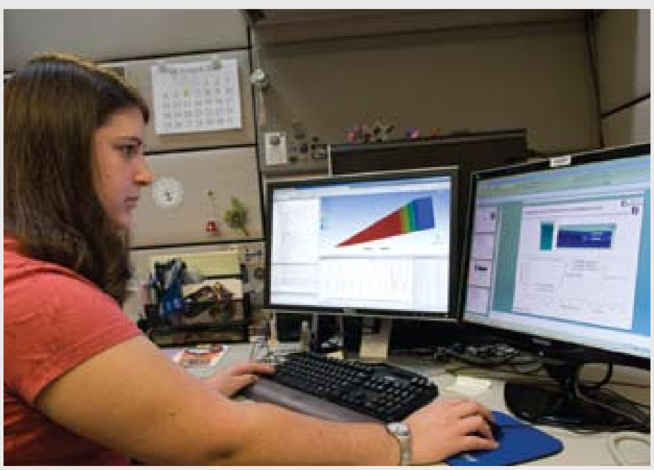
Stennis Space Center (SSC) engineers and scientists carried out a variety of NESC sponsored activities including continued support for the A3 test stand, thermal analysis and ground measurements for the Max Launch Abort System (MLAS), involvement in the Wireless Connections in Space Project, and technology advancement and infusion for the Exploration Systems and Space Operations Mission Directorates. Activities employed the unique capabilities and facilities available at SSC.



Michael Smiles
NESC Chief Engineer at SSC

Exploration Systems

A3 Test Stand: SSC is building a new test stand, A3, to enable rocket engine testing in simulated altitude conditions. NESC is working on two issues for A3. The first concerns the need for a deeper understanding of the "un-start" condition of the diffuser. The Chemical Steam Generators (CSGs) that generate steam also produce high concentrations of oxygen that enter the diffuser and react with unburned hydrogen from the J-2X engine, thus creating an "un-start" condition that reduces the flow of steam. This combustion process can reduce the effectiveness of the diffuser and produce damaging temperatures and pressures. The second issue is a vibration analysis of the A3 test stand. The NESC is providing an independent assessment of this issue.



Rebecca Junell performed a thermal analysis on the MLAS boost skirt.

Mark Turowski (left) and Jonathan Morris demonstrate the ISHM system.

Max Launch Abort System (MLAS): The SSC team assisted in predicting thermal loading from the MK 70 solid rocket motors used for the MLAS vehicle. The objective of the transient thermal analyses was to determine whether the thermal protection of vehicle structures was adequate for the test duration. The loading scenarios included convection due to plume reflection off the ground during the beginning of the launch and radiation from the rocket motors and plume throughout the launch. Radiation values were predicted analytically by MSFC engineers and validated with physical testing by the SSC technology group at WSTF, while convection values were calculated at SSC from the results of a computational fluid dynamics analysis. The results of the thermal analysis were used to determine what areas required thermal protection. In one specific case (the aft facing surface of the boost ring), the analysis showed the installed cork layer was not necessary and could be removed.

A second thermal analysis predicted motor temperatures based on ambient conditions prior to the launch to support go/no-go decision criteria. Analysis of the solid rocket motors under ambient conditions and various wind speeds showed the propellant temperature matching between the motors would remain within acceptable flight-rule temperature bounds.

SSC provided additional support to MLAS by developing an ambient temperature monitoring system to provide input to the solid rocket motor thermal model. Temperature measurements began several days before launch and were completed at L-6 hours.

Space Operations

Integrated Systems Health Management (ISHM): The NESC funded a pilot ISHM implementation to increase technical readiness level and functional capability level of this technology. This activity was intended to mitigate complexity issues in operating A3, where up to 27 CSGs will be operating simultaneously. The ISHM pilot implementation consisted of a computer in the E-2 test control room interfaced with sensor data. Prior to being passed to the ISHM model, data was first processed within a Virtual Intelligent Sensor Environment to capture anomaly indicators (e.g., flat sensor, design limit violations, and excessive noise). The ISHM model was created using the ISHM Model Building Toolkit created by SSC. The system supports incremental augmentation of capabilities such as upgrades to anomaly detection and root cause analysis. Plans are being developed to scale up this successful pilot to perform ISHM on the CSG Skid Test Program, which consists of three CSGs operated in parallel.

WHITE SANDS TEST FACILITY

In 2009, White Sands Test Facility (WSTF) scientists and engineers continued to assist the NESC with important projects and issues related to Exploration Systems and Space Operations. Support largely involved Composite Overwrapped Pressure Vessel (COPV) testing, modeling and data collection; pyrotechnic device analysis and testing; and technical support for the Propulsion and Nondestructive Evaluation (NDE) Technical Discipline Teams, and the Composite Pressure Vessel Working Group (CPVWG).

Dr. Nancy Currie
NESC Chief Engineer at JSC and WSTF

General

Carbon Stress Rupture Data Collection: WSTF has developed a specialized library for the CPVWG, involving collection of applicable stress rupture and static strength data for strands, fibers, and vessels. The library currently contains more than 800 technical reports, journal articles, conference papers, reference manuals, abstracts, dissertations, unpublished reports, datasets, and other types of technical literature. Data are still sought from valid sources.

Composite Pressure Vessel Nondestructive Evaluation (NDE) Development: In coordination with the CPVWG, WSTF is developing sensitive NDE methods and ASTM standards for quantitative NDE for COPVs. For example, teamwork between the CPVWG and NASA NDE Working Group has produced a Laser Profilometer for application to small COPVs. The new system maps the interior of vessels to within ~0.002 inches and is currently providing precise data to both the NESC Autofrettage and Plastically Responding Liner Test Projects. A second generation version of the Laser Profilometer has been designed to evaluate larger diameter cylindrical COPVs with ellipsoidal ends. Fabrication of this unit is planned to begin in early FY10. Acoustic emission is also being applied and has shown particular promise for detecting and monitoring the stress-wave propagation produced by actively growing defects in COPV composite overwraps.

Carbon COPV Modeling of Autofrettage Response: Long-term reliability of COPVs remains uncertain. Although design, test, and manufacturing procedures are well developed, additional data are needed due to the complexity of the structures. One current focus is accurate characterization of vessel response to the manufacturing autofrettage processes and to use this data to adjust current COPV models to improve numerical analysis capabilities. To obtain needed data, T1000 and IM7 vessels were separately modeled with state-of-the-art finite element analysis techniques at GRC and WSTF, and then tested at WSTF. During test, comprehensive real-time instrumentation first characterized the liner response after wrapping, then characterized the response during autofrettage, and then characterized vessel behavior during post-autofrettage pressure cycles. The Laser Profilometer was applied before and after autofrettage and precisely indicated areas of deformation.

(Above) Tim Gallus (left), MEI Technologies, and Ralph Lucero (right), Jacobs Technology, team up to map the interior of COPVs used in the NESC CPVWG Autofrettage Test Project.

(Right) WSTF Mechanical Technician Don Saunders (with cap) and WSTF Electrical Technician Robert Browning (on floor) support COPV system assembly.

Ares I-X rolls to the launch pad. The NESC assisted the Project in resolving several issues over the past 24 months.

From left (back row): Richard Schwartz (ATK); Thomas Horvath (LaRC); Ralph Roe, Jr. (NESC Director/Presenter); Tod Palm (Northrop Grumman); Michael Bay (independent consultant); Doyle Arboneaux (LaRC); Steven Summitt (ATK); Rene Ortega (MSFC); Gerald Kinder (Boeing); Charles Campbell (JSC); Dawson Vincent (Northrop Grumman); Peter Parker (LaRC); Tim Wilson (NESC Deputy Director/Presenter); Fred Hall (ATK); Stephen Williams (ATK). **From left (front row):** Donald Roth (GRC); Patrick Forrester (NESC Chief Astronaut/Presenter); Jeffrey Jordan (ATK); Ian Batchelder (Lockheed Martin); Gary Dittemore (JSC); Brian Hall (WFF); Hung Pham (JPL); Timothy Cannella (LaRC); Linda Facto (JPL); Elizabeth Holleman (MSFC); John Aldrin (independent consultant). **Not pictured:** Mark Hilburger (LaRC) and Mitchell Davis (NESC).

NESC Director's Award

Honors individuals who take personal accountability and ownership in initiating clear and open communication on diverse and controversial issues. A key component of this award is based on the process of challenging engineering truths.

Elizabeth D. Holleman

In recognition of technical excellence in the professional and persistent pursuit of the technical risks associated with the Orbiter Gaseous Hydrogen Flow Control Valve poppet cracking prior to the flight of STS-119.

Rene Ortega

In recognition of technical excellence in the professional and persistent pursuit of the technical risks associated with the Orbiter Gaseous Hydrogen Flow Control Valve poppet cracking prior to the flight of STS-119.

NESC Leadership Award

Honors individuals who have had a pronounced effect upon the technical activities of the NESC.

Doyle T. Arboneaux

In recognition of outstanding leadership and production management of hardware fabrication in support of the Max Launch Abort System.

Charles H. Campbell

In recognition of outstanding leadership in acquiring unprecedented boundary layer transition measurements during the STS-119 mission using the Space Shuttle Orbiter as a flight test article.

Brian A. Hall

In recognition of outstanding leadership as the Vehicle Manager for the successful Max Launch Abort System Flight Demonstration Test.

Thomas J. Horvath

In recognition of outstanding leadership in identifying, characterizing, and employing unique thermal imaging techniques to observe Space Shuttle boundary layer transition during the STS-119 and STS-125 missions.

Jeffrey D. Jordan

In recognition of outstanding leadership and management of the NASA Engineering and Safety Center tasks on the ATK TEAMS contract.

Tod E. Palm

In recognition of outstanding leadership of the Max Launch Abort System Structures Team.

Peter A. Parker

In recognition of outstanding leadership for broad acceptance of best-practice experimental planning, execution and analysis through use of established, efficient design of experiments methods.

Steven W. Summitt

In recognition of outstanding leadership of the design, manufacturing, and test deliverables for the Composite Crew Module Project.

Stephen A. Williams

In recognition of outstanding leadership of the touch labor and facility resources for the Composite Crew Module Project.

NESC Engineering Excellence Award

Honors individual accomplishments of NESC-job related tasks of such magnitude and merit as to deserve special recognition.

John C. Aldrin

In recognition of exceptional technical support to the NASA Engineering and Safety Center Computational Nondestructive Evaluation Tool Assessment Team.

P. Michael Bay

In recognition of exceptional technical support to the Orion Integrated Design Optimization Team.

Mark W. Hilburger

In recognition of exceptional engineering excellence in the development of a comprehensive plan to improve Shell Buckling Knockdown Factors for the Constellation Program.

Donald J. Roth

In recognition of exceptional technical support to the NASA Engineering and Safety Center Nondestructive Evaluation Tool Assessment Team.

Dawson D. Vincent

In recognition of engineering excellence in the development and implementation of the out of autoclave splice for the Composite Crew Module Project.

NESC Administrative Excellence Award

This award honors individual accomplishments or contributions that contribute substantially to support NESC's mission.

Ian H. Batchelder

In recognition of exceptional information technology and system administration support to the NASA Engineering and Safety Center.

NESC Group Achievement Award

Honors a group of employees comprised of government and non-government personnel for outstanding accomplishment through the coordination of individual efforts that have contributed substantially to the accomplishment of the NESC's mission.

Composite Crew Module Fabrication Team

In recognition of outstanding contributions in manufacturing excellence on the Composite Crew Module Project (award accepted by Fred Hall on behalf of the team).

DC/DC Converter Guidelines Development Team

In recognition of outstanding efforts in testing hybrid DC to DC converters for space applications and developing a guidelines document on how to use them effectively (award accepted by Linda Facto on behalf of the team).

Hypersonic Thermodynamic Infrared Measurements (HYTHIRM) Team

In recognition of outstanding technical contributions in remote thermal and visual imaging as demonstrated during the STS-119 and STS-125 Space Shuttle missions and the Max Launch Abort System test flight (award accepted by Richard Schwartz on behalf of the team).

International Space Station Solar Array Thermal Vacuum Test Team

In recognition of outstanding contributions to the successful testing of the International Space Station Solar Array Mast in JPL's Space Simulator Facility (award accepted by Hung Pham on behalf of the team).

Langley Research Center Office of Procurement Support Team

In recognition of exceptional support to the NASA Engineering and Safety Center mission through excellence in acquisition (award accepted by Timothy Cannella on behalf of the team).

Max Launch Abort System Resident Engineer Team

In recognition of exceptional efforts as part of the Resident Engineer Program for the Max Launch Abort System Flight Demonstration Test (award accepted by Gary Dittemore on behalf of the team).

Max Launch Abort System Team

In recognition of outstanding contributions to the design, development and flight test of the Max Launch Abort System (award accepted by Brian Hall on behalf of the team).

Orbiter Boundary Layer Transition Flight Experiment Team

In recognition of outstanding contributions in developing and conducting a hypersonic boundary layer transition experiment using the Space Shuttle Orbiter as a flight test vehicle during STS-119 re-entry (award accepted by Gerald Kinder on behalf of the team).

NESC Special Recognition Award

Honors employees who have provided dedicated service to the NASA Engineering and Safety Center.

Mitchell L. Davis

In recognition of outstanding leadership and engineering excellence as the NASA Engineering and Safety Center's NASA Technical Fellow for Avionics.

In memoriam

Mr. Glenn Tsuyuki, a member of the NESC's Crew Exploration Vehicle Smart Buyer Design Team and more recently a member of the Passive Thermal Technical Discipline Team, passed away in July 2009. He will be missed and remembered for his significant contributions to the NESC and the Jet Propulsion Laboratory.

Core Leadership Team

Ralph R. Roe, Jr.

NESC Director

Mr. Ralph R. Roe, Jr. serves as NESC's Director at Langley Research Center (LaRC). Mr. Roe has over 26 years of experience in human space flight program management, technical management, and test engineering. Mr. Roe previously held several key positions in the Space Shuttle Program, including Vehicle Engineering Manager, Launch Director, and Kennedy Space Center Engineering Director.

Timmy R. Wilson

NESC Deputy Director

Mr. Timmy R. Wilson is NESC's Deputy Director. Mr. Wilson was formerly the NESC's Chief Engineer at Kennedy Space Center (KSC). Prior to joining NESC, Mr. Wilson served as Deputy Chief Engineer for Space Shuttle Processing at KSC. Mr. Wilson has over 28 years of engineering and management experience supporting the Space Shuttle Program.

Michael P. Blythe

NESC Deputy Director for Safety

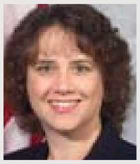
Mr. Michael P. Blythe is NESC's Deputy Director for Safety and is resident at the Johnson Space Center (JSC). Prior to joining the NESC, Mr. Blythe served as the Acting Assistant Associate Administrator in the Office of the Administrator at NASA HQ. Mr. Blythe came to the Office of the Administrator from the Office of Chief Engineer where he served as the Director for the Engineering and Program/Project Management Division. In this capacity, he was responsible for establishing and implementing Agency engineering and program/project management policy, procedures and processes to improve the efficiency and success of NASA's investments.

Dr. Daniel Winterhalter

Chief Scientist

Dr. Daniel Winterhalter is NESC's Chief Scientist and is resident at the Jet Propulsion Laboratory (JPL). Dr. Winterhalter has over 31 years of experience as a research scientist at JPL. His research interests include the spatial evolution of the solar wind into the outer reaches of the heliosphere, as well as its interaction with and influence on planetary environments. In addition, as a member of several flight teams, he has been intimately involved with the planning, launching, and operation of complex spacecraft and space science missions.

Dawn M. Schaible



Manager, Systems Engineering Office

Ms. Dawn M. Schaible is Manager of NESC's Systems Engineering Office at Langley Research Center (LaRC). Prior to joining NESC, Ms. Schaible worked in the International Space Station/Payload Processing Directorate at Kennedy Space Center. Ms. Schaible has over 22 years of experience in systems engineering, integration, and ground processing for the Space Shuttle and International Space Station Programs.

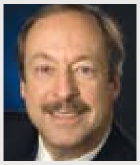
Daniel J. Tenney

Manager, Management and Technical Support Office

Mr. Daniel J. Tenney is Manager of NESC's Management and Technical Support Office at Langley Research Center (LaRC). Prior to joining the NESC, Mr. Tenney served as the Deputy Chief Financial Officer for Systems at LaRC where he managed over 30 information systems. Mr. Tenney has 20 years of professional financial, accounting, and systems experience at NASA.

NASA Headquarters Liaison

Wayne R. Frazier



NASA Headquarters Senior SMA Integration Manager

Mr. Wayne R. Frazier currently serves as Senior Safety and Mission Assurance Manager in the Office of Safety and Mission Assurance (OSMA), where he is assigned as the Liaison Officer to NESC, the Office of the Chief Engineer, the Software Independent Verification and Validation Facility in West Virginia, and other remote activities of OSMA. He was formerly Manager of System Safety in the OSMA at NASA Headquarters and has over 34 years of experience in System Safety, Propulsion and Explosive Safety, Mishap Investigation, Range Safety, Pressure Systems, Crane Safety and Orbital Debris Mitigation.

NESC Principal Engineers

Clinton H. Cragg

NESC Principal Engineer

Mr. Clinton H. Cragg is a Principal Engineer with NESC at Langley Research Center (LaRC). Mr. Cragg came to NESC after retiring from the U.S. Navy. Mr. Cragg served as the Commanding Officer of the U.S.S. Ohio and later as the Chief of Current Operations, U.S. European Command. Mr. Cragg has over 31 years of experience in supervision, command, and ship-borne nuclear safety.

Steven J. Gentz

NESC Principal Engineer

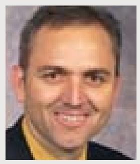
Mr. Steven J. Gentz is a Principal Engineer with NESC at Langley Research Center (LaRC). Mr. Gentz joined NESC from the Marshall Space Flight Center with over 26 years of experience involving numerous NASA, Department of Defense, and industry failure analyses and incident investigations, including Challenger, Columbia, Tethered Satellite System, and the TWA 800 Accident Investigations.

Continued on next page...

NESC Principal Engineers *Continued*

Dr. Michael G. Gilbert
NESC Principal Engineer

Dr. Michael G. Gilbert is a Principal Engineer with NESC at Langley Research Center (LaRC). Dr. Gilbert was formerly the NESC Chief Engineer at LaRC. Before joining NESC, he was Head of the LaRC Systems Management Office. Dr. Gilbert has over 31 years of engineering, research, and management experience with aircraft, missile, spacecraft, Space Shuttle, and International Space Station programs.



Michael T. Kirsch
NESC Principal Engineer

Mr. Michael T. Kirsch is a Principal Engineer with NESC at Langley Research Center (LaRC). Mr. Kirsch joined NESC from the NASA's White Sands Test Facility (WSTF) where he served as the Deputy Manager responsible for planning and directing developmental and operational tests of spacecraft propulsion systems and related subsystems. Mr. Kirsch has over 20 years of experience in managing projects and test facilities.

NESC Chief Engineers

Dr. Nancy J. Currie
NESC Chief Engineer

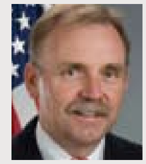
Dr. Nancy J. Currie is NESC's Chief Engineer at Johnson Space Center (JSC). Dr. Currie came to the NESC from JSC, where she served as the Deputy Director of the Engineering Directorate. Dr. Currie has over 21 years of expertise in robotics and human factors engineering. Selected as an astronaut in 1990, Dr. Currie is a veteran of four Space Shuttle missions and has accrued 1000 hours in space.

Walter C. Engelund
NESC Chief Engineer

Mr. Walter C. Engelund is NESC's Chief Engineer at Langley Research Center (LaRC). Mr. Engelund came to the NESC from LaRC, where he served as the Head of the Atmospheric Flight and Entry Systems Branch. Mr. Engelund has over 20 years of experience as a recognized expert in launch and entry vehicle aerodynamics, atmospheric flight dynamics and hypersonic flight systems.

R. Lloyd Keith
NESC Chief Engineer

Mr. R. Lloyd Keith is NESC's Chief Engineer, as well as the Center Chief Engineer at the Jet Propulsion Laboratory (JPL). Mr. Keith has over 32 years of experience working in both technical and managerial positions. Mr. Keith has supported a number of flight projects including the Mars Pathfinder Project, SeaWinds, Stardust, Mars '98, New Millennium Deep Space 1, and the Flight Hardware Logistics Program.

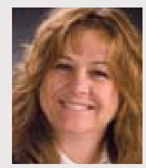


Nans Kunz
NESC Chief Engineer

Mr. Nans Kunz is NESC's Chief Engineer at Ames Research Center (ARC). Mr. Kunz came to the NESC from the Systems Engineering Division at ARC. Mr. Kunz has over 31 years of engineering experience leading and managing NASA programs and projects including serving as the Chief Engineer of the Stratospheric Observatory For Infrared Astronomy (SOFIA) Project.

Stephen A. Minute
NESC Chief Engineer

Mr. Stephen A. Minute is NESC's Chief Engineer at Kennedy Space Center (KSC). Mr. Minute came to the NESC from KSC, where he served as the Chief of the Space Shuttle Safety, Quality, and Mission Assurance Division. Mr. Minute has over 25 years of engineering and management experience in the Space Shuttle and International Space Station Programs.



Dr. Tina L. Panontin
NESC Chief Engineer

Dr. Tina L. Panontin is NESC's former Chief Engineer at Ames Research Center (ARC). She continues to serve as the ARC Chief Engineer and formerly served as the Chief of the Failure Analysis and Materials Group at ARC. Dr. Panontin has over 26 years of experience in solving complex problems, assessing the health of systems and organizations, investigating anomalies and failures, and developing tools that support systems engineering processes.

Dr. Charles F. Schafer
NESC Chief Engineer

Dr. Charles F. Schafer is NESC's Chief Engineer at Marshall Space Flight Center (MSFC). Dr. Schafer came to the NESC from MSFC where he served as the Deputy Manager of the Propulsion Research Center of the Science and Technology Directorate. Dr. Schafer has over 43 years of experience in leading research and technology activities in advanced earth-to-orbit and in-space propulsion, including work in nuclear propulsion, plasma propulsion, advanced chemical propulsion, and new chemical propellant development.

Steven S. Scott
NESC Chief Engineer

Mr. Steven S. Scott is NESC's former Chief Engineer at Goddard Space Flight Center (GSFC). He continues to serve as the GSFC Chief Engineer. Mr. Scott formerly served as the NESC Discipline Expert (now called NASA Technical Fellow) for Software. Mr. Scott has over 25 years experience in systems engineering and satellite software engineering.

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NESC Chief Engineers *Continued*

Michael D. Smiles

NESC Chief Engineer

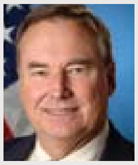
Mr. Michael D. Smiles is NESC's Chief Engineer at Stennis Space Center (SSC). Mr. Smiles joined the NESC from SSC, where he served as the Safety and Mission Assurance (S&MA) Manager. Mr. Smiles has over 24 years of management and technical experience with NASA at SSC and Marshall Space Flight Center.

Bryan K. Smith

NESC Chief Engineer

Mr. Bryan K. Smith is NESC's Chief Engineer at Glenn Research Center (GRC). Mr. Smith joined the NESC from GRC, where he served as Deputy Chief of the Power and In-Space Propulsion Division and Chief of the Space Flight Project Office. Mr. Smith has over 22 years of engineering and management experience leading the development of space flight systems.

Dr. James F. Stewart



NESC Chief Engineer

Dr. James F. Stewart is NESC's Chief Engineer at Dryden Flight Research Center (DFRC). Dr. Stewart joined the NESC from DFRC where he served as the Dryden Exploration Mission Director. Dr. Stewart has over 43 years of management and technical experience leading missile and aircraft programs.

Timothy G. Trenkle

NESC Chief Engineer

Mr. Timothy G. Trenkle is NESC's Chief Engineer at Goddard Space Flight Center (GSFC). Mr. Trenkle joined the NESC from GSFC, where he has over 17 years of technical experience serving as the technical lead for a number of flight programs and technical assignments including serving as the Chief Engineer for the National Polar-Orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project (NPP).

Clayton P. Turner

NESC Chief Engineer

Mr. Clayton P. Turner is NESC's former Chief Engineer at Langley Research Center (LaRC). He continues to serve as LaRC's Chief Engineer. He has over 19 years of management and technical experience including serving as the technical/programmatic lead for several projects including the Gas Permeable Polymer Materials (GPPM) Project and the Gas and Aerosol Monitoring Sensorcraft (GAMS) Project.

NASA Technical Fellows

Michael L. Aguilar

NASA Technical Fellow

Mr. Michael L. Aguilar is the NASA Technical Fellow for Software and is resident at Goddard Space Flight Center (GSFC). Mr. Aguilar joined the NESC from GSFC where he served as the James Webb Space Telescope (JWST) Instrument Software Manager. Mr. Aguilar has over 33 years of experience on embedded software development.

Mitchell L. Davis

NASA Technical Fellow

Mr. Mitchell L. Davis is the former NASA Technical Fellow for Avionics and was resident at Goddard Space Flight Center (GSFC). Mr. Davis was the Chief Engineer of the Electrical Systems Branch at GSFC prior to joining the NESC. Mr. Davis has over 27 years of experience in power and avionics. In September 2009, Mr. Davis accepted a position as the Chief Avionics Systems Engineer in the Electrical Engineering Division at GSFC.

Cornelius J. Dennehy

NASA Technical Fellow

Mr. Cornelius J. Dennehy is the NASA Technical Fellow for Guidance Navigation and Control (GNC) systems and is resident at Goddard Space Fight Center (GSFC). Mr. Dennehy came to NESC from the Mission Engineering and Systems Analysis Division at GSFC, where he served as the Division's Assistant Chief for Technology. Mr. Dennehy has over 29 years of experience in the architecture, design, development, integration, and operation of GNC systems, and space platforms for communications, defense, remote sensing, and scientific mission applications.

Roberto Garcia

NASA Technical Fellow

Mr. Roberto Garcia is the NASA Technical Fellow for Propulsion and is resident at Marshall Space Flight Center (MSFC). Mr. Garcia came to NESC from the Solid Propulsion Systems Division where he served as Division Chief. Mr. Garcia has over 18 years of experience in performing aerodynamic, hydrodynamic, and engine system design and analysis of rocket propulsion.

Oscar Gonzalez

NASA Technical Fellow

Mr. Oscar Gonzalez is the NASA Technical Fellow for Avionics and is resident at Goddard Space Flight Center (GSFC). Mr. Gonzalez came to the NESC from GSFC where he served as the International Space Station/Express Logistic Carrier (ELC) Avionics Systems Manager. Mr. Gonzalez has over 31 years of NASA and private industry experience where he has held a variety of critical leadership roles in power electronics, electrical systems, instrument systems, and avionics systems.

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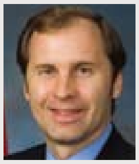
NASA Technical Fellows *Continued*

Denney J. Keys

NASA Technical Fellow

Mr. Denney J. Keys is the NASA Technical Fellow for Electrical Power and is resident at Goddard Space Flight Center (GSFC). Mr. Keys served as the Lead Power Systems Engineer in the Power Systems Branch at GSFC before joining the NESC. Mr. Keys has over 29 years of private industry and NASA experience with electrical power systems.

Dr. Curtis E. Larsen



NASA Technical Fellow

Dr. Curtis E. Larsen is the NASA Technical Fellow for Loads and Dynamics and is resident at Johnson Space Center (JSC). Prior to joining the NESC, Dr. Larsen was the Technical Discipline Manager for Cargo Integration Structures in the Space Shuttle Program's Flight Operations and Integration Office. Dr. Larsen has over 29 years of engineering experience with expertise in stochastic structural dynamics, structural safety, and probabilistic engineering applications.

Daniel G. Murri

NASA Technical Fellow

Mr. Daniel G. Murri is the NASA Technical Fellow for Flight Mechanics and is resident at Langley Research Center (LaRC). Mr. Murri served as Head of the Flight Dynamics Branch at LaRC before joining the NESC. He has over 28 years of engineering experience conducting numerous wind-tunnel, simulation, flight-test, and theoretical studies in the exploration of new technology concepts and in support of aircraft development programs.

Dr. Cynthia H. Null

NASA Technical Fellow

Dr. Cynthia H. Null is the NASA Technical Fellow for Human Factors and is resident at Ames Research Center (ARC). Before joining the NESC, Dr. Null was a scientist in the Human Factors Division and Deputy Program Manager of the Space Human Factors Engineering Project. Dr. Null has 23 years of experience lecturing on Human Factors, and another 17 years of experience in Human Factors applied to NASA programs.

Joseph W. Pellicciotti

NASA Technical Fellow

Mr. Joseph W. Pellicciotti is the NASA Technical Fellow for Mechanical Systems and is resident at Goddard Space Flight Center (GSFC). Mr. Pellicciotti served as the Chief Engineer for the GSFC Mechanical Systems Division before joining the NESC. Mr. Pellicciotti has over 21 years of combined private industry and NASA experience designing structure and mechanisms for commercial, military, and civil spacecraft.

Dr. Robert S. Piascik

NASA Technical Fellow

Dr. Robert S. Piascik is the NASA Technical Fellow for Materials and is resident at Langley Research Center (LaRC). Dr. Piascik joined the NESC from the LaRC Mechanics of Materials Branch and the Metals and Thermal Structures Branch, where he served as a Senior Materials Scientist. Dr. Piascik has over 25 years of experience in the commercial nuclear power industry and over 16 years of experience in basic and applied materials research for several NASA programs.

Dr. William H. Prosser

NASA Technical Fellow

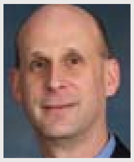
Dr. William H. Prosser is the NASA Technical Fellow for Nondestructive Evaluation and is resident at Langley Research Center (LaRC). Dr. Prosser joined the NESC from the Nondestructive Evaluation Sciences Branch at LaRC. Dr. Prosser has over 22 years of experience in the field of ultrasonic and acoustic emission sensing techniques.

Dr. Ivatury S. Raju

NASA Technical Fellow

Dr. Ivatury S. Raju is the NASA Technical Fellow for Structures and is resident at Langley Research Center (LaRC). Dr. Raju was the Senior Technologist in the LaRC Structures and Materials Competency prior to joining the NESC. Dr. Raju has over 34 years of experience in structures, structural mechanics, and structural integrity.

Steven L. Rickman



NASA Technical Fellow

Mr. Steven L. Rickman is the NASA Technical Fellow for Passive Thermal and is resident at Johnson Space Center (JSC). Mr. Rickman joined the NESC from JSC's Thermal Design Branch where he served as the Chief. Mr. Rickman has over 24 years of management and technical experience in passive thermal control.

Henry A. Rotter

NASA Technical Fellow

Mr. Henry (Hank) A. Rotter is the NASA Technical Fellow for Life Support/Active Thermal and is resident at Johnson Space Center (JSC). Mr. Rotter joined the NESC from the JSC Crew and Thermal Systems Division and the Space Launch Initiative Program, where he was Engineering Manager and the Orbital Space Plane Team Leader for life support and active thermal control teams. Mr. Rotter has over 42 years of life support and active thermal control systems experience during the Apollo, Space Shuttle, and Orbital Space Plane Programs.

Dr. David M. Schuster

NASA Technical Fellow

Dr. David M. Schuster is the NASA Technical Fellow for Aerosciences and is resident at Langley Research Center (LaRC). Prior to joining the NESC, Dr. Schuster was the Branch Head for the Structural and Thermal Systems Branch in the Systems Engineering Directorate. Dr. Schuster has over 31 years of experience in the aerospace industry with expertise in aeroelasticity and integrated aerodynamic analysis.

Whereabouts of former NESC personnel

Frank H. Bauer

NESC Discipline Expert for Guidance Navigation and Control (2003 – 2004) Currently serving as the Exploration Systems Mission Directorate Chief Engineer at NASA HQ

J. Larry Crawford

NESC Deputy Director for Safety (2003 – 2004) Left NESC to become Director of Safety and Mission Assurance at Kennedy Space Center (KSC) and has since retired

Dr. Charles J. Camarda

NESC Deputy Director for Advanced Projects (2006 – 2009) Left the NESC to become Senior Advisor for Innovation in the Office of the Chief Engineer at NASA HQ

Kenneth D. Cameron

NESC Deputy Director for Safety (2005 – 2008) Left the NESC to accept a position with Northrop Grumman

Steven F. Cash

NESC Chief Engineer at Marshall Space Flight Center (MSFC) (2005) Currently the Manager, Space Shuttle Propulsion Office at MSFC

Derrick J. Cheston

NESC Chief Engineer at Glenn Research Center (2003 – 2007) Left the NESC to participate in the Senior Executive Service Candidate Development Program (SESCDP)

Dennis B. Dillman

NESC Chief Engineer at NASA Headquarters (2005 – 2008) Currently an Engineer in the Science Mission Directorate at NASA HQ

Freddie Douglas, III

NESC Chief Engineer at Stennis Space Center (SSC) (2007 – 2008) Currently the Manager, Office of Safety and Mission Assurance at SSC

Patricia L. Dunnington

Manager, Management and Technical Support Office (2006 – 2008) Retired

Dr. Michael S. Freeman

NESC Chief Engineer at Ames Research Center (ARC) (2003 – 2004) Retired

T. Randy Galloway

NESC Chief Engineer at Stennis Space Center (SSC) (2003 – 2004) Currently the Director of the Engineering and Test Directorate at SSC

Dr. Edward R. Generazio

NESC Discipline Expert for Nondestructive Evaluation (2003 – 2005) Currently a Senior Research Engineer, Research & Technology Directorate, LaRC

Dr. Richard J. Gilbrech

NESC Deputy Director (2003 – 2005) Currently the Associate Director at Stennis Space Center

Michael Hagopian

NESC Chief Engineer at Goddard Space Flight Center (GSFC) (2003 – 2007) Currently the Chief Engineer in the Engineering Directorate at GSFC

David A. Hamilton

NESC Chief Engineer at Johnson Space Center (JSC) (2003 – 2007) Retired

Dr. Charles E. Harris

NESC Principal Engineer (2003 – 2006) Currently the Director, Research & Technology Directorate at LaRC

Dr. Steven A. Hawley

NESC Chief Astronaut (2003 – 2004) Left the NESC to become the Director of Astromaterials Research and Exploration Science at Johnson Space Center (JSC) and has since retired

Marc S. Hollander

Manager, Management and Technical Support Office (2005 – 2006) Left the NESC to accept a position as the Associate Director for Management, National Institutes of Health

George D. Hopson

NASA Technical Fellow for Propulsion (2003 - 2007) Retired

Keith L. Hudkins

NASA Headquarters Office of the Chief Engineer Representative (2003 – 2007) Retired

Danny D. Johnston

NESC Chief Engineer at Marshall Space Flight Center (MSFC) (2003 – 2004) Left the NESC to work a detailed assignment at MSFC in the NASA Chief Engineer's Office and has since retired

Michael W. Kehoe

NESC Chief Engineer at Dryden Flight Research Center (DFRC) (2003 – 2005) Left the NESC to become the DFRC Liaison in the Crew Exploration Vehicle Flight Test Office at JSC and has since retired

Robert A. Kichak

NESC Discipline Expert for Power and Avionics (2003 – 2007) Retired. Serving as a contract consultant to NASA/NESC.

Dr. Dean A. Kontinos

NESC Chief Engineer at Ames Research Center (ARC) (2006 – 2007) Currently an Engineer in the Office of the Chief Engineer at ARC

Julie A. Kramer White

NESC Discipline Expert for Mechanical Analysis (2003 – 2006) Currently the Chief Engineer, Crew Exploration Vehicle Office at JSC

Steven G. Labbe

NESC Discipline Expert for Flight Sciences (2003 – 2006) Currently the Chief Engineer, Constellation Program Office at JSC

Matthew R. Landano

NESC Chief Engineer at Jet Propulsion Laboratory (JPL) (2003 – 2004) Returned to his assignment at JPL as the Director of Office of Safety and Mission Success

David S. Leckrone

NESC Chief Scientist (2003 – 2006) Currently the Senior Project Scientist for the Hubble Space Telescope at GSFC

John P. McManamen

NASA Technical Fellow for Mechanical Systems (2003 – 2007) Currently the Chief Engineer, Space Shuttle Program Office at JSC

Brian K. Muirhead

NESC Chief Engineer at Jet Propulsion Laboratory (JPL) (2005 – 2007) Currently the Program Systems Engineer in the Constellation Program's Program Systems Engineering Office at JSC

Dr. Paul M. Munafo

NESC Deputy Director (2003 – 2004) Left the NESC to become the Assistant Director for Safety and Engineering at Marshall Space Flight Center (MSFC) and has since retired

Stan C. Newberry

Manager of NESC's Management and Technical Support Office (2003 – 2004) Left NESC to become the Deputy Center Director at Ames Research Center (ARC) and has since left NASA to accept a position at DoD

Dr. Shamim A. Rahman

NESC Chief Engineer at Stennis Space Center (2005 – 2006) Currently the Deputy Director of the Engineering and Test Directorate at SSC

Jerry L. Ross

NESC Chief Astronaut (2004 – 2006) Currently the Chief of the Vehicle Integration Test Office at JSC

John E. Tinsley

NASA Headquarters Senior Safety and Mission Assurance Manager for NESC (2003 – 2004) Left NESC to become the Director of the Mission Support Division at NASA Headquarters and has since left NASA to accept a position with Northrop Grumman

NESC Publications 2009

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NESC Publications 2009 *Continued*

Presented Papers

1. Propulsion for the Max Launch Abort System (MLAS); JANNAF Joint Propulsion Meeting; 04/14/2009 - 04/17/2009 Las Vegas, NV

2. Fracture Mechanics Analyses of Reinforced Carbon-Carbon Wing-Leading-Edge Panels; 51st AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference; 04/12/2010 - 04/15/2010 Orlando, FL

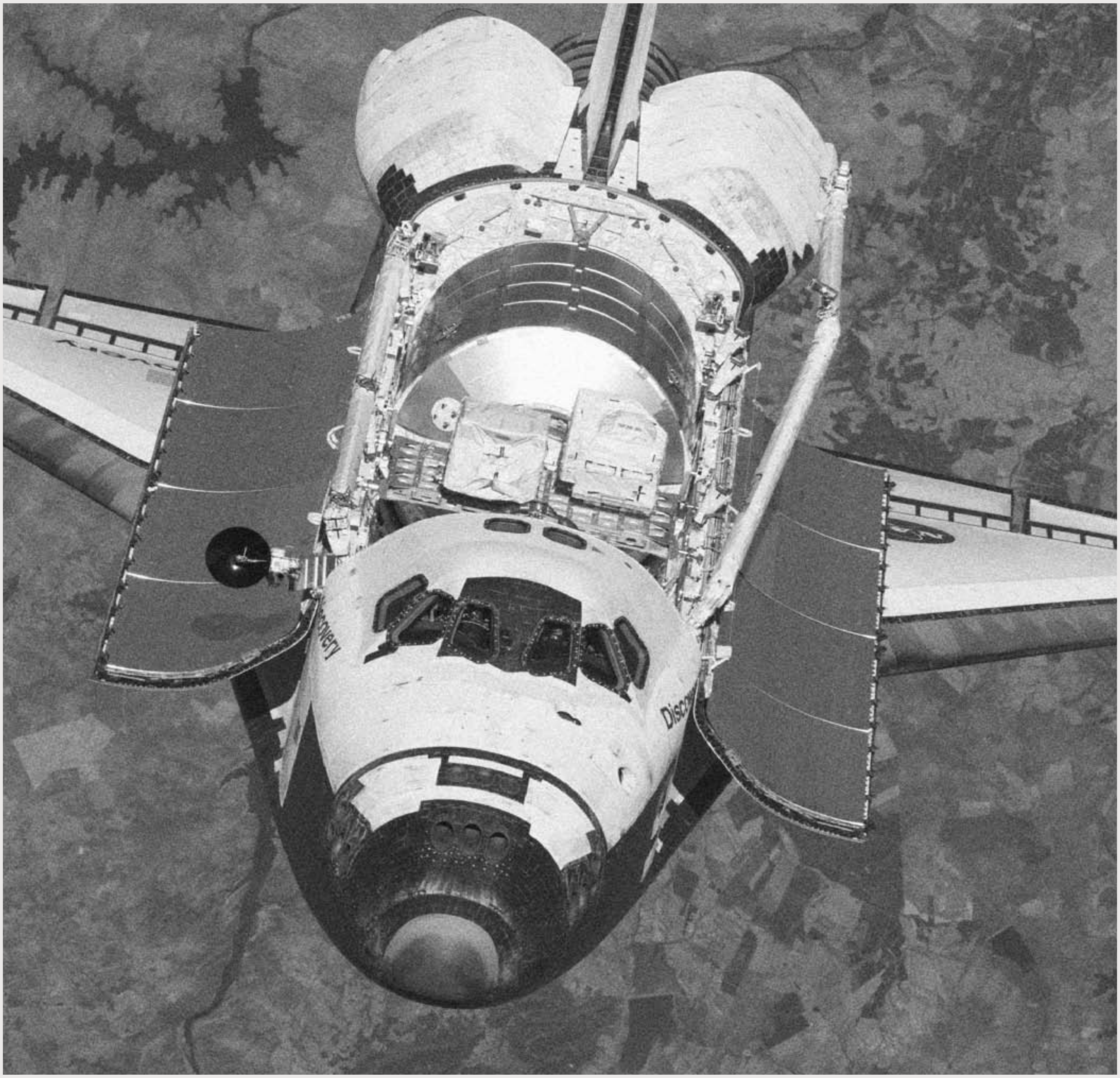
3. Design and Development of the Solar Dynamics Observatory (SDO) Electrical Power System; AIAA 7th International Energy Conversion Engineering Conference; 08/02/2009 - 08/05/2009 Denver, CO

4. Space Shuttle Wing-Leading-Edge Panel Thermo-Mechanical Analysis for Entry Conditions; 51st AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference; 04/12/2010 - 04/15/2010 Orlando, FL

5. A Review of the MLAS Parachute Systems; 20th AIAA Aerodynamic Decelerator Systems Technology Conference; 05/04/2009 - 05/07/2009 Seattle, WA

6. A Comparison of Fault-Tolerant GN&C System Architectures Using the Object Process Network (OPN) Modeling Language; AIAA Guidance, Navigation, and Control Conference (GNC) 2009; 08/10/2009 - 08/13/2009 Chicago, IL

7. A Physics-Based Temperature Stabilization Criterion for Thermal Testing; 25th Aerospace Testing Seminar, 10/13/2009 - 10/15/2009 Manhattan Beach, CA.



The Space Shuttle Discovery approaches the International Space Station for docking.

Forty Years Later

Forty years ago, men from Earth began for the first time to leave our home planet and journey to the moon.

From 1968 to 1972, NASA's Apollo astronauts tested out new spacecraft and journeyed to uncharted destinations.

It all started on May 25, 1961, when President John F. Kennedy announced the goal of sending astronauts to the moon before the end of the decade. Coming just three weeks after Mercury astronaut Alan Shepard became the first American in space, Kennedy's bold challenge set the nation on a journey unlike any before in human history.

Eight years of hard work by thousands of Americans came to fruition on July 20, 1969, when Apollo 11 Commander Neil Armstrong stepped out of the lunar module and took "one small step" in the Sea of Tranquility, calling it "a giant leap for mankind."

Six of the missions — Apollos 11, 12, 14, 15, 16 and 17 — went on to land on the moon, studying soil mechanics, meteoroids, seismic, heat flow, lunar ranging, magnetic fields and solar wind. Apollos 7 and 9 tested spacecraft in Earth orbit; Apollo 10 orbited the moon as the dress rehearsal for the first landing. An oxygen tank explosion forced Apollo 13 to scrub its landing, but the "can-do" problem solving of the crew and mission control turned the mission into a "successful failure."

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