National Aeronautics and Space Administration

NASA ENGINEERING & SAFETY CENTER

2008 TECHNICAL UPDATE

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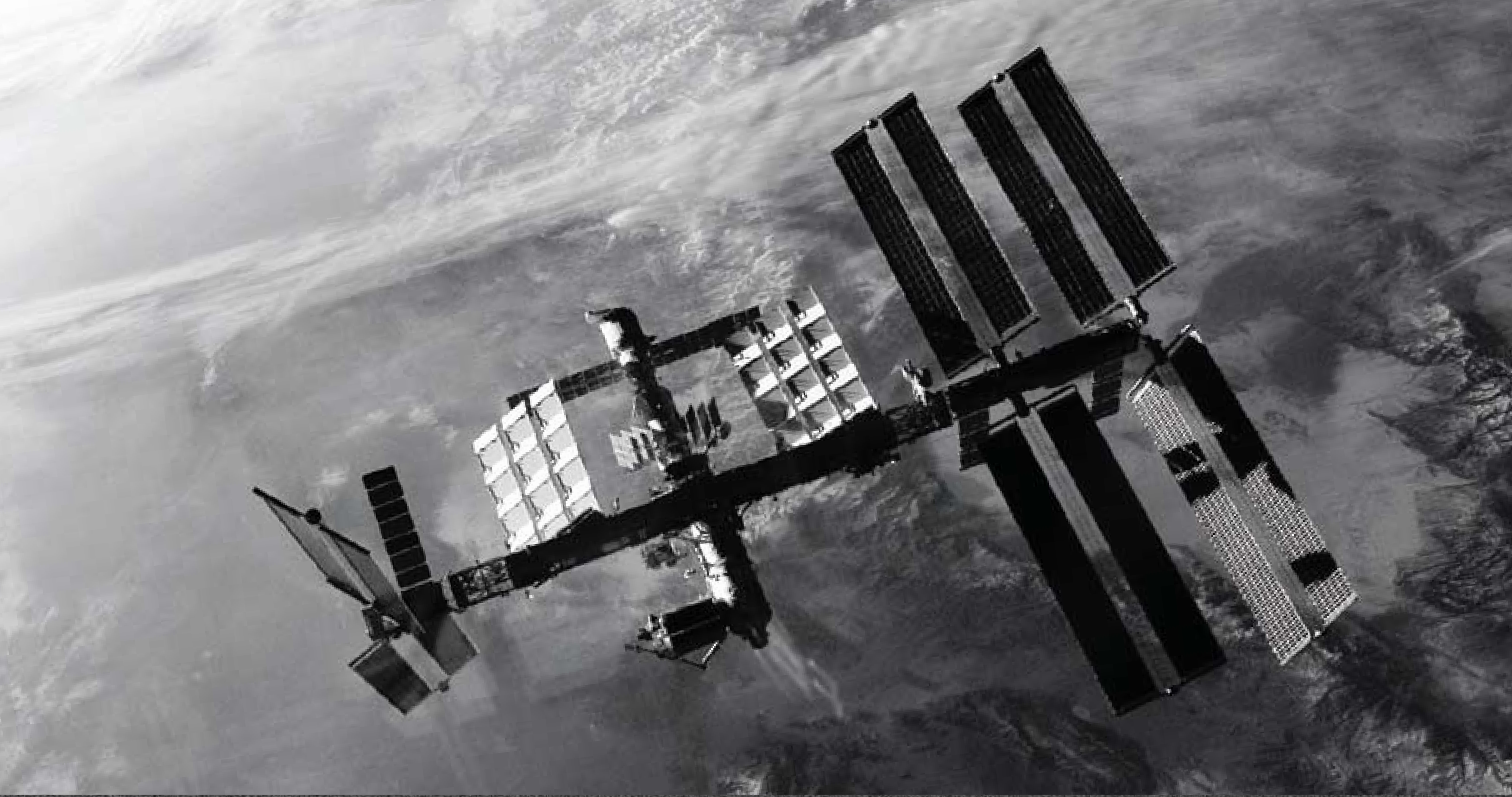

It gives me a lot of pleasure to recognize the 5th anniversary of the establishment of the NASA Engineering and Safety Center. It also offers, for me, a valuable reminder that it is important always to be open to new ideas and new approaches to solving problems. When the NESC was established, I was more than a bit pessimistic that it could work, that it could provide value for the Agency over and above that offered by our various center engineering directorates. I was wrong. The synergy that has been achieved by the NESC and its cross-agency approach to solving difficult technical problems has been truly impressive. It is, in my mind, a useful model for future endeavors and a great example that it is actually possible for us to "be NASA", to rise above some of the parochial geographic concerns which have plagued NASA for five decades. These days, when someone tells me that the NESC is looking at a particular issue, I am reassured, because I know that if a solution can be found, this group will find it.

– Dr. Michael D. Griffin, NASA Administrator

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Cover images clockwise from upper left - International Space Station solar array anomaly resolution, Composite Overwrapped Pressure Vessel testing, Orion Composite Crew Module construction pathfinder and Max Launch Abort System forward fairing wind tunnel testing.

The NASA Engineering and Safety Center (NESC) is now 5 years old and more vibrant and influential than ever. It is time to reflect a bit on how the NESC has evolved to become the success it has; clearly it has achieved its primary goal to engage the best personnel in NASA and from the outside to address our most difficult problems. However, over the last 5 years it has become more; it serves to train our workforce through the NESC Academy, it provides the technical leaders through the NASA Technical Fellows who provide leadership for their discipline. The NESC provides common tools to remove misunderstanding, and develop new tools as it has with the Max Launch Abort System and the Composite Crew Module. By all measures of organizational success the NESC and its people have excelled — so we all look forward to the next 5 years as the NESC and NASA pioneer this 'New Ocean.'

Christopher Scolese NASA Associate Administrator

From its inception, the NESC's core tenet has been to assemble the best possible technical expertise to apply to NASA's toughest and most important problems. For tasks large and small, the NESC has demonstrated its agility and reach by quickly assembling the needed talent, whatever the source, and quickly bringing it to bear on a wide range of challenges. In the past year, the NESC has added to its strong record and continues to be the "go to" resource for NASA Programs and Projects. A few examples include expanding NASA's technical experience with composites via the Composite Crew Module work for Constellation, increasing our depth of knowledge on the Reinforced Carbon-Carbon Orbiter wing leading edges, providing micrometeorite and orbital debris design input for the James Webb Space Telescope or characterizing solar array mass buckling behavior for the International Space Station. Perhaps the highest accolade is that it has become difficult to imagine what NASA would do if we did not have the NESC! On behalf of many, I offer my thanks and congratulations to the whole team for another year of excellent work.

Michael Ryschkewitsch NASA Chief Engineer

The NESC has continued to serve the Agency over the past year as "the" technical organization of choice for our toughest engineering problems. They have developed over time an exceptional ability to expeditiously place the best people from both inside and outside of the Agency on the team. Of special importance to me this past year has been the discipline they have put into their technical reports. When an NESC assessment team reports their results, they take the time and effort to write them in a format that clearly states the problem, the scope and method of the assessment, and a clear English discussion of the results, findings and recommendations. And, they show the data. In an organization like NASA, this should not have been a big deal. But, over time, our hurry-up PowerPoint culture had led us to tolerate incomplete technical reporting almost as a standard. Old mishap lessons learned are replete with communications failures, so I applaud the NESC for reminding us all of the important contribution of clear communications to safety and technical excellence.

Bryan O'Connor NASA Chief Safety and Mission Assurance Officer

From left: Ralph Roe, Jr., Dawn Schaible, Tim Wilson, Kenneth Cameron, and Patricia Dunnington

This year marks NASA's 50th anniversary and the 5th year that the NASA Engineering and Safety Center (NESC) has provided the Agency with the value-added independent assessments, testing and analyses it needs to address its highest-risk issues. The NESC's operating model reaches across the Agency, industry, other government agencies and academia to create diverse technical teams, and this inclusive outreach continues to be our true strength. Our broad-based, multi-disciplinary teams have provided NASA with a unique resource, and we are pleased to feature members of these teams throughout this year's Technical Update.

The NESC has used the broad-based team approach on two major efforts this year that are increasing the Agency's understanding and capabilities for designing and building future spacecraft. Both the Composite Crew Module and Max Launch Abort System teams are featured in this publication. In addition to the numerous activities on behalf of the Constellation Program, the NESC continued to actively engage in the Space Shuttle and International Space Station Programs – including the Shuttle launch pad flame trench damage and ISS solar array buckling anomaly resolutions. The NESC has also maintained a focus on the Agency's critical science missions, such as Kepler and Phoenix. This publication will also feature the NESC's efforts to advance the state of the disciplines for many of our NASA Technical Fellows.

Over the past five years, the NESC has demonstrated the value and power of broad-based, diverse teams. While our team members have changed, with many of our alumni going on to key leadership positions in the Agency, we have remained true to our core mission: providing NASA with a strong, independent resource to solve its toughest technical problems. We strive to remain current, relevant, and responsive to our customers and stakeholders. We have actively shared the lessons and results of our activities across the Agency through various avenues, including this publication. We are very proud to highlight our accomplishments and team members in this year's Technical Update.

Current NASA Technical Fellow Disciplines

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

Future Technical Fellow Disciplines

- Electrical Power
- Passive Thermal
- Space Environments
- Cryogenics
- Sensors/Instrumentation
- Systems Engineering

How the NESC works

NASA's mission is to pioneer the future in space exploration, scientific discovery and aeronautical research. Achieving this requires unique technologies that inevitably give rise to problems that require unique solutions. Imagine if the people working on those problems could easily call on the entire Agency — not just colleagues within their program or their Center — to help with the most difficult problems. They would have available a pool of 18,000 talented people from across the country from which to draw. Take that proposition one step further – beyond the confines of NASA to the engineering and scientific community as a whole – and the pool of available talent would increase significantly.

Now further imagine a small organization within NASA, not reporting to any one Center or specific program, but a resource for the entire Agency. Fill this organization with the leading authorities in 13 different engineering disciplines. Give the authorities the resources to form standing teams of experts in their disciplines from across NASA, industry, academia, and the government. Add an engineering representative for each Center, and a group of engineers dedicated to leading multi-discipline teams in solving technical problems. Finally, solidify the organization with strong systems engineering and a resourceful business office. This organization exists. It is called the NASA Engineering and Safety Center (NESC).

The NESC Model

The NESC provides objective engineering and safety assessments of NASA's high risk projects, following the principle that safety is achieved through engineering excellence. By searching out all of the resources available, the NESC creates successful broad-based teams by tapping into the best the Agency has to offer. Although based at the Langley Research Center, by design, the NESC maintains a decentralized framework with members located at all of the Centers including Headquarters. Then by reporting directly to the NASA Chief Engineer, the NESC maintains a separation from the mission directorates and their programs, and from Center leadership, to provide an alternate reporting path through which problems can be addressed. The NESC also works closely with the NASA Office of Safety and Mission Assurance and the NASA Safety Center.

The NESC is divided into the following six offices:

1. NASA Technical Fellows

The NASA Technical Fellows are the Agency's senior technical experts in 13 engineering disciplines (see inset). Each Technical Fellow leads a technical discipline team (TDT) made up of experts from across the country – both inside and outside of NASA. They provide a pool of discipline-specific expertise from which to draw when assessment teams are formed.

NASA Technical Fellows act as stewards for their disciplines by sponsoring workshops, conferences, and discipline-advancing activities. They also work to maintain consistency in Agency-level standards and incorporate lessons-learned into NASA's engineering processes. Periodically, each Technical Fellow will present a "state-of-the-discipline" to the Agency's senior leadership to enhance awareness of specific concerns within the discipline. Some of these concerns are pursued with resources provided by the NESC — resources granted specifically for the purpose of proactively answering technical challenges faced by their disciplines that may impact NASA's programs in the future.

2. NESC Chief Engineers

Each Center plus Headquarters has an NESC Chief Engineer (NCE). The NCEs provide insight into the programs that impact their own Centers. They also help coordinate the facilities and resources of each Center as required to support NESC assessments and activities.

3. Systems Engineering Office (SEO)

The Systems Engineering Office provides system engineering and integration for assessments and other NESC activities. The SEO and the SEO-led Systems Engineering TDT provide technical expertise in systems engineering processes such as systems analysis, statistics, data mining and trending, and requirements analysis.

4. Principal Engineers Office (PEO)

The PEO is responsible for technical assessments carried out by the NESC. The Principal Engineers (PEs) and back-up PEs lead assessment teams – especially for those activities that require the participation of multiple disciplines – and provide guidance for assessments led by individuals from outside of the NESC. The PEs have the project management skills to complement the focused expertise of the NASA Technical Fellows.

5. Management and Technical Support Office (MTSO)

The MTSO is the NESC's business office. Because the NESC relies on support from many companies and agencies outside of NASA, an effective business office is essential to handle the budgetary and contracting challenges faced by the NESC and the technical aspects of setting up and maintaining partnerships.

6. Office of the Director

In addition to the Director and his Deputy, the Office of the Director includes a Deputy Director for Advanced Projects and a Deputy Director for Safety. Also under the Director's Office are the Chief Scientist and a representative from the astronaut corps detailed to the NESC as the NESC Chief Astronaut.

NESC Review Board (NRB)

The NESC leadership team meets weekly as the NESC Review Board. All decisions made by the NESC are products of the NRB. Each member has equal footing and brings his or her background to the decision-making process. The success of the NRB results from its broad diversity and the outstanding technical competence of its members.

Broad-based Teams

The NESC builds networks of technical expertise with discipline specialists that are selected from all 10 NASA Centers. These broad-based teams work on NASA's most critical issues, together with additional experts that have been recruited from industry, academia, and other government agencies. In the 5 years since its creation, the NESC has advanced the art of bringing such a diversity of individuals together to benefit the entire Agency, its Centers, its programs, its projects, and its people.

Chief among these benefits are better-informed stakeholder decisions on technical issues in the near term, and better Agency decision-makers in the longer term. The Agency also benefits from innovative solutions that result from the diversity that the NESC intentionally builds into its teams. The Agency further benefits from the geographically-dispersed networks of expertise that endure long after the teams are disbanded. Finally, Agency programs and projects benefit as the NESC's safety culture is spread across the enterprise.

Partnerships

To take advantage of expertise available outside of NASA, the NESC has leveraged partnerships with other government agencies such as the National Transportation Safety Board, the Federal Aviation Administration, and the Department of Defense. The NESC has also enlisted the resources and personnel of national laboratories and independent research organizations like Sandia and Lawrence Livermore National Laboratories, Southwest Research Institute, Los Alamos National Laboratory, and the National Institute of Aerospace. Other participants for NESC activities are pulled from industry partners ranging from large aerospace companies such as Alliant Techsystems, Boeing, Lockheed Martin, and The Aerospace Corporation, down to smaller companies and individual consultants.

Services for the Agency

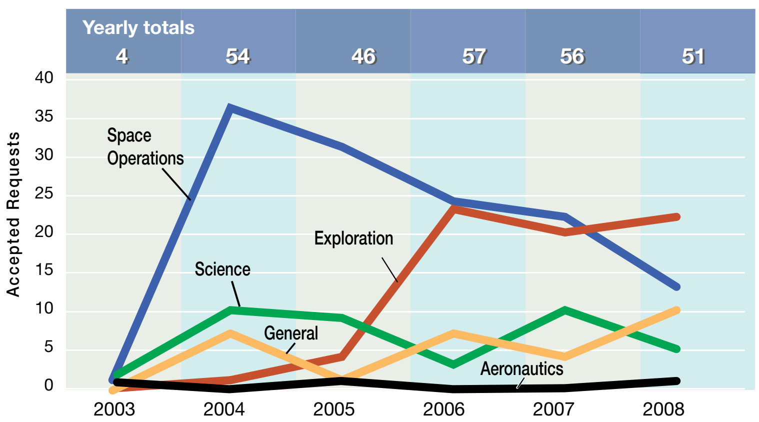
The NESC's primary vehicle for pursuing engineering issues is the assessment. Assessment teams are formed by pulling in technical experts from the TDTs and other sources to create a tiger team atmosphere that is focused on a specific technical issue. Requests for NESC assistance come from various sources: Associate Administrators, program/project managers, scientists and engineers, NASA contractors, and even the general public. The level of participation

— Continued on following page

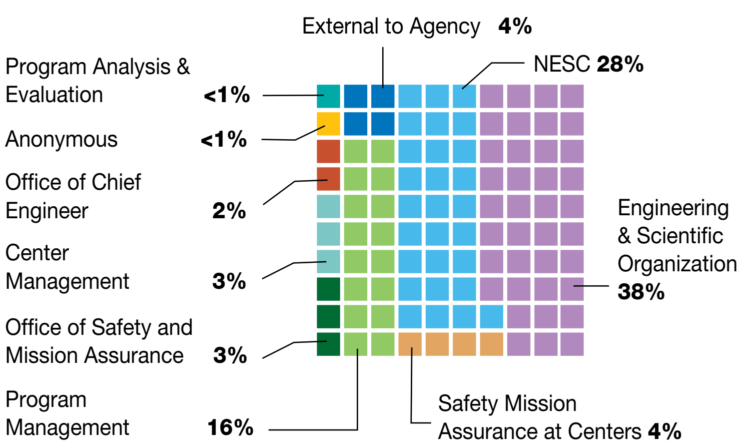
Members of the NRB (NESC Leadership Team)

- NESC Director
- NESC Deputy Director
- Chief Astronaut
- Chief Scientist
- Deputy Director for Safety
- Deputy Director for Advanced Projects
- MTSO Manager
- SEO Manager
- All Principal Engineers
- All NASA Technical Fellows
- All NESC Chief Engineers

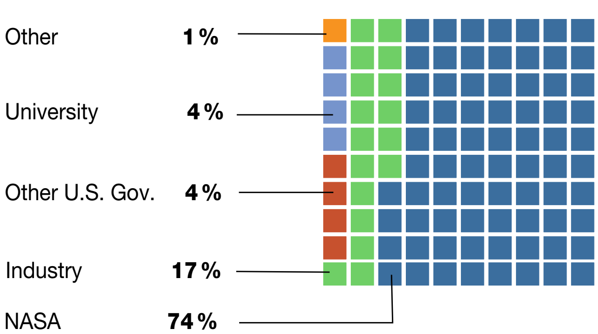
Accepted Requests by Mission Directorate: 268 Total



Source of Accepted Requests: 268 Total



2008 Technical Discipline Team Composition



All statistics as of Nov. 12, 2008

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from the NESC in an assessment can range from the furnishing of expertise for consultation to a completely independent investigation with testing, modeling, and analysis. The results from every assessment are published in a final report that has been discussed and approved by the NRB.

The diversity and technical excellence of the NESC also provides a centralized source from which specific expertise can be drawn for other Agency needs such as technical review boards, mishap investigations, and situations where real-time technical advice is required. The NESC also provides a framework for creating Agency-wide teams, with members brought in from around the Agency to participate in activities that extend beyond the NESC. Another important goal of the NESC is to educate. The NASA Technical Fellows share their insight and experience through the NESC Academy, in conferences and seminars, and by encouraging junior level engineers to participate in TDTs. In fact, all members of the TDTs (over 600-plus), by interacting with the leaders of their engineering disciplines, gain experience and knowledge to bring back to their home Centers and organizations.

In summary

As NASA celebrated its 50th anniversary in 2008, the NESC observed its 5th. While the NESC as an organization has evolved over the past 5 years, the primary mission remains unchanged – to improve safety through engineering excellence. This Technical Update serves to highlight many of the activities that have succeeded by employing the NESC model, but the greater goal of the NESC is to foster the atmosphere of Agency-wide cooperation and set the example of the power of diversity to promote engineering excellence. Available to anyone searching for an independent engineering assessment, the NESC can be reached through any NESC Chief Engineer or by email at **nesc@nasa.gov.** More contact information and many NESC reports are available from the NESC website: **www.nesc.nasa.gov.**

Upper shell of the Composite Crew Module (foreground) is being prepared for mating with the lower shell (background).

The NESC model:

"I have witnessed the effectiveness of the NESC model, which brings together engineering talent from around the country to tackle difficult problems. While at times hard to manage, this inclusion of a diverse set of individuals with varied backgrounds and experiences, ultimately leads to better technical solutions."

– Mike Hagopian, Chief Engineer for Engineering Directorate, GSFC

Learning from the Past

An important function of the NASA Technical Fellows Program is the NESC Academy that was established to capture, share, and preserve the lifetimes of experiences and knowledge of NASA scientists and engineers and to guide the next generation of the Agency's technical staff in the art of technical problem solving. The key objective is to broaden NASA engineers' experiences and technical skills through interaction with the NASA Technical Fellows and selected members of their TDTs. The ultimate goal is for each NASA Technical Fellow to have an opportunity to deliver their discipline-specific Academy course. Team work. Imagination. Flexibility. Innovation. All of these elements and many more have been integral to the creation and growth of the NASA Engineering and Safety Center (NESC) Academy, which celebrated its third year in operation in June 2008. To date, the Academy has developed and offered 10 discipline courses in the classroom and has launched nine of them as online courses via the Academy website. Two courses, Propulsion and Human Factors, have been repeated. Courses have been provided to 368 individuals from across the NASA Centers.

This year the following courses were offered:

Loads and Dynamics with NASA Technical Fellow Dr. Curtis Larsen and colleagues

The University of Houston at Clear Lake, Dec., 2007

Understanding loads and dynamics is critical to NASA's mission, a mission that includes safe and reliable human and robotic space travel and air transportation systems. Loads and dynamics combines mathematics, physics, statistics, probability, structural and mechanical engineering, and systems theory into one field vital to the safety and success of every NASA mission. An emphasis of the course was that loads and dynamics problem mitigations were "trade-offs" for other areas (e.g., payload), so it is a balancing act requiring teamwork to make a mission successful. The Academy emphasized lessons learned from past experts.

Structures/Nondestructive Evaluation (NDE) with NASA Technical Fellows Dr. Ivatury Raju and Dr. William Prosser and colleagues

National Institute of Aerospace, April, 2008

This course offered an overview of the collaboration between the two major disciplines. This was not a course that focused on equations, but rather took a broader view of concepts, processes and lessons learned. Course topics included: Failure Prediction in Structures and NDE, System Integration, Structural Modeling and Analysis, Structural Stability, Validation Testing and other related topics. Dr. Raju and Dr. Prosser collaborated with other experts to bring to life the real world issues faced during their extensive aerospace careers.

Innovative Engineering Design with Dr. Charles Camarda and colleagues

Penn State University, July, 2008

Innovative Engineering Design differed from previous NESC Academy offerings in that the participants and instructors worked and played hard together in the creative environment of the Penn State Learning Factory. Design methodologies ranged from "skunk works" — like rapid prototype development — to current launch vehicle development programs, and focused on the conceptual design phase. Students learned techniques to leverage their creative thinking and to apply innovative, hands-on design methods in solving real vehicle design problems. Dr. Camarda mixed academia with faculty from Penn State, MIT, and Georgia Tech with aerospace experts to immerse the students in a "Space Boot Camp-like" experience.

Repeat courses offered this year included:

Space Propulsion Systems with Mr. George Hopson and colleagues

Tulane University, May, 2008

The encore delivery of Space Propulsion Systems was presented by George Hopson and colleague Len Worlund. Hopson's four decades of contributions to America's space program include work on Skylab, the Space Shuttle, and the International Space Station. In this two-day course, Mr. Hopson who worked with the renowned Werhner von Braun, shared stories from meetings with von Braun and gave his guidance and insight on: lessons learned, best practices, problem solving/resolution, Agency knowledge being lost, working at NASA, and latest trends.

Human Factors with NASA Technical Fellow Dr. Cynthia Null and colleagues

National Institute of Aerospace, June, 2008

Dr. Null's expertise in human factors bridges academia and aerospace. This was an encore performance of the original classroom offering. The course content focused on the integration of human factors into NASA missions from conception through operations to include detailed case studies and problem-solving activities. Topics included: Developing in-space systems, Procedure development, Maintenance and manufacturing, Control center design and Ground operations.

NESC Academy courses available online and the course leader

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

More information can be found at:
http://www.nescacademy.org

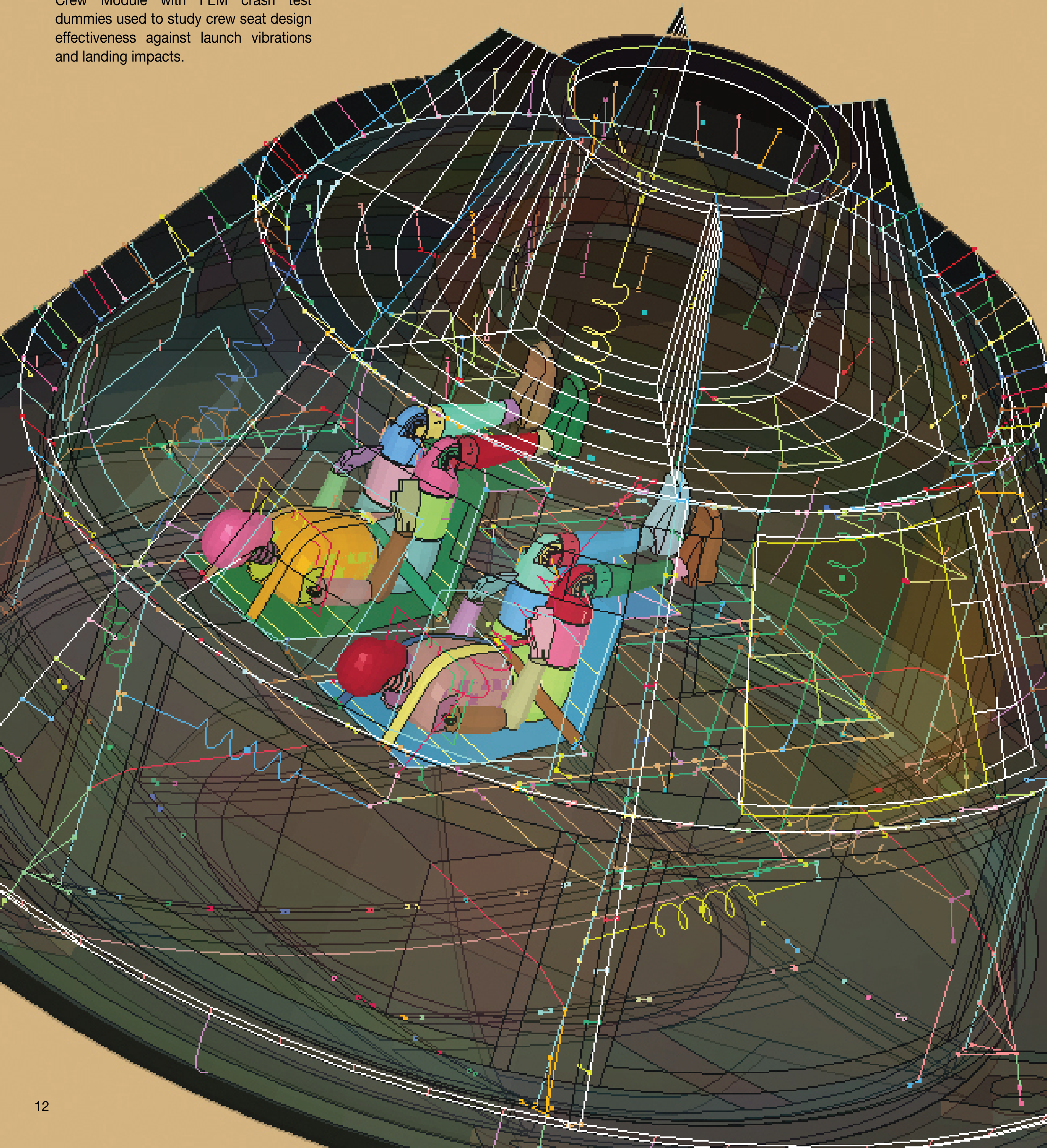
The NESC Academy experience:

"I'm a new engineer with NASA working with the crawler transporter. This course has been a great opportunity to hear the cumulative knowledge of all the teachers here, as well as a lot of the students sharing their knowledge base from their different projects."

– Gordon Coffey, Kennedy Space Center, student at Academy Structures/NDE course

Technical Highlights

Finite element model (FEM) of the Orion Crew Module with FEM crash test dummies used to study crew seat design effectiveness against launch vibrations and landing impacts.



Exploration

Collecting Flight Force Measurements to Improve Coupled Loads Analysis

Problem: Traditionally, acceleration measurements are used to reconstruct flight loads in structures. The penalties of using only acceleration are the weak correlation of Coupled Loads Analysis (CLA) and conservative qualification testing. Thus, a need exists to utilize force measurements in the CLA process. Force measurements will greatly benefit all future missions and could assist the Orion Crew Module requirements and development process.

Boeing employees Gerry Darter (left), Henry Fung (center), and Eric Thomas (right) install instrumentation on the GLAST PAF to collect flight force measurements.

NESC Contribution: An NESC team is demonstrating the benefits of acquiring interface force measurements during flight. A simplified approach was used that involved mounting of strain gages on the trussed Payload Adaptor Fitting (PAF) of the Gamma-Ray Large Area Space Telescope (GLAST) spacecraft, now called the Fermi Telescope, in a way that forces and moments may be derived. The NESC is developing methodologies to predict interface forces based on these strain measurements that will be validated in ground testing. The PAF design used on this flight is the most suitable test article for resolving forces based on strain measurements.

Results: GLAST was successfully launched in June 11, 2008. Post-flight data analysis is complete and flight coupled loads reconstruction underway. The next step consists of reconciling flight-based forces with flight reconstruction and/or nominal coupled loads results. The team will investigate the benefits of flight force measurements and the force prediction methodologies developed for use in ground testing to eliminate or substitute the use of strain gages in future launch vehicle flights.

Analysis of Constellation Program Mass Properties

Problem: The NASA Constellation Program (CxP) Chief Engineer requested an independent assessment to review and compare the current CxP mass and performance management implementation against industry practices.

Lockheed Martin Corp.

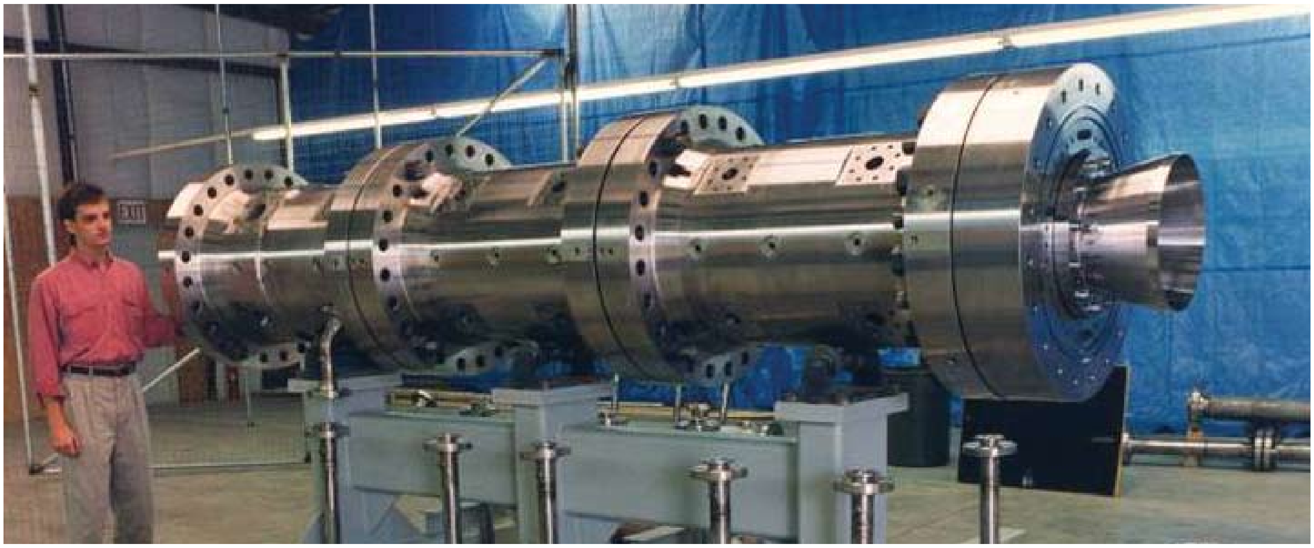
The number of parts on the Crew Exploration Vehicle, Orion, and other CxP components requires accurate knowledge of mass properties and its effects on the vehicle's performance.

NESC Contribution: The NESC investigated: standards terminology, mass and performance data capture and reporting, mass properties and margin management plans, mass margins, mass growth allowance (MGA), launch vehicle performance reserves, integrated performance margins, and sequential mass properties. The NESC team also reviewed the current project calculations and reporting of predicted mass, MGA and project management reserve, and identified methods to assess margins with respect to maturity and project phase.

Results: Findings addressed details in terminology, data collection, accounting, reporting, adherence to standards, and the results of applying a method that assessed weight as a function of design maturity. Recommendations incorporated specifics for refining the CxP mass properties processes, thoroughly engaging the system designers in managing mass growth, and improved practices for tracking and measuring the mass growth risk. Results are being implemented to improve the overall accuracy of current mass properties and performance processes, ongoing analysis and reporting.

Lessons Learned: Programs and projects should recognize and incorporate the discipline of mass properties management early in the project life cycle. Implementation of mass properties management, requirements and practices should be based on industry standards, use of consistent terminology, data collection, margin measurement and reporting methodology.

Exploration



Steve Skelley, a propulsion engineer of the MSFC's Fluid Dynamics Branch, studies the assembly of the solid rocket motor airflow test rig. The rig internally replicates the wetted surfaces of the RSRM at specific times in the burn. The proposed design modifications for reducing the thrust oscillations will be tested in this rig to verify their effectiveness.

Prediction and Reduction of Ares SRB Thrust Oscillation

Problem: The Ares I vehicle has a thrust oscillation frequency close to the vehicle's second axial structural mode frequency. The NESC was asked to make an independent prediction of the thrust oscillation in the five segment Reusable Solid Rocket Motor (RSRMV) and to develop motor design change options for reducing or eliminating it.

NESC Contribution: The NESC team included personnel from JSC, MSFC, LaRC, Gloyer-Taylor Laboratories LLC (GTL), ATK, and Jacobs Engineering Group. GTL provided access to key expertise at Penn State University, the California Institute of Technology, and at the University of Tennessee Space Institute. Additionally, GTL provided expertise with their Universal Combustion Device Stability™ (UCDS) system that predicts and identifies the specific design sources of propulsion system instabilities. Using the UCDS simulation, the team identified and cataloged the design features that cause thrust oscillation and their individual contribution to the overall oscillation amplitude. Design options for eliminating and/or reducing the contribution of individual design features were developed and analytically evaluated using UCDS. The best options were provided to the NASA Constellation Program-chartered Thrust Oscillation Focus Team and the Ares project.

Data from the shuttle RSRM ground test at Promontory, Utah was used to validate thrust oscillation models.

Results: Independent confirmation of the predicted RSRMV thrust oscillation frequency and amplitude characteristic was achieved. The specific contribution of individual design features was quantified for the first time. This provides very valuable information to address the thrust oscillation phenomena. Variability seen in thrust oscillations can be accounted for by inhibitor protrusion height and edge shape variability. With measured control of the regression rate of the inhibitors, particularly in the aft of the motor, substantial reduction in oscillation amplitudes could be achieved. Specific suggested design improvements will be experimentally assessed by the Ares project. Introduction of the most successful modifications will be evaluated as a potential upgrade in the future.

Lessons Learned: Aerodynamic streamlining principles apply within a rocket combustion chamber in the same manner that they apply in external aerodynamics. By applying aerodynamic streamlining principles inside rocket combustion chambers, the dynamic stability of the motor can be substantially improved.

Exploration

Review of the Launch Abort System Motor Qualification Plan

Problem: The Launch Abort System (LAS) system for Orion includes three new design solid rocket motors (SRM). The supplier team has baselined a qualification program for the three SRMs (Abort Motor, Attitude Control Motor, and Jettison Motor) while the government propulsion engineering team proposed a larger, more comprehensive set of qualification tests. To implement the larger qualification test matrix would significantly impact the baselined LAS qualification program. The LAS Project Office asked the NESC to conduct an independent assessment and provide a recommendation as to what is required to qualify the three LAS SRMs.

NESC Contribution: The NESC formed an independent review team of experienced engineers, including industry experts, consultants, and retired NASA personnel to conduct this assessment. Both the supplier and Government LAS teams provided data for their approaches to LAS SRM qualification and their rationale showing the logic for their approaches to qualify the motors for human space flight application.

The NASA and Orion industry team conducted a successful test firing of the LAS abort motor.

Results: The NESC team conditionally agreed that the qualification plan as proposed by the motor suppliers for LAS can provide adequate demonstration that the motor designs are robust and have sufficient margins. A list of 10 conditions was supplied as part of the report. Included in these conditions was that all design and performance requirements must be verified as a part of the formal qualification program by a combination of tests and analyses, and that design and manufacturing processes should be mature at the beginning of full scale qualification motor testing. It was also noted that effective, clear, and timely communication must occur between the motor suppliers and the government engineering team.

A minority view was expressed on the NESC team that the baselined motor qualification plans are not acceptable and that it is improbable that there will be sufficient data necessary to establish that the motors meet all the key requirements at the end of the proposed qualification program. One of the premises of this perspective is that the LAS motor's design departs significantly from previous configurations.

Ares I-X Upper Stage Simulator Project Independent Structural Review

Problem: The NESC was requested to perform an independent review of structural design calculations and modeling of the Ares I-X Upper Stage Simulator (USS) and report any recommendations associated with the design methodology or structural integrity, including any need for additional mechanical testing.

NESC Contribution: The NESC team consisted of the NASA Technical Fellow for Loads and Dynamics, the NASA Technical Fellow for Structures, and experts from MSFC, ATA Engineering, Quartus Engineering, and Applied Structural Dynamics.

Results: The NESC team found that the USS Project stress analyses were conservative and robust, followed industry accepted methods, and provided high margins of safety via the structural design. Finite Element Model (FEM) development was generally good, utilizing industry accepted methods. Concerns with the use of linear triangular elements were mitigated due to high margins of safety provided by the structural design. Some minor issues were identified and addressed by the USS Project. Adequate capability of the segment-to-segment bolted joints was demonstrated by test and analysis, with adequate "as-designed" margins of safety. Final "as-built margins" following flange machining to reduce gapping were not available for review. Existing design and analysis for other structure and joints was found adequate for proposing use of "no-test" factors of safety.

Lesson Learned: Consistent application of FEM best practice techniques within an organization can be improved by training, mentoring, and internal peer review.

Ares I-X illustration

Exploration

NGC

Apollo and Shuttle veteran T.K. Mattingly and Karrie Trauth, Northrop Grumman, discuss large scale composite structure fabrication.

Calspan

Resident Engineer Geminesse Dorsey prepares an eight percent scale model of the MLAS fairing for wind tunnel testing at the Calspan facility.

Max Launch Abort System Risk Mitigation Project

Problem: The launch abort system (LAS) for the Orion crew exploration vehicle will provide a means of automatically separating the crew module from the launch vehicle in the case of emergency while on the launch pad through ascent to orbit. As a risk mitigation effort for the technical development of the Orion launch abort system, the then Associate Administrator for the Exploration Systems Mission Directorate requested the NESC design, build, and test an alternative concept independent of the project development.

NESC Contribution: The Max Launch Abort System (MLAS), named after Maxime (Max) Faget, a Mercury-era pioneer, will be theoretically capable of extracting the CEV from the launch vehicle at any time from crew ingress at the launch pad through staging and successful ignition of the second or upper stage of the Crew Launch Vehicle (CLV). The MLAS Flight Test will culminate with at least one full-scale unmanned pad abort test to demonstrate the viability of this alternate concept. In order to be timely and relevant to the Constellation Program, the NESC was challenged to complete this first flight test in parallel with the Orion LAS Pad Abort Test 1.

The MLAS flight test vehicle is designed to lift the crew module (CM) simulator from the launch pad to an altitude high enough and with enough distance downrange to allow the CM to execute a nominal landing. The MLAS pad abort flight test will demonstrate a passively controlled coast phase, reorientation and extraction of a CM simulator from the fairing. The test will also include a landing parachute demonstration of an alternative landing system configuration for CM recovery.

The MLAS team is comprised of over 150 engineers, researchers and analysts from across the Agency and industry. NESC has partnered with the Wallops Flight Facility for the pad abort test to leverage both their launch range and sounding rocket development expertise. To minimize the development and manufacturing time, the MLAS team is employing existing technology and off-the-shelf hardware to the greatest extent possible. The full-scale composite fairing is being manufactured by Northrop Grumman Ship Systems in Gulfport, Mississippi. The four MK-70 solid rocket motors are surplus US Navy motors obtained from the Wallops sounding rocket inventory.

As a resident engineer, meeting and working with people from the entire NASA Agency has been an interesting learning experience. The One NASA concept is alive and well on the MLAS Team!

—Terrian Nowden, MLAS Resident Engineer, GRC

The MLAS team has also capitalized on an opportunity to share lessons-learned and pass on corporate knowledge by bringing Apollo-era veterans as mentors and advisors together with junior engineers with 5-10 years of experience. The mentors have provided the MLAS team with first-hand knowledge acquired while building a human-rated spacecraft. The junior engineers, referred to as Resident Engineers based on the concept of medical residencies, are getting hands-on experience with the entire design, build and test life cycle. The multi-generational nature of the team has been rewarding and enriching for all involved and is helping to meet the goal of expanding NASA's experience base in fast turnaround design and development projects.

Exploration

Technicians prepare the forward fairing nose ring for installation.

The full scale Orion Crew Module simulator being prepared for mass properties measurements.

MLAS major structural components

One quarter of the composite forward fairing being lifted in the Wallops Payload Processing Facility.

Photos and graphic/NASA

Technicians install an inert separation joint in the bottom of the Coast Skirt.

Wind tunnel testing of the Orion Crew Module separating from the MLAS forward fairing.

Univ. of Washington

On Multi-Center Teams:

My membership on the Materials TDT has provided me the opportunity to work with many people at the space flight Centers... Often the space flight Centers don't understand the value of research Centers until our unique capabilities solve their real problems.

– Brian Jensen, Senior Researcher for Advanced Materials, LaRC, Materials TDT

Exploration

New Shell Buckling Test Facility at MSFC used for testing 8-ft-diameter cylinders subjected to combined compression, bending and internal pressure.

Updating of Launch Vehicle Shell Buckling Knockdown Factors

Problem: The NESC Shell Buckling Knockdown Factor Project (SBKF) was established in March 2007 to develop and validate new analysis-based shell buckling design factors (a.k.a. knockdown factors) for Ares I and Ares V metallic and composite launch vehicle structures. Improved, i.e., 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.

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 and the first series of large-scale buckling test articles, programmatic and technical support, peer reviews, and advocacy. In addition, the NESC has helped coordinate activities between LaRC and MSFC, the two primary centers involved in this project, and has enabled an efficient working relationship between the Centers.

Dr. Mark Hilburger (left) and Dr. Robert Thornburgh (right), structures engineers from LaRC, monitor test data during the shell buckling test at MSFC.

Results: In FY08, the SBKF project designed and fabricated a new test facility to test 8-ft-diameter cylindrical shell structures subjected to combined axial compression and bending. Two 8-ft-diameter, 2195 Aluminum-Lithium (Al-Li) orthogrid cylinder test articles have also been designed and fabricated. The first test article was successfully tested in November 2008 and the second article will be tested in January 2009. Sub-component tests of 2195 Al-Li orthogrid stiffened panels are being conducted at LaRC to investigate local skin pocket buckling and stiffener crippling behavior. This test data is being used to assess the current design approaches for these structural details and validate new high-fidelity numerical simulations of common Ares-like structural details.

Exploration

ATK

(Foreground) The lower shell cured inner skin on the lower shell cure tool. (Background) Aluminum honeycomb core on the upper pressure shell following the core tack cycle at the ATK factory in Iuka, MS.

Composite Crew Module Pressure Vessel Pathfinder Development

Problem: In 2006, the NESC studied the feasibility of a (primary structure) composite crew module for the Constellation Program Crew Exploration Vehicle. The overall finding indicated a composite crew module was feasible, but a detailed design would be necessary to quantify technical characteristics, particularly in the areas of mass and manufacturability. Subsequently the NASA Administrator, Associate Administrator for the Exploration Systems Mission Directorate, and the Constellation Program Manager chartered the NESC to design, build, and test a composite crew module structural test article with the goal of developing a network of Agency engineers with hands-on experience using structural composites on complex habitable spacecraft design. The NESC Composite Crew Module (CCM) Project was chartered in January of 2007, with a goal of delivering a full-scale test article for structural testing 18 months after project initiation.

NESC Contribution: Led by the NESC, the project team is a partnership between NASA and industry, which includes design, manufacturing, and tooling expertise. Partners include civil servants from ARC, DFRC, GRC, GSFC, JSC, JPL, KSC, LaRC, MSFC, the Air Force Research Laboratories, and contractors from Alcore, Alliant Techsystems, Bally Ribbon Mills, Collier Corporation, Genesis Engineering, Janicki Industries, Lockheed Martin, and Northrop Grumman.

The composite crew module team operates in a virtual environment, electronically 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 constraints that utilize a backbone for securing internal components. The team evaluated design solutions and focused on a design that utilizes aluminum honeycomb sandwich and solid polymer matrix laminate material systems. One unique feature of the composite crew module design was the structural integration of the packaging backbone with the floor and pressure shell walls. This provides a load path that accommodates load sharing with the heatshield, especially for water landing load cases. Another unique feature of the composite design is the use of lobes between the webs of the backbone. This feature puts the floor into a membrane type loading resulting in a lower mass solution. Connecting the floor to the backbone and placing lobes into the floor resulted in mass savings of approximately 150 pounds to the overall primary structure design.

Exploration

Janicki Industries

(Far Left) Dr. Dan Polis (on floor), CCM Materials lead, GSFC, and Mike Kirsch, NESC (on ladder), installing pre-preg carbon fiber fabric ply on the inner mold line skin.

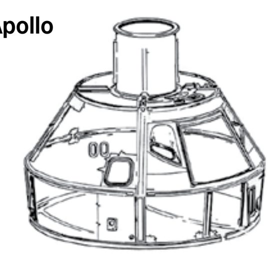
(Left) A tool proof of the upper pressure shell is extracted at the tooling vendor, Janicki Industries in Sedro-Woolley, WA. The tool proof was created to validate that the tool draft angle was sufficient to extract the part.

The design is constructed in two major components: an upper and lower pressure shell. The two halves are joined in a process external to the autoclave to enable subsystem packaging of large or complex subsystems. The initial and preliminary design concepts were reviewed by an independent review panel in March and June 2007. The team conducted building block testing of critical design and technology areas, which were used to validate critical assumptions and design allowables for the final design. The detailed design was reviewed and approved in December 2007 by an independent review panel. Full-scale fabrication of the upper and lower pressure shells began in February 2008, and post-cure assembly operations started in late May. The project plan is to statically test the combined upper and lower shell assembly to verify that the analysis models predict the response of the structure under load, and then repeat the static tests with internal pressure up to 30 psi. Testing is scheduled to occur at LaRC in March 2009.

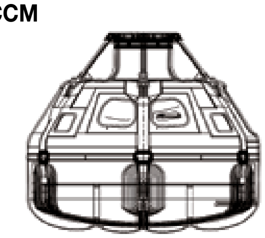
Results: In September 2008, the Orion project was asked to evaluate the implications of adapting a composite crew module in the baseline Orion design. A tiger team was formed between Orion and the NESC composite crew module team to evaluate opportunities and challenges. At this stage of the overall Orion vehicle design, the composite crew module does not appear to offer significant mass or unit cost savings because of the complex nature of its design. It also posed a significant threat to the Orion schedule because of the manufacturing changes required by composite versus metallic materials. However, because of the advantages of the split clam shell design found on the composite crew module, Orion is considering adopting this approach for their aluminum-lithium configuration.

Lessons Learned: Design lessons show that 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 backbone subsystem packaging feature offers a weight savings. 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 design through tailoring of layups or core density. Composite solutions offer opportunity for lower piece-part numbers resulting in a lower drawing count which helps minimize overall life cycle costs. Also, a minimal number of tools are required to manufacture the primary structure. Thermal and dynamic property differences from aluminum are under investigation; however, preliminary estimates do not indicate that composites create system level issues.

Apollo



CCM

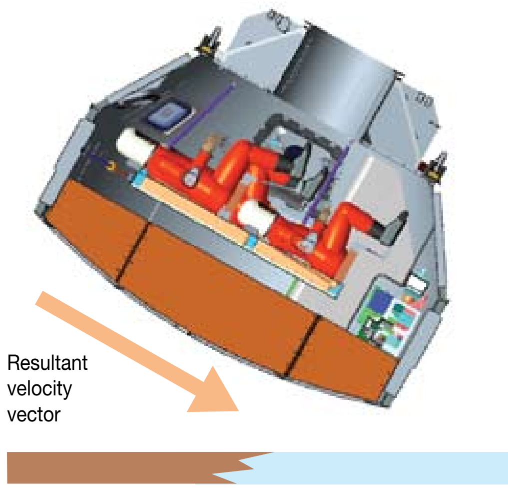


Illustrations of the Apollo and CCM pressure vessels.

Exploration

Improved Crew Seat Attenuation Designs for the Orion Crew Module

Problem: The Orion Project requested alternate seat attenuation designs to be developed and analyzed for the Crew Module (CM) with primary emphasis to provide improved crew survivability for nominal water and Contingency Land Landing (CLL). The NESC was later asked to evaluate crew seat design options to reduce the effects of the Ares thrust oscillations problem and its effect on landing loads.



The NESC worked to improve impact attenuation in the Z-axis (along the spine) of Orion crew members.

NESC Contributions: The assessment team consisted of designers and analysts from multiple NASA centers including GSFC, JSC, JPL and LaRC, contractors, academia, NASCAR seat design experts and engineers from the Apollo era with design and test experience on its landing systems. Prior to developing alternate concepts, assessment members had the opportunity to evaluate the seat attenuation systems in the Apollo XVII Command Module, and in mockups of the Soyuz and Orion CM.

Results: The Orion baseline crew seats are located on a rigid pallet, which is suspended in the volume of the CM by load attenuating struts. The struts attenuate the loads to the crew when the pallet is accelerated in response to an external force applied to the CM. An Orion landing (water or land) orients the CM such that the reclined crew impacts the earth's surface "feet first", resulting in a major force vector along the axis of the crew's spine. Analysis performed by NESC members assisting with finite element modeling of Orion occupant injuries found that improving the lateral restraint of the crew as well as holding the crew tighter in a conformal seat reduced injury risk. An NESC seat design expert developed and tested mockups of improved harnessing techniques to achieve these results.

NESC team member Pete Rossoni performs a fit check in an Orion seat mock-up at JSC.

The team focused detailed design and analysis effort on investigating the effectiveness of incorporating an isolation system between the seat pallet and the CEV pressure vessel structure. Two concepts 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 seat attenuation models to examine a range of pallet isolation properties for crew landing attenuation. This led to a request from the Orion Project to examine mitigating the effects of Thrust Oscillation (TO) from the Ares stage 1 solid rocket booster on the crew using isolation concepts. Coupled loads models for launch and landing models were used to examine the optimal TO isolation frequency that would minimize crew loads during all phases of the Orion flight. Hardware design concepts for implementation of this feature have been generated and specific recommendations for the baseline seat system such as the shoulder harness attach point were also developed. Isolation system models showed reduction in the impact acceleration forces experienced by the seat occupant in all three axes for most load cases over the Orion baseline design by reducing the dynamic amplification portion of the load for crew response in the axis along the crew spine.

The NESC team is planning to evaluate smart materials and active systems to improve the strut performance over the baseline. Results from the TO study confirmed the optimal crew isolation frequency of 4.5Hz and revealed a potential problem with a rocking mode of the crew seat should isolation be implemented at that location. The 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.

Improving Orion Crew Impact Tolerance Modeling

Problem: Reliable injury predictive tools and injury criteria are required for protecting Orion crew members during water and land landings. 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 Orion requires modification and study.

NESC Contribution: The NESC is supporting the Orion Project's investigation in the use of crash test dummies for assessing injury risk for the Orion crew. The study objective is to better predict loads on the crew during water and land landings. Results from finite element math models and physical sled tests with the dummies are being compared to the whole body injury models commonly referred to as the Brinkley criteria, which have been typically used for aerospace applications. The crash dummy 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. This information will be used to understand trends in occupant protection and to define acceptable injury criteria associated with seat restraint and attenuation systems. An accurate crew injury tolerance model would allow any changes to the Orion structure, seat attenuation system and landing conditions to be examined for its safety effects on the crew.

Results: While this work is ongoing, results thus far indicate the crash test dummies used in conjunction with the Brinkley criteria provide a useful set of tools for predicting and eliminating potential crew injuries. The finite element math 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.

Finite Element Hybrid III crash test dummy models represent the Orion crew members. Dr. Charles Lawrence, GRC, (right) developed this integrated model of the Orion crew module and seat attenuation system.

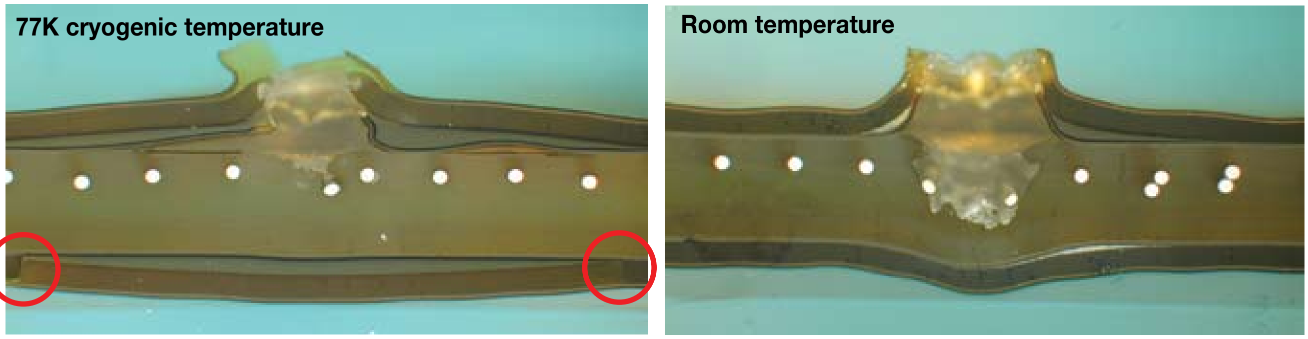
MLAS team members lower the Crew Module Simulator into a mass properties measurement fixture.

Developing professional relationships:

...by working with people outside your normal sphere of influence, you meet individuals who are able to challenge you and who help bring out the best in you… and vice versa. A mutually beneficial relationship develops, the projects become more exciting, and the quality of work is superbly better than the sum of what the individuals could have produced.”

– Dawn Phillips, MSFC, Structures TDT

Science



Optical cross-section at 30X of ribbon cable harness after High Velocity Impact testing. Harness was impacted by a 0.20mm diameter Sodium-Lime-Glass projectile at 6.92 km/s at 0˚ impact angle. The impact in left image was at a cryogenic temperature and indicates damage of lesser depth but includes cracks marked by red circles compared to room temperature impact on right.

Hypervelocity Particle Impact Resistance of JWST Electrical Cables

Problem: The James Webb Space Telescope (JWST) uses a series of fine gauge wires and cables to interconnect the cryogenically operated (35K) optics and detectors to the warmer (~300K) electronics of the Integrated Science Module (ISIM). It was proposed that these cables, which are exposed to direct meteoroid flux in the Earth-Moon L2 environment, can be damaged by the meteoroids.

NESC Contribution: The NESC conducted an independent study of the cryogenic cable harnesses vulnerability and shielding requirements for the ISIM. Hypervelocity impact (HVI) tests were conducted that provided data on particle size/energy at the failure threshold for the ISIM's exposed cables, and evaluated shielding options to protect the ISIM cable harnesses from meteoroid impact damage.

Results: The harness exposure, spacecraft orbit, and meteoroid environment as well as harness impact testing results were combined to predict the probability of ISIM mission success. This mission success prediction was then compared to the mission success requirement to define the necessary meteoroid shielding. The historical approach to meteoroid protection was also reviewed. One unexpected result found during testing was a large deviation between damage predictions and test results. Damage was estimated from the extrapolation of an analytical damage equation — valid for aluminum shields — to shields of different metals and compared with the test results. The extrapolated damage equation predicted better shield performance than the tests showed. The effects of cryogenic temperature were assessed on harness damage tolerance. The results showed that ambient temperature impact testing was adequate because less damage was seen at cryogenic temperatures. To cool the test articles in the vacuum chamber of the test range, an enclosure was built to insulate against convection, conduction, and radiation. A pressure system delivered cryogenic gas to the enclosure. One result was that the conductors within the ribbon cable assembly (silver-colored spheres in the cross-section above) apparently moved during impact, and thereby sustained less damage than had been expected for these types of impacts which did not fully penetrate or pass through the harness. HVI testing was also performed to study the contamination potential from micrometeoroid impact on the Aft Optics Assembly (AOA) light enclosures from debris generated by penetrations through the enclosures.

WSTF

Dennis Garcia, WSTF (right) uses a mirror to view inside the JWST cryogenic box to verify impact on target. Paul Mirabal, WSTF (left) verifies projectile integrity post test on the high speed imaging system.

Science

Risk Assessment of Kepler Reaction Wheel Premature Failure

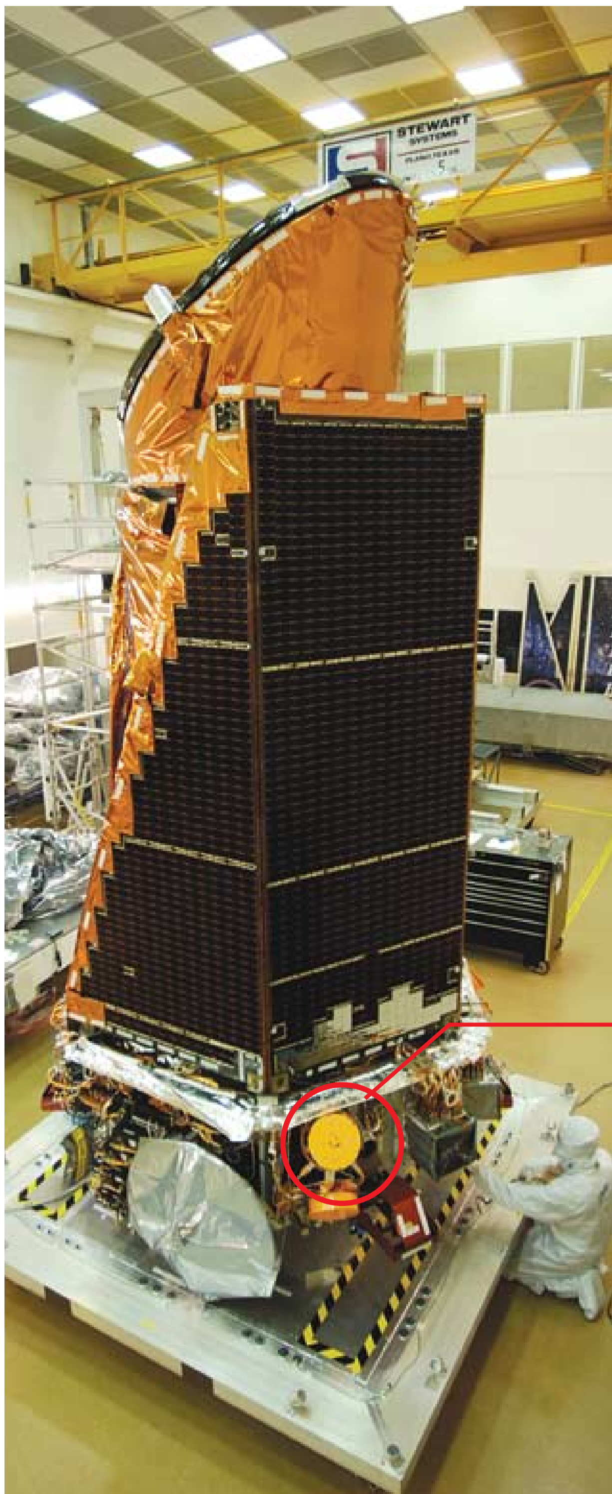
Problem: One of the Reaction Wheel Assemblies (RWA) that is used to provide attitude control authority and stability on the Thermosphere, Ionosphere, Mesosphere Energetics and Dynamics (TIMED) spacecraft, failed in February, 2007 after five years of continuous operation on orbit. Four RWAs of similar design have failed after two and a half years operation on two other spacecraft. The RWAs on the Kepler spacecraft, due to launch in early 2009, are identical to the TIMED RWAs. Based on the results of a Jet Propulsion Laboratory (JPL) failure investigation, the Kepler Project directed that design changes and corrective measures be implemented in the RWAs. Because the modifications were limited to minimize the overall impact to the Kepler mission, the NESC was asked to assess the risk to success of the Kepler mission from a RWA failure, given the history of flight failures and the limited modifications being implemented.

NESC Contribution: A multi-discipline, multi-Center team was formed by the NESC that included mechanism and tribology experts from GSFC, JPL and LaRC as well as Industry consultants. The assessment of RWA anomalies and associated risk to the Kepler project was broken into two parts. The first was an evaluation of the mechanism design and its ability to meet project life requirements. The second was an evaluation of the wheel usage.

To evaluate the mechanism design, the NESC team performed analyses and tests and also used data that was available from other NASA tiger teams involved with this issue. A Ball Speed Variation analysis was performed on the RWA bearings to assess the effects of misalignment. The team also evaluated the change in bearing lubricant film thickness as a function of rotational speed and operational temperature. The results of these tests and analyses fed into the short term and long term recommendations for the unit.

The NESC team also reviewed operational strategies for use of the Attitude Control System (ACS) with the Kepler Chief Engineer and the lead ACS engineer at the prime contractor. The strategies would maximize RWA life by minimizing the total number of RWA revolutions. Several operational recommendations previously not considered by the project resulted from these discussions and analyses.

Results: The direct results of this assessment warranted both in process and post assembly inspections and tests to reduce project risk. Ultimately, it was determined that the robustness of the ACS system (due to RWA redundancy) results in a low level of risk to meeting the project's minimum mission objectives. The NESC team's contributions provided the Kepler Project Management the data required for their overall mission performance assessments and on orbit operational suggestions should an anomaly occur with two RWA units.



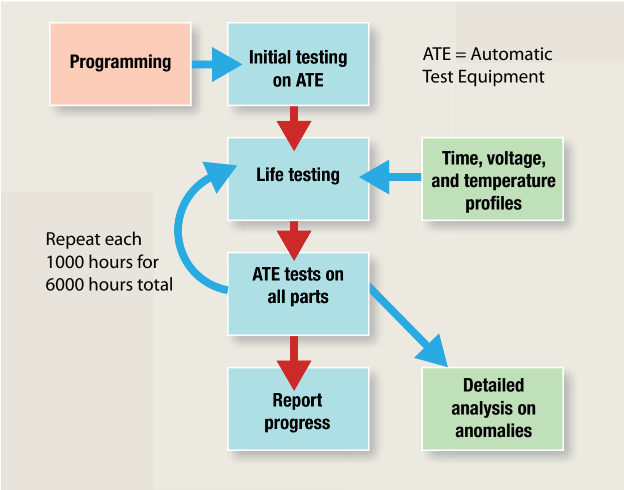
(Left) Kepler spacecraft showing the location of two of the four Reaction Wheel Assemblies. A reaction wheel is shown (above).

General

RTAX Risk Mitigation Testing

Problem: Multiple projects across the Agency strongly desire to use the latest RTAX-S series Field Programmable Gate Arrays (FPGAs). These parts offer significant advantages over the use of the previous version RTSX-S or –SU regarding maintenance of signal integrity, capacity, capability, speed, and electrostatic discharge (ESD) tolerance. Reported user 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. These concerns were not a result of the part performing in a clear failure mode condition, but rather a result of user application issues combined with unknown limitations of the original –S part with regard to marginal programmed antifuses. It is desired to avoid a similar late discovery of issues for the latest RTAX-S FPGAs.

NESC Contribution: The NESC is conducting a test of 80 units (2 lots) of RTAX250S and 80 units (2 lots) of RTAX2000S programmed with an algorithm designed to emulate expected space flight applications. The test will subject the parts to the voltage specification limit and to the temperature specification limit conditions. The selected representative space flight designs include multiple copies of a Military Specification 1553 Remote Terminal interface, an 8-bit micro-processor (PIC 16F84), an error detection and correction algorithm, a memory controller, and a Universal Asynchronous Receiver/Transmitter.



RTAX250S FPGA and RTAX2000S FPGA Test Plan.

Results: The test was started in the second quarter of Calendar Year 2008 and is expected to be finished in the first quarter of Calendar Year 2009. The parts have passed the 1000 hour point of a planned 6000 hour test. Preliminary results have indicated no major issue at this time.

Entry, Descent, and Landing Data Repository and Analyses Task

Problem: NASA and the Entry, Descent, and Landing (EDL) community lack a common repository of EDL data from previous Earth and planetary flight missions to aid in the design of future EDL systems. Recent missions to Mars will provide a wealth of information, however, much of the older data has been lost or is at risk of being unusable due to poor storage conditions. Some examples are: Viking EDL data and Viking design data (parachute tests); Planetary Atmosphere Entry Tests (from Wallops and Ames); Pioneer Venus (EDL); Galileo (ED); Magellan (aero-braking data); Project Fire (Apollo design and test data for re-entry); and Shuttle EDL test data.

NESC Contribution: The NESC EDL Repository team is focusing on two aspects: (1) to locate, collect, and digitize NASA technical and engineering EDL material, and (2) to develop a secure, web-based repository (EDL-R). It is password-protected and requires user-authorization for sensitive documents. EDL-R has browse and search capabilities, email notification of new material, and will follow a strict Submit, Review, and Release life cycle.

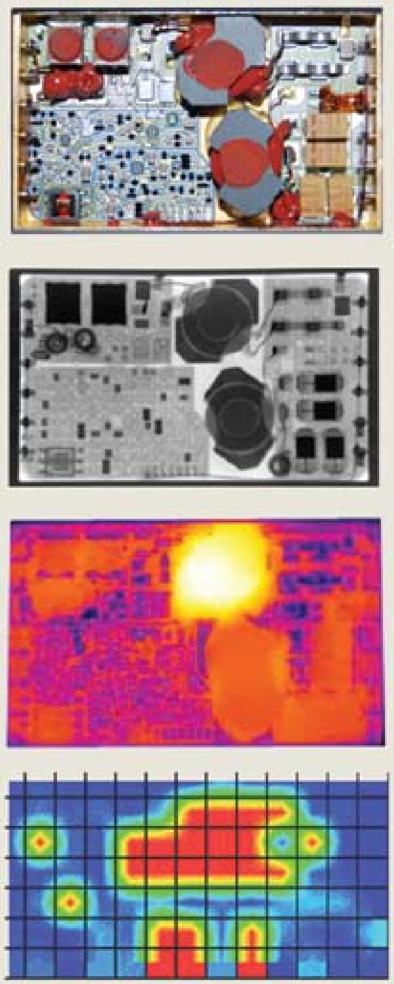
Illustration of Mars Exploration Rover entry.

Results: Beta testing of EDL-R was completed in February 2008. Since then selected users from NASA and academia have used it to archive material. In addition to continued data addition, the remaining work includes documentation (user guide, curator guide, etc.), and the implementation of some features such as Browse-by-Mission, Virus Check, etc. It is anticipated that the full system will be fielded in FY 09, and transferred to a NASA-selected Center for continued growth and maintenance.

General

Development of DC/DC Converter Application Guidelines

Problem: Hybridized DC/DC converters are ubiquitous in flight hardware designs, forming an important bridge between the spacecraft power bus and localized users of power within instruments and other electronic subsystems. These parts are actually complex micro-systems containing the same types of elements that one would expect to see on a printed circuit board except all within a 12 inch^2 package. For many years they have been found to inconsistently meet performance and quality requirements and to fail catastrophically in flight hardware. The complexity and cost of these parts can have a severe impact on program schedule and budget when a failure occurs or can be mission-ending if the failure occurs in flight. Hybrid DC/DC converter flight failures have been demonstrated or have been suspected on several projects including GRACE, Hubble Space Telescope, and the International Space Station. In addition, numerous flight projects, both manned and unmanned, have had severe pre-launch cost and schedule impacts due to hybrid DC/DC converter quality and application issues. It is well established within NASA that there is difficulty with converter specifications and how that data can be interpreted and used.



Test images of a typical hybrid DC/DC converter: (top to bottom) cover removed, X-ray, thermal under load, and electron microscope at 24 MHz.

NESC Contribution: The NASA Engineering and Safety Center (NESC) funded the development of a guidelines document to capture the knowledge that projects seem to constantly re-learn about DC/DC converters, particularly converters of hybrid microelectronics technology. Testing of several types of DC/DC converters was conducted to develop a standard set of test approaches and procedures for flight projects to use. This testing explored the operation of DC/DC converters at different conditions (thermal, power levels, etc.) to show where problems typically can be expected. The vendors were consulted regarding datasheet improvements that provide additional types of information important to projects. Standard tests, test procedures, sample datasheets, etc. were developed and are included in the guidelines document.

The guidelines document also covers a broad spectrum of general information including applications overview, mission environments, performance requirements, design practices, test methods, hybrid packaging and elements, quality levels, vendor-contract-related topics, and handling and installation precautions. The guidelines document also contains appendices on DC/DC converter usage by project and failure history in NASA hardware, a DC/DC converter specification template, boilerplates for contract documents, and a checklist for implementing this guidelines document for a flight project. These can be used by projects to get a jump start on their planned usage of DC/DC converters while eliminating many of the typical problems that are often encountered.

Results: The document provides a practical set of guidelines for characterization, selection, purchase, and application of hybridized DC/DC converters in NASA flight hardware to prevent or mitigate failures and risks in the field. The document describes practices that should be integrated into the following local processes: electrical system design and validation, electrical circuit design, thermal and packaging design, device characterization and evaluation, device qualification, device selection, and device procurement and acceptance testing. The recommendations and guidelines directly address a history of problems NASA has encountered with this device type. The document is meant to be used as a guideline; it is not mandatory and is not intended to be invoked as a requirements document by NASA Centers. Several current projects have already started using this information.

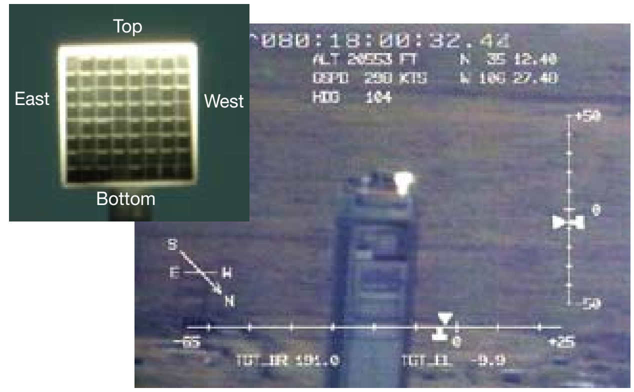
Lessons Learned: A NASA website has been developed to track the usage of converters as well as any failures. These data will be used to ensure the lessons-learned are communicated across NASA Centers, as well as being added to the Lessons Learned Information System (LLIS).

General

HYTHIRM Validation and Calibration Testing Demonstration

Problem: Predicting aeroheating of complex surfaces during hypersonic entry into an atmosphere is complex, driven by uncertainties in both boundary layer transition (BLT) onset and subsequent turbulent heating. The inability to accurately predict these phenomena with numerical turbulence models can impose unnecessarily large thermal protection system margins that translate to reduced payload capability and degraded mission performance. Global temperature infrared (IR) images with adequate spatial resolution and dynamic range could non-intrusively complement thermocouple data by providing spatially continuous surface temperatures at targeted Mach numbers.

NESC Contribution: The HYpersonic AeroTHermodynamic InfraRed Measurements (HYTHIRM) team, established by the NESC, undertook a field deployment to perform radiometric calibration and validation of the nation's existing suite of land-based and airborne IR imaging assets and tools for remote thermographic imaging. The test subject was a Shuttle tile array heated to surface temperatures typical of a Shuttle re-entry. The Sandia National Laboratory's National Solar Thermal Test Facility in Albuquerque, NM, was used to aim an intense solar beam at a 4 ft x 4 ft panel of 64 Shuttle LI-900 ceramic tiles located on top of a 200-ft high tower (right). Thermocouples installed on the array and an IR imager located in close proximity to the test target provided actual surface temperature conditions.



Cast Glance aircraft IR image of the Shuttle tile array heated by the solar collectors. (Inset) Image of non-uniform, top-to-bottom, heating of Shuttle tiles with temperatures ranging from 2000 °F to 500 °F.

Results: The HYTHIRM systems were successfully calibrated and analysis of the imagery was used to evaluate the performance of the IR imaging assets. The team demonstrated the viability of obtaining surface temperature measurements of hypersonic flight vehicles, and more specifically, to reliably acquire, track and return surface temperatures of the Orbiter during entry aero-heating and provide flight BLT thermography data. These data could be utilized for calibration and validation of empirical and theoretical aero-heating tools.

NESC Data Mining and Trending Working Group (DMTWG)

Problem: The NESC is leading an Agency level Data Mining and Trending Working Group whose purpose is to assist in the formulation and implementation of a 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. The NESC's collaboration with other organizations has enabled cross pollination of ideas, particularly regarding methodology and lessons learned.

NESC Contribution: The DMTWG is assisting NASA organizations in strengthening trending activities for the Agency's programs and projects. This is being accomplished in part by developing a data mining toolbox including tools such as the commercial data mining software, SAS. The team is also aiding 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 provides a forum to enhance communications across the Agency in the areas of data mining, trending, and statistics by sharing ideas, methods, technologies, processes, tools, and lessons learned.

USA

Delmar Foster, Senior Analyst for United Space Alliance, performs data mining using SAS Enterprise and Text Miner software.

General

Probabilistic Requirements Verification

Problem: Probabilistic requirements — those which include quantifiable uncertainty — occur in significant numbers in Constellation Program (CxP) requirements documents. Verification has sometimes been confusing or difficult for requirements owners and verifiers. A team was commissioned by the Constellation Chief Engineers Forum (CxCEF) to provide guidance for generating verifications with probability and confidence for both Monte Carlo analysis and all other applicable areas.

Dr. K. Preston White (Left), University of Virginia, a key member of the probabilistic requirements verification team.

NESC Contribution: The NESC provided expertise to the CxCEF team in statistics and probabilistic risk assessment (PRA) from several NASA Centers and academia through its Systems Engineering Technical Discipline Team's NESC Engineering Statistics Team (NEST).

Results: A pair of broadly-applicable templates modeling verification statements applicable to both probabilistic Safety, Reliability and Quality Assurance (PRA-type) and engineering performance requirements. The templates include: a "six-step" best-practice process for ensuring that verification is truly achieved; a tutorial glossary aimed at standardizing terms and explaining statistical concepts in engineering language; and a method for predicting the number of simulation trials necessary to prove verification of engineering performance requirements to the required risk level. For the NESC team, post delivery follow-up has been proven vital. Team members continue to supply consulting services to CxP users on applying the recommendations. In return, the team is learning how its recommendations could be extended to other programs.

Flight Battery Working Group Update

Problem: Batteries are used in virtually every space mission and the differences in the application, duration, and operations result in the use of a large array of batteries and, therefore, battery issues. In the past there has been no coordinated NASA-wide approach to the common issues. The large array of issues include: exceeding the recommended wet life prior to launch, recognizing cell degradation signatures, and understanding the features and limitations.

NESC Contribution: In 2006 the NESC chartered the NASA Aerospace Battery Working Group to carry out a series of tasks based on Agency-wide issues related to aerospace batteries. Studies were performed, issues were discussed, and test programs were executed in the generation of a series of recommendations and guidelines to reduce risk associated with various aspects of implementing battery technology in the aerospace industry. Over the past year, the working group, comprised of representatives from NASA Centers including GRC, JSC, GSFC, MSFC and JPL addressed (among others) the following technology areas: Recommendations for Binding Procurements of Battery Systems; Wet Life of Nickel-Hydrogen (Ni-H2) Batteries; Generic Safety, Handling and Qualification Recommendations and Guidelines for Lithium-Ion (Li-Ion) Batteries; Generation of a Guidelines Document that addresses Safety and Handling and Qualification of Li-Ion Batteries.

Li-Ion spacesuit pouch cell.

Results: The working group published a report entitled "Generic Safety, Handling and Qualification Recommendations and Guidelines for Lithium-Ion (Li-Ion) Batteries." The document provides a summary of aerospace Li-Ion battery performance, guidance for the selection, design, operation and qualification of Li-Ion batteries, and specific guidance related to the use of pouch cells, commercial 18650 cells in high capacity, high voltage series/parallel strings, and recommendations for defining safe operational conditions for Li-Ion batteries.

Space Operations

Investigation of ISS Solar Alpha Rotary Joint Issue

Problem: As a result of high current, auto-tracking of the starboard Solar Alpha Rotary Joint (SARJ) was halted in 2007. The SARJ is a circular component that allows the truss to rotate to keep the solar arrays pointed at the sun. Inspection of the starboard SARJ revealed severe damage to the outer steel race with large quantities of magnetized debris present on both the race ring and trundle bearing assembly (TBA). The NESC was asked to support the International Space Station (ISS) Program anomaly root cause investigation team.

NESC Contribution: NESC Mechanical Systems Technical Discipline Team (TDT) members and gear and tribology experts from GRC, GSFC and MSFC reviewed SARJ build records, consulted on lubrication solutions, and provided testing of root causes. NESC members inspected the SARJ static test article and TBA returned from orbit, supported vacuum roller traction rig testing at GRC, and block on ring testing at MSFC.

Magnetized debris seen on the SARJ trundle bearing assembly. Twelve trundle bearing assemblies are equally spaced around the circumference of the SARJ and provide precision support and alignment during rotation of the SARJ.

Results: The NESC's efforts provided the necessary data to exonerate potential root causes such as incorrectly installed TBA rollers and led to the discovery that gold plating adhesion was an issue on several TBAs during the initial build. Further investigation revealed that the gold adhesion issue might be a distinguishing characteristic between the current nominal operations of the ISS port SARJ versus the anomalous starboard SARJ. The team validated their hypotheses with laboratory testing which resulted in physical proof of the low friction benefit of gold surfaces. The ISS Program anomaly investigation team has adopted this as a very likely contributor to the SARJ anomaly and the NESC team continues to support them with the corrective action for short and long-term operations.

Lessons Learned: The report for this assessment is not yet complete and lessons learned are still in process.

Determination of EMU Space Suit Glove Damage Modes

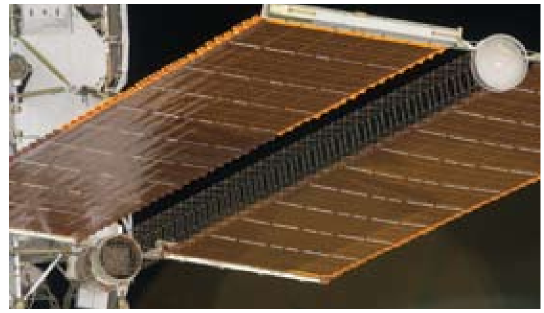
Problem: The number of Extravehicular Mobility Unit (EMU) gloves damaged during extravehicular activities has increased. The NESC is assisting a JSC Materials and Processes team to identify glove damage modes.

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

Close-up of damage in the thumb region on right EMU glove.

Results: Three damage modes were identified, which are likely the result of glove contact with off-nominal surfaces. The first damage mode noted was a linear separation of Vectran™ fabric most likely produced by a press-and-draw motion of the glove over a relatively sharp surface severing multiple yarns along a single path and resulting in a linear shaped hole. At each fabric weave, a higher region or crown of yarn is exposed to rubbing contact with surfaces. The second damage mode, crown abrasion, is a common fabric damage mode and is characterized by severed frayed fiber ends located on each side of the crown and flattened fibers at the center of the crown. Finally, a snag-and-pull damage mode was noted. The loose Vectran™ fabric weave is snagged by contact with an off-nominal surface protrusion. A portion of the snagged yarn is damaged (severed) as the fabric is pulled away from the surface.

Space Operations



(Above) On orbit, the solar array mast extends, retracts, and provides structural support for the solar array panels.

(Left) Mathew Stegman (left) from JPL, Justin Templeton (center), and Dr. Kenny Elliott (on ladder) from LaRC set up the ISS solar array mast in JPL's 25-foot-diameter Space Simulator Facility. The mast was subjected to the extreme temperatures of space to investigate the conditions that cause mast buckling.

Reproduction of ISS Solar Array Mast Shadowing

Problem: Partial shadowing of the 108-foot-long support masts on the International Space Station (ISS) solar arrays can occur. This induces differential heating between the sunlit and the shadowed portions of the mast structure. The resulting thermal strains are predicted to buckle the mast in as little as 30 minutes. The condition was not considered in the original design of the mast. The 30 minute maximum exposure time has added complexity to controlling the solar arrays to avoid failure and raised concerns if attitude control were lost for any considerable period of time. ISS program management requested the NESC conduct an independent assessment of the thermal and structural analyses predicting the failure and its time to effect.

NESC Contribution: The NESC conducted an initial assessment of the analyses and did not find any modeling or analysis assumptions or techniques that could be improved to gain more margin and lengthen the time to mast buckling. However, it was observed that this partial shadowing thermal condition was not tested in the mast's original development or qualification process. As a result the NESC is conducting a ground test program to provide the best possible thermal and structural response data for correlation of the mast models. The NESC contracted with the mast manufacturer to design and fabricate a special instrumented mast test section that was exposed to a simulated space vacuum and solar environment in the JPL's 25-foot diameter Space Simulator facility. The mast was tested in October 2008.

Results: Preliminary test data are being examined. Final test data will be correlated into thermal and structural models of the solar array masts. Predictions of the mast buckling failure load under the partial shadowing condition will be updated. The NESC will work with the ISS Structures and Mechanisms team to recommend appropriate constraints for on-orbit operations.

Solving the Agency's toughest problems:

The NESC model of assembling a team of discipline experts from different NASA centers and companies enables solutions to problems otherwise not solvable.

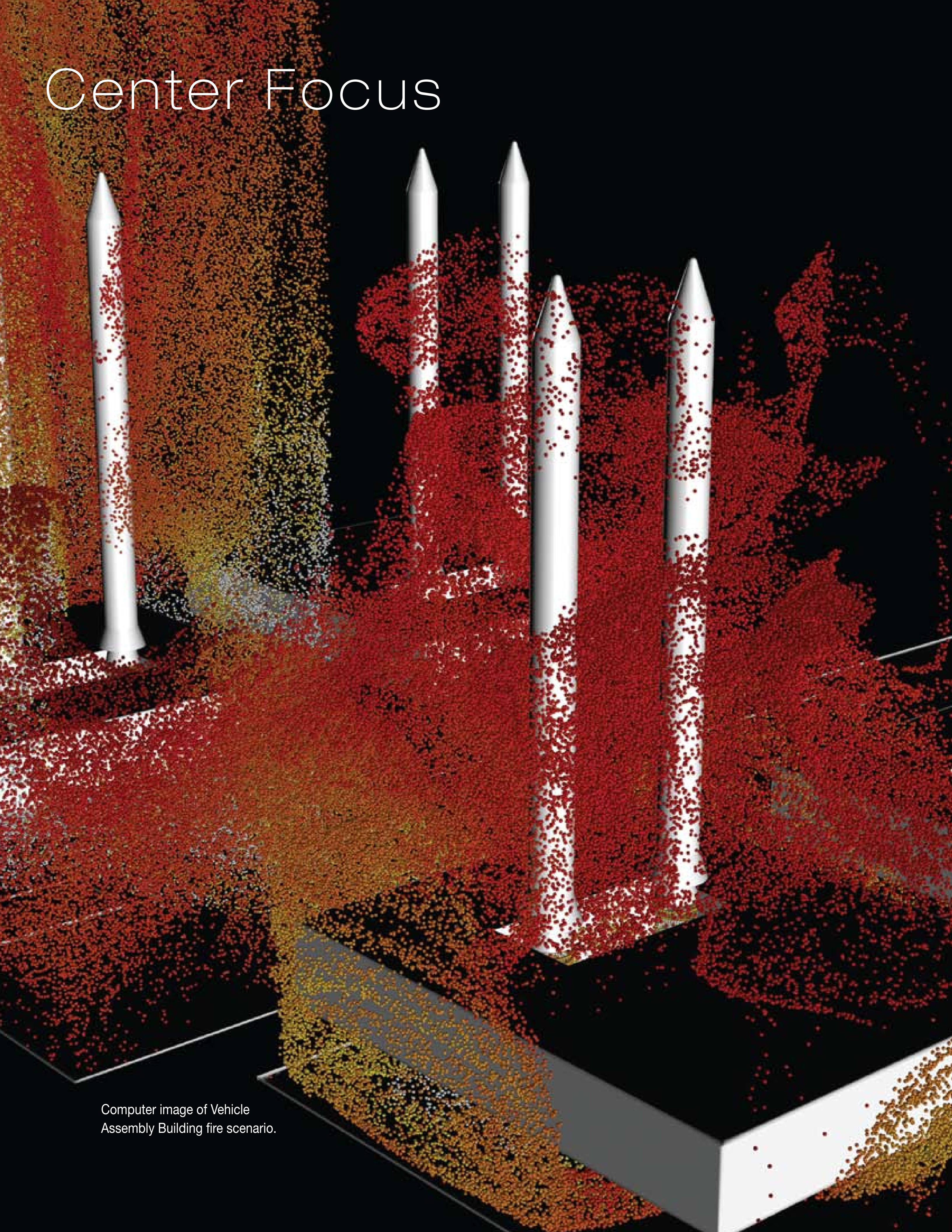
— Don Shockey, Director SRI International Center for Fracture Physics, Materials TDT

NASA and its extended family in Government, Industry and Academia represent the most powerful engineering resource in the world.

— Paul M. Munafo, Chief Engineer, Teledyne Brown Engineering, Materials TDT

Port side truss segments showing solar array components.

Center Focus



Computer image of Vehicle Assembly Building fire scenario.

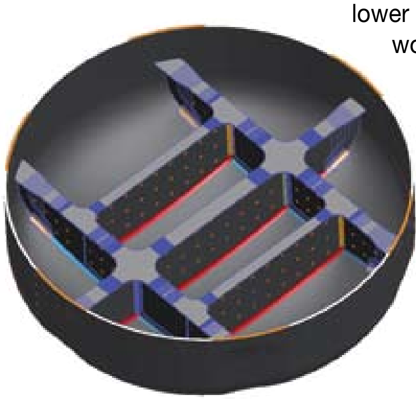
Dr. Tina Panontin
NESC's Chief
Engineer at ARC

Ames Research Center

During 2008, Ames Research Center (ARC) continued to provide a wide variety of expertise to NESC activities. Over 50 ARC civil servants and contractors provided support to the NESC's Technical Discipline Teams and technical assessments. ARC provided experts in disciplines ranging from human factors, data mining, and computational modeling to composites, aeroacoustics, and nondestructive evaluation testing. The NASA Technical Fellow for human factors, Dr. Cynthia Null, is resident at ARC.

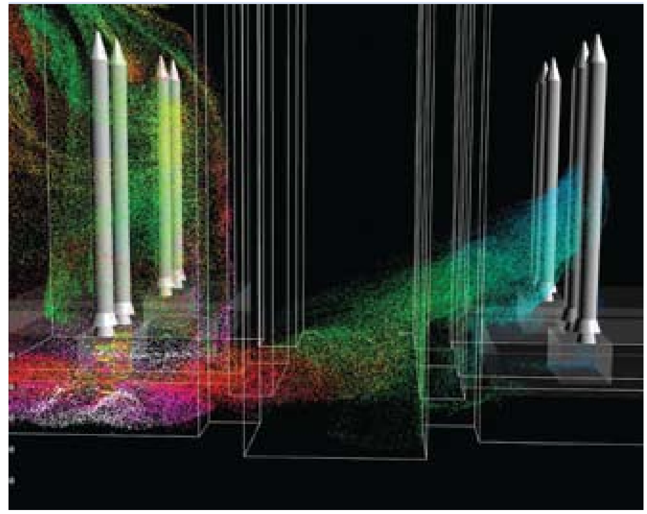
Exploration Systems

Composite Crew Module (CCM): ARC personnel are a key part of the NESC's CCM team, leading the design of the lower primary structure. The innovative design, in which the floor beams carry pressure load instead of the traditional ring frame and dome, has yielded a 100 lbs. mass savings. A variation of the load sharing backbone has been adopted by the Orion Project. An additional 50 lbs. mass savings was realized by shaping the shell into lobes which was easily accomplished with composites. ARC personnel performed analysis of test components and assisted in the composite fabrication at ATK Iuka. Most of the lower structure is bonded with woven preform technology developed by Lockheed Martin. A new structural element was needed at two intersections along the main beams, but existing preform technology was not mature. Titanium fittings were designed as back-ups while composite preforms could be developed. Fittings were fabricated and shipped to ATK Iuka for assembly into test specimens. Pi preform shear strength tests will be performed at Ames in late 2008.



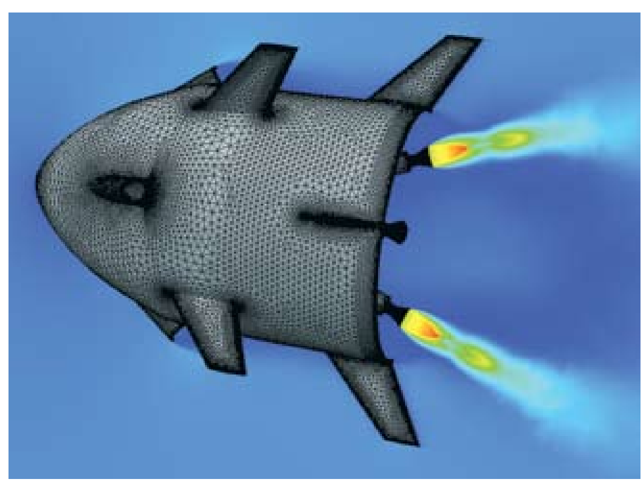
Lower section of the 12-foot CCM Pressure Vessel

Vehicle Assembly Building (VAB) Analysis: To support upcoming space exploration missions, modeling and simulation experts are providing a computational framework for simulating elements of the ground operations of future launch vehicles at KSC. Part of this NESC-sponsored effort is determining whether the VAB at KSC, used for the Space Shuttle, is properly equipped to safely handle the storage of significantly more fuel required for the Agency's next-generation Ares I and Ares V vehicles. ARC experts are developing the capability to employ high fidelity CFD tools (OVERFLOW and Cart3D) to predict the effects of various fire scenarios in the VAB. The modeling will help determine the probability of the solid rocket boosters in any of the other three bays igniting, then identify the maximum possible heat flux generated in the worst-case scenario and the resulting effects on nearby structures at KSC.



Results from the OVERFLOW simulation tool show instantaneous particle traces colored by temperature in a VAB fire scenario.

Max Launch Abort System (MLAS): The USM3D flow solver is generating MLAS aerodynamic data that cannot be readily generated experimentally. ARC engineers improved USM3D, focusing on increased performance and support for larger problem sizes. As a result, run time has been reduced by 5 times, and memory requirements have been reduced by 2 times. Simulations that took a week now take a day. ARC engineers are also incorporating visualization capabilities into the USM3D code that will allow the user to view the progress of computations on their desktop.



USM3D flow solution of the MLAS at a subsonic flight condition.

SEE ALSO: *CCM, Page 18*

Dr. James Stewart
NESC's Chief
Engineer at DFRC

Dryden Flight Research Center

Dryden Flight Research Center (DFRC) engineers have contributed to the NESC's multi-discipline teams in addressing the Agency's toughest problems. This year DFRC scientists and engineers supported NESC assessments in the areas of Composite Crew Module Structural tests, Hypersonic Thermodynamic Infrared Measurements (HYTHIRM), and have supported Max Launch Abort System (MLAS) project and Space Shuttle.

Exploration Systems

Composite Crew Module (CCM) Structural Testing: DFRC is supporting the structural testing on the NESC's CCM team with fiber optic sensing and measurement technology. DFRC engineers are using NASA-developed fiber optic sensor technology to monitor the structural strains in approximately 300 locations along four optical fibers mounted on the CCM. Each fiber is approximately the diameter of a human hair and can be placed in geometrically complex regions where conventional sensors can not be installed. Such areas include the regions in a highly loaded bolted joint, between L-brackets and a composite substrate. The fiber optic system, which has recently been flown on the Ikhana Unmanned Aerial Vehicle, can monitor strains at record rates that surpass commercially available systems. The CCM team supported testing of this technology at LaRC, with the support of the DFRC engineers.

Max Launch Abort System (MLAS): DFRC is supporting MLAS launch operations at the Wallops Flight Facility by providing flight termination receiver /decoder equipment for use as a command uplink to the MLAS flight test vehicle.

Space Operations

DFRC senior engineers participated in a wide range of activities pertaining to NESC loads and dynamics work. One major area of activity was related to the Broadband Aeroacoustic Stator Simulator (BASS) Project which evolved to support the root-cause determination of the Space Shuttle Main Engine flowliner cracking due to acoustic resonance. DFRC engineers were involved in modifications of the BASS software code to facilitate implementation of coupling of wall motion and unsteady loading in the flowliner.

General

Hypersonic Thermodynamic Infrared Measurements (HYTHIRM): DFRC supported the NESC sponsored HYTHIRM project with Dryden's Mobile Aerial Tracking and Imaging System (MATRIS). The objective of HYTHIRM was to bring high resolution infrared imaging assets to support the Space Shuttle boundary layer transition experiment. On STS-119, a special tile with local roughness will be placed on the port wing of the orbiter windward surface to induce boundary layer transition at higher Mach numbers.

Allen Parker, Dr. Lance Richards (Group Lead) and Anthony Piazza of the Advanced Structures and Measurement Technology Group check the fiber optics measurement system at DFRC before the CCM test at LaRC.

Mobile Aerial Tracking and Imaging System (MATRIS) set up to support the HYTHIRM calibration test at Sandia National Laboratory's Solar Tower.

The earlier transition will result in additional heating that will be measured on the Orbiter by discreet thermocouples. The IR assets will add global thermal imaging to the discreet measurements. This data will be used to improve prediction methods of aeroheating and boundary layer transition at hypersonic conditions. The improved predictions will aid in future thermal protection system design and damage assessments. In preparation for the Shuttle tests this year the MATRIS and other HYTHIRM assets participated in a calibration test at the Sandia National Labs Solar Tower that was sponsored by the NESC. Engineers from PVP Advanced EO Systems Inc. Tustin, CA, built the MATRIS system and supported the calibration test which was the first field test of MATRIS.

SEE ALSO: *MLAS, Page 14; HYTHIRM, Page 27*

Glenn Research Center

Bryan Smith
NESC's Chief
Engineer at GRC

Glenn Research Center (GRC) contributed to a broad range of assessments and discipline advancing studies for the NESC. GRC draws upon Engineering, Research and Technology, Safety & Mission Assurance and Facilities organizations to provide the unique skill sets and facilities required to successfully complete special tests, and evaluations in support of NESC assessments.

Exploration Systems

Orion Occupant Protection: GRC is currently supporting work on Orion Crew Module (CM) occupant protection systems. The primary objective of the effort is to develop spacecraft design alternatives and injury criteria that ensure the CM design provides minimal risk to the crew during nominal and contingency landings. This work includes crew protection systems such as the crew seat pallet attenuation, seat designs and development of tools to predict injuries and injury criteria.

Space Operation

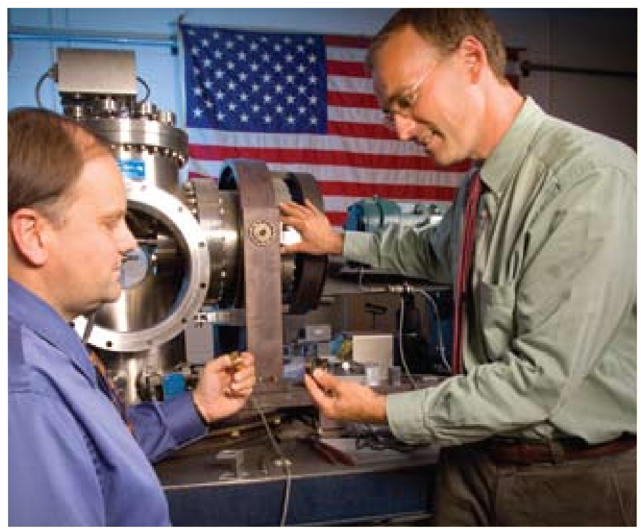
International Space Station Solar Alpha Rotary Joint (SARJ): GRC personnel performed a forensic failure analysis and supporting tests to investigate failure mechanisms and anomaly resolution for the SARJ. Roller manufacturing specifications and tolerances, combined with key trundle design features, including sensitivity to the effects of sliding friction coefficient and limited compliance, were investigated to develop failure scenarios for the SARJ. A review of the manufacturing records, discussions with the suppliers, and in-house testing revealed that adhesion of gold, has a solid lubricant film is critical to extending the life and performance of the rolling elements.

Additional GRC Space Operations support included providing expertise in plasma sources, plasma diagnostics, and simulation of space plasma conditions for investigations into charging models used to determine safe operations for the Extravehicular Mobility Unit and safe operations with the International Space Station plasma contactor unit.

General

GRC personnel have leadership positions within two Agency-level working groups sponsored by the NESC. The Composite Pressure Vessel Working Group (CPVWG) has advanced understanding of aging effects for Orbiter Kevlar/Epoxy Composite Overwrapped Pressure Vessels (COPVs). This work supports a collaborative effort with the Orbiter Project to perform a long-term stress rupture test with the benefit of contributing to applications of COPVs for the Constellation Program. GRC personnel also participated in the Flight Battery Working Group and developed guidelines that addressed safety, handling and qualification of Li-Ion batteries for crewed and robotic applications.

Bryan Smith (left) NESC Chief Engineer at GRC and NESC CCM Project Manager Michael Kirsch (right) discuss pull test results for critical composite interface joints used in the CCM Project.



Tim Krantz (left) and Chris Dellacorte (right) of the Tribology & Mechanical Components Branch, review test results of gold solid lubricant film adhesion for the SARJ anomaly investigation.

Technical Discipline Team

GRC support to the NESC Technical Discipline Teams included Structures and Nondestructive Evaluation for composite materials in spacecraft structures. Trades focused on safety factors and material allowable values in critical structures. Probabilistic structural simulations were used as methods to quantify risk for highly stochastic conditions in loadings and materials. GRC personnel, experienced in these methods for high-temperature composites in aircraft propulsion systems, were able to apply this method to spacecraft component reliability.

SEE ALSO: *Orion Modeling, Page 21; SARJ, Page 29*

Steven S. Scott
NESC's Chief
Engineer at GSFC

Goddard Space Flight Center

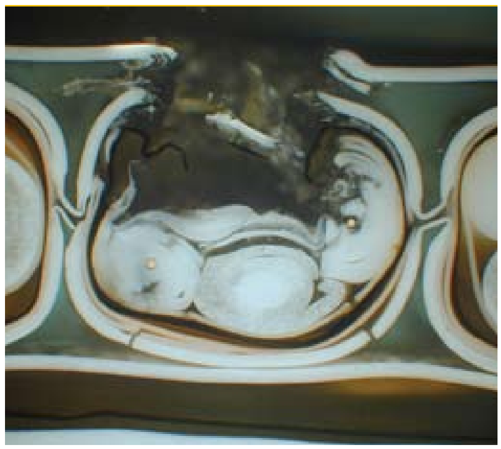
The Goddard Space Flight Center (GSFC) continued its wide-ranging support to the NESC with over 140 resident and matrixed specialists involved in 56 tasks. GSFC provides expertise in Electronic, Electrical, and Electromechanical (EEE) parts, spacecraft electronics, guidance, navigation and control (GNC), materials, mechanical and power components and systems, reliability, software, and systems engineering. The Center benefited from participating in NESC activities as many had NASA- and industry-wide importance. Four NASA Technical Fellows reside at Goddard: Michael Aguilar, Software, Mitchell Davis, Avionics, Neil Dennehy, GNC, and Joe Pellicciotti, Mechanical Systems.

Exploration Systems

The Center supported many Constellation Program (CxP) tasks for the NESC. Several addressed prominent design and system architecture issues: Ares aeroacoustic loads during launch, vehicle seat attenuation designs for assuring crew safety and survivability, the reliability of the GNC System, and the Program's Safety, Reliability and Quality Assurance implementation. GSFC's sister facility, the Wallops Flight Facility (WFF), provided considerable support to the Max Launch Abort System (MLAS) Project.

Space Operations

Key expertise for NESC Space Shuttle Program (SSP) support included substantive contributions identifying and resolving External Tank Engine Cut-Off Sensor reliability issues, Fuel Cell Pump Motor risks, Rudder/Speed Brake operational risks from chipped actuator gear teeth, and Solid Rocket Booster electronic component fatigue failures. Center engineers identified solar array "steering" joint degradation mechanisms – needed for supplying power to the Station, and tested Teflon™ wire integrity against embrittlement in the space radiation environment for the International Space Station.



Magnified image of multi-conductor wire damage from a 0.65 mm particle collision at 7 km/sec.

Natalie Panek, NASA Intern, setting up a transformer for wire fatigue testing with mentor, Dr. Henning Leidecker.

Science

NESC science mission assessment support included an instrumented payload adaptor ring for the Fermi Gamma-ray Space Telescope's to better understand coupled loads during launch, pre-launch risk assessments for the Dawn, Fermi, and Phoenix missions, mishap investigations for a spacecraft processing accident and telescope motor anomaly, and space laser transmitter EEE parts radiation testing. An extensive effort evaluated electrical cable vulnerability to hypervelocity particle impacts for the James Webb Space Telescope.

General

NESC discipline advancing tasks address potential NASA-wide problems before they create significant impacts. The Center provided key support to discipline advancing assessments for Field Programmable Gate-Array reliability, DC-to-DC Converter failures, threaded fasteners for aerospace uses, a NASA/industry cooperative space battery program, and demonstrated high-speed optical data transfer using SpaceWire.

NESC Awards

Dr. Michael J. Dube (Discipline Deputy – Mechanical Systems) received the prestigious NESC Director's Award for technical excellence for supporting and resolving numerous Agency-wide anomalies. Jim Lanzi, WFF Flight Mechanics Engineer, received an Engineering Excellence Award for his MLAS flight test vehicle work. A Group Achievement Award for the SSP Engine Cut-Off System Investigation Team was accepted by Dr. Henning Leidecker.

SEE ALSO: *MLAS, page 14; HYTHIRM, page 27*

R. Lloyd Keith
NESC's Chief
Engineer at JPL

Jet Propulsion Laboratory

In 2008, the Jet Propulsion Laboratory (JPL) participated in numerous NESC assessments for the Science, Exploration Systems and Space Operations Mission Directorates.

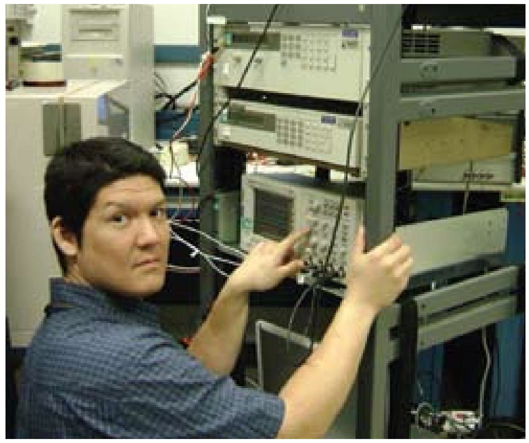
Space Operations

The JPL 25-foot Space Simulator is being used to create conditions that could cause buckling of the International Space Station solar array masts. Tests were completed in October and data analysis is underway.

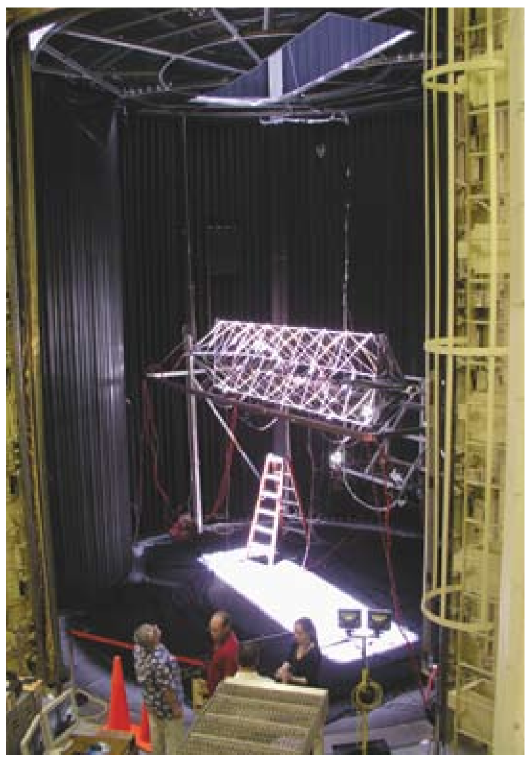
Science

A Reaction Wheel Assembly (RWA) on the Thermosphere Ionosphere Mesosphere Energetics and Dynamics (TIMED) spacecraft was autonomously shut down by the spacecraft's fault detection software after failing a torque check. Two other satellites currently are using these wheels in the operations phase and several future missions including the upcoming Kepler Project are in the implementation phase and planning to use these wheels, all from the same manufacturer.

JPL's Office of the Chief Engineer formed a team to investigate the anomalies, evaluate the risk to current and future missions, and if possible give recommendations to mitigate the risk. Based on the results, the Kepler Project decided to mitigate the risk by reworking the RWAs instead of incorporating new design changes. The JPL Chief Engineer and Kepler Project requested an independent review by the NESC to validate the risk posture and plans for the RWA usage for Kepler. In response, the NESC formed an independent team that provided six specific recommendations for the Kepler mission and long-term recommendations for the future missions. These recommendations enabled the risks to the Kepler Project to be evaluated. The NESC assessment and its recommendations will also be valuable to future NASA and industry missions to assess project risks and develop mitigation plans when using RWAs from this manufacturer.



Tom Trippany, JPL, is shown adjusting parameters for the DC/DC converter testing.



The JPL 25-foot Space Simulator, with ISS solar array mast installed, provides the vacuum and thermal conditions found in space.

General

JPL is supporting the NESC-led Composite Pressure Vessel (CPV) and Flight Battery working groups. JPL is providing the leadership and is the host for the COPV Working Group to study the long-term safety of COPVs. In support of the Flight Battery Working Group, Glenn Research Center is using JPL battery experts and test facilities.

The NESC Robotics Technical Discipline Team (TDT), led by JPL, is working several tasks to advance robotic exploration.

The Direct Current (DC/DC) Converters task has completed a comprehensive guidelines document for developers of power systems as well as test methodologies to be used. The guidelines directly address a history of problems NASA has encountered with this device type. A practical set of guidelines is given for characterization, selection, purchase, and application of hybridized DC/DC converters in NASA flight hardware to prevent or mitigate future failures and risks in the field. Several current projects have already started using this information and have been pleased with the results.

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.

The Wireless Avionics task has developed a set of long-term requirements, developed an architectural approach and developed a preliminary prototype to prove out the concepts. ARC, GSFC, JPL and JSC avionics engineers are working this task cooperatively.

SEE ALSO: *ISS mast shadowing, Page 30; Kepler RWA, Page 24; EDL repository, Page 25; DC/DC converter, Page 26*

Johnson Space Center

Dr. Nancy J. Currie
NESC's Chief Engineer at JSC

NESC personnel at Johnson Space Center (JSC) continued to support the safe and successful execution of Space Shuttle Program (SSP) and International Space Station (ISS) missions and the development of the next generation of human-tended spacecraft for the Constellation Program. NESC personnel provided technical insight into NASA's human spaceflight programs by serving as non-voting members on major technical boards and panels. They also provided JSC managers with periodic status briefings regarding NESC activities related to their programs/projects. They provided real-time mission support by serving as a member of the SSP and ISS Mission Management Teams. In addition to the NESC Chief Engineer, the NASA Technical Fellows for Loads and Dynamics and Life Support/Active Thermal and a member of the Systems Engineering Office are resident at JSC as are the NESC Deputy Directors for Safety and Advanced Projects.

One major component of the International Space Station (ISS) remains to be installed. S6 contains the fourth and final set of solar arrays and batteries.

Exploration Systems

In recognition of the importance of independent assessment of design and development efforts for the next generation of human-tended spacecraft, the NESC is engaged at all levels of the Constellation Program. Numerous independent assessments of issues affecting the Constellation Program and Project elements were conducted during 2008. An independent team, led by the NASA Technical Fellow for Mechanical Systems, developed alternate seat and seat attenuation designs for Orion to reduce the potential for crew injuries. NESC personnel provided peer reviews of the Orion and Ares aerodynamic and aerothermodynamic database, models, and methodologies. They also assessed external pressure field predictions of Orion and Ares aeroacoustics and the predicted micrometeoroid environments for Constellation elements. NESC experts analyzed the loads and dynamics of the Orion/ARES vehicle stack and were involved extensively in improving the capability to model human response to accelerations to determine the potential risk of crew injury during landing scenarios.

Space Operations

In support of the Space Shuttle Program and Orbiter Project Office an interdisciplinary team of experts in structures, NDE, materials, mechanical systems, loads and dynamics, aerosciences and flight mechanics assisted with the root cause investigation and testing protocols for the anomalous local degradation of silicone carbide coating integrity on the Reinforced Carbon-Carbon wing leading edges of the Orbiter. Other Space Shuttle issues that the NESC assessed or assisted with included: a buckling issue with the Orbiter radiator retract flexhoses, water-hammer effects in the orbiter Coolant Loop, atmospheric circulation issues on the Orbiter, and damage that occurred to the KSC Pad 39A flame trench walls during launch of STS-124.

The NESC conducted several independent assessments of issues affecting the ISS and its operations including thermal and structural analysis to support investigations into buckling issues associated with solar array mast longeron shadowing, damage modes and potential on-orbit remediation options for the Solar Alpha Rotary Joint, and failure investigation efforts for an incident in which a Self-Contained Oxygen Generation System (SCOG) exploded on a Royal Navy submarine. The ISS uses both US and Russian SCOGs. Testing conducted at White Sands Test Facility reproduced the physical effects of the explosion and assisted in root cause identification of the failure and a redesign to prevent reoccurrence.

NESC Awards

Kenneth L. Hodges received the NESC Engineering Excellence Award for the design, development, and implementation of state-of-the-art non-destructive techniques for the composite crew module project. Dr. John C. Graf received the NESC Director's Award for the investigation of the Self Contained Oxygen Generator explosion on a British Royal Navy submarine.

SEE ALSO: *Orion seat attenuation, Page 20*

Stephen A. Minute
NESC's Chief
Engineer at KSC

Kennedy Space Center

The NESC is involved in multiple activities and projects at the Kennedy Space Center (KSC). Likewise, KSC continues to provide excellent support and expertise to a wide variety of NESC assessments and testing across the Agency. More than 30 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.

Exploration Systems

KSC engineers and researchers are working with the NESC on the Max Launch Abort System (MLAS). The MLAS project is focused on alternate launch abort techniques as risk mitigation for Constellation's Orion Project. A unique aspect of the MLAS project is the Resident Engineer program. Engineers that are relatively early in their career are being 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 has two engineers assigned to this project.

KSC researchers were also involved in the NESC MLAS Project. Personnel from KSC's Electrostatics and Surface Physics Laboratory characterized the electrostatic build-up characteristics of the fairing material being used in the MLAS concept. In addition, a KSC engineer is on the design team of the NESC Composite Crew Module Project, developing expertise and techniques for potential composite use on crewed space vehicles.

Dr. Carlos Calle (left), Dr. Michael Hogue, (center), and Dr. Charles Buhler (right) with KSC's Electrostatics and Surface Physics Laboratory take electrostatic measurements from a sample of MLAS fairing material.

KSC's Samantha Manning (center) and Sarah Quach (right) are getting real-time, hands-on design experience with NASA's Technical Fellow for Avionics Mitch Davis (left) at a MLAS design review as part of the MLAS Resident Engineer program.

Space Operations

NESC personnel were engaged in assessments at KSC for the Space Shuttle, including the main engine cut-off sensor anomaly root cause investigation and subsequent design changes, Nondestructive Evaluation techniques in support of the crawler track shoe cracks and casting flaws, and the launch pad flame trench brick wall integrity.

Likewise, the NESC supported the International Space Station (ISS) in several assessments by bringing Agency experts together to review program issues. In particular, Dr. Chris Iannello of KSC augmented the NESC Avionics TDT with his understanding of electrical power in assessing the ISS Russian BOK3 computer shutdown, the Shuttle/ISS power transfer system startup transients, and the ISS Solar Array Wing Lessons Learned Team. In addition, the NESC is partnering with KSC to assess safe operating distances around the Shuttle Vehicle Assembly Building (VAB) associated with an anticipated increase in the amount of solid propellant segment processing for the Ares I and Ares V boosters. The NESC is modeling the ignition characteristics of the propellant and motor segments within the VAB. KSC researchers continued support for the NESC on enhanced insulation materials, including Aerogel, for potential use on the Shuttle ET inter-tank flange.

Science

The NESC is actively working with KSC's Launch Services Program on a Flight Force Measurement project to use flight measured strain data to resolve the actual flight forces at spacecraft interfaces. The system was flown on the GLAST mission.

SEE ALSO: *MLAS, Page 14; CCM, Page 18*

Langley Research Center

Clayton P. Turner
NESC's Chief
Engineer at LaRC

Langley Research Center (LaRC) continued to support the NESC mission to address the Agency's high risk programs and projects. Langley is the home Center for the NESC Director's Office. The NASA Technical Fellows for Materials — Dr. Robert Piascik, Nondestructive Evaluation (NDE) — Dr. William Prosser, Structures — Dr. Ivatury Raju, Aerosciences — Dr. David Schuster and Flight Mechanics — Mr. Daniel Murri are also resident at LaRC.

Space Operations

LaRC supported the NESC investigation of the Orbiter Reinforced Carbon-Carbon (RCC) Silicon Carbide (SiC) coating liberation discovered in the Orbiter's thermal protection system. The RCC, located along the wing leading edge and nose cap, protects the Orbiter from damaging plasma during re-entry. LaRC carbon-carbon composite material experts are conducting tests to develop an understanding of the damage phenomenon and assist in developing solutions. RCC specimens were exposed to simulated re-entry profiles using Langley's Multi-parameter Mission Simulation Facility. The specimens are used to develop new mechanical tests that will determine the loss of adhesion strength of the protective SiC coating to the RCC substrate and to characterize selected mechanical properties of RCC.

Exploration Systems

LaRC experts in structures, materials, and nondestructive evaluation (NDE) made significant contributions to the NESC Shell Buckling Knockdown Factor (SBKF) assessment. SBKF was initiated with the goal of developing and validating new analysis-based shell buckling knockdown factors that date from the 1930s to the 1960s for relevant Ares V type metallic and composite shell structures. The first set of two 8-ft-diameter, orthogrid barrel test articles for validation testing were designed and fabricated by the Langley-led team.

LaRC has also made major contributions to NESC independent technical assessments such as the critical initial flaw size (CIFS) of defects in welds in the Ares I-X Upper Stage Simulator (USS). The USS is an inert stage that simulates the upper stages of the Ares I launch vehicle. The Langley Fatigue and Fracture Laboratory and Environmental Fatigue Laboratory were used during the test to characterize the steel that is used in the USS. Tests were conducted on welds and fatigue crack growth rate tests were also conducted.

General

LaRC provided technical leadership in the NESC sponsored development and release of a NASA technical standard for models and simulations and also led the NESC sponsored HYpersonic THermodynamic InfraRed Measurements sensing methods and tools that will be used for thermographic imaging of aero-heating on the Orbiter during entry. The goal is to provide data that could be used for calibration and validation of empirical and theoretical aero-heating tools for future Agency missions.

Dr. David Dawicke and Greg Shanks conduct fracture tests on welded A516 Steel for critical initial flaw sizes (CIFS) in USS segments for Ares I-X

Wallace Vaughn (left) and Craig Ohlhorst (right) examine an RCC test coupon after a high temperature mission simulation cycle in LaRC's Multi-parameter Mission Simulation Facility.

NESC Awards

This year, Langley personnel received four group awards and four individual awards. Recipients of the NESC Group Achievement Award were the 8% MLAS Model Team, the Ice Mitigation Approaches for Space Shuttle External Tank Team, the NESC Ares I-X USS Critical Initial Flaw Size Analysis Team, and the Langley Mission Support Team. Dr. Kenny Elliott received the NESC Director's Award and James Beaty, Dr. David Dawicke, Dr. Norman Knight, and Erik Tyler received NESC Engineering Excellence Awards.

SEE ALSO: *MLAS, Page 14; Shell buckling, Page 17; HYTHIRM, Page 27*

Marshall Space Flight Center

Dr. Charles F. Schafer
NESC's Chief
Engineer at MSFC

Orthogrid panel segment welded into a barrel section in the Vertical Weld Tool for the Shell Buckling Knockdown Factor work.

(Below) Lewis "Chip" Moore examines a trundle bearing assembly prior to performing profile measurements.

Marshall Space Flight Center (MSFC) engineers have been supporting NESC efforts across a broad range of activities during 2008. Following the retirement of George Hopson, the NASA Office of the Chief Engineer named Roberto Garcia (resident at MSFC) as the NASA Technical Fellow for Propulsion.

Exploration Systems

The NESC is involved in Ares and Orion work at MSFC and has participated in several assessments and project reviews. The Shell Buckling Knockdown Factor assessment was initiated by the NESC in 2007 with the goal of developing and validating new analysis-based shell buckling knockdown factors for relevant Ares V type metallic and composite shell structures including Aluminum-Lithium orthogrid and composite sandwich constructions. MSFC and LaRC engineers are working together to develop and implement new high-fidelity structural testing methods and measurement techniques. Manufacturing and validation testing activities at MSFC will support the test and analysis-based knockdown factor development and validation.

Shell barrels manufactured at MSFC passed all required post-fabrication nondestructive evaluation and were instrumented for testing. Structural testing began in November 2008 in a new large-scale test facility designed, fabricated and assembled at MSFC. The shells are subjected to combined axial compression, bending and internal pressure.

MSFC engineers are continuing their activities in the NESC Composite Crew Module work, in which a multi-center team developed an Agency-wide expertise in design, analysis, manufacture, and testing of such a large composite structure. Fabrication of all building block test elements and process scouting tests are continuing at MSFC with the completion of a full-scale upper pressure shell manufacturing demonstration article in Iuka, MS.

Space Operations

MSFC personnel participated in NESC assessments of flight and operations hardware for the Space Shuttle Program and the International Space Station (ISS) Program. NESC personnel at MSFC continued to participate in Space Shuttle propulsion reviews including pre-flight readiness reviews.

MSFC engineers made key contributions to the ISS Solar Alpha Rotary Joint (SARJ) assessment. A trundle bearing assembly that had been removed from the SARJ on orbit was sent to MSFC for evaluation. This work included tribological evaluation of bearing failures, precision dimensional and surface metrology on program critical hardware, fundamental friction and wear testing, advanced materials analysis, and loading a special grease gun as a potential EVA repair tool. All 17 spare trundle bearing assemblies in the ISS inventory, and the 12 assemblies from the SARJ structural test article were sent to MSFC for the same detailed tribological examination.

General

MSFC engineers continued to participate in the NESC-sponsored Composite Pressure Vessel (CPVWG) Working Group. The CPVWG working group is the Agency's technical group responsible for reviewing and developing composite pressure vessel technologies related to human and robotic space missions.

SEE ALSO: *MLAS, Page 14 Shell buckling, Page 17; CCM, Page 18; SARJ, Page 29*

Michael D. Smiles
NESC's Chief Engineer at SSC

Stennis Space Center

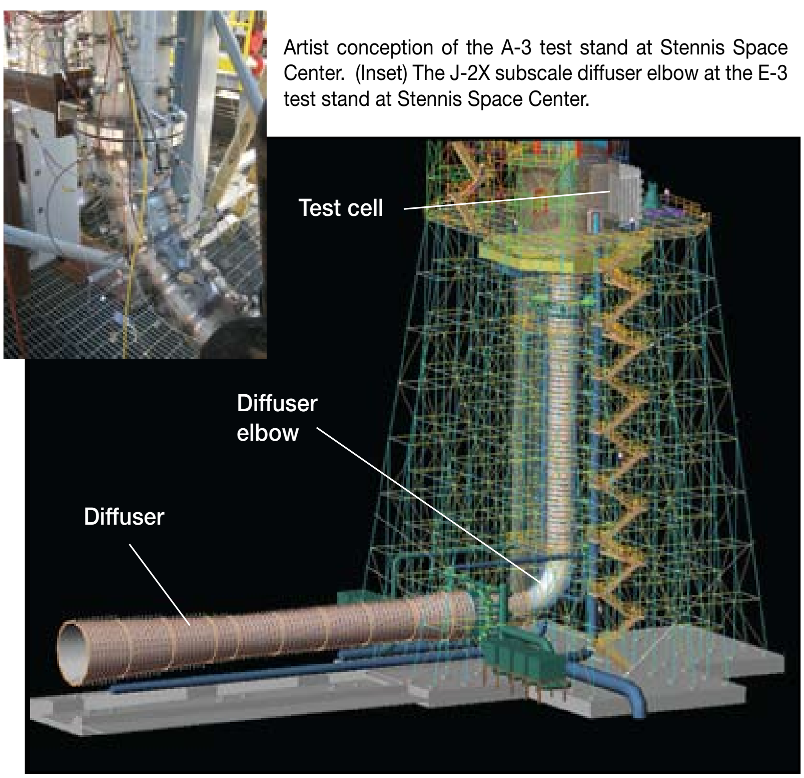
Stennis Space Center (SSC) engineers supported NESC assessments by using the unique capabilities and facilities available at SSC.

Exploration Systems

A-3 Test Stand: SSC is testing the J-2X engine that will be used in the second stages of Ares I and Ares V. The A-3 test stand will be used to test the J-2X at simulated altitude conditions, including a high altitude start test capability to provide flight duration tests of 500 seconds. With personnel from SSC, the NESC supported an independent assessment of the baselined cost and schedule estimate for the A-3 test stand. The NESC also formed a team that included SSC engineers to assess the thermal and dynamic loads that could be generated by the facility. Critical to the A-3's performance is a diffuser that incorporates the first and second-stage steam ejectors required to simulate high altitude. SSC had initiated the Subscale Diffuser Test (SDT) program, which is a 1/17 scale of the A-3 diffuser, to provide design validation for A-3. The NESC team used the SDT to verify and validate the modeling tools used to predict facility response, facility-induced environments (far-field acoustics, heat flux, etc.), and operational conditions. Predictions using Computational Fluid Dynamics analysis of the SDT diffuser flow path were performed. The predictions compared well to experimental data obtained during the SDT program. Computational heat transfer and aero-acoustics analyses were also performed to provide feedback to the project team in their evaluation of thermal and acoustic management strategies.

Integrated System Health Management (ISHM): The NESC also took proactive measures to adapt an ISHM capability developed at SSC to the SDT program. ISHM capabilities can provide several benefits including detection of anomalies, diagnosis of root causes, determination of effects and prediction of future anomalies. An anticipated benefit of the ISHM capability is its scalability to support the full scale diffuser on A-3. The SDT ISHM pilot capability was then replicated to support the Chemical Steam Generator (CSG) testing. The CSGs provide the steam required to operate the Subscale Diffuser.

Max Launch Abort System (MLAS): SSC engineers participated on the NESC MLAS team to assist in predicting thermal and dynamic loading of the solid rocket abort motors. They collected and analyzed heat flux data from a representative solid rocket motor (MK70) during ground testing at Indian Head, Maryland. SSC also supported MSFC with overpressure measurements during a sounding rocket launch at Wallops Island, Virginia, to predict the thermal and acoustic loads on the MLAS flight test vehicle. SSC personnel provided an analysis of the thermal radiative effects from the MK70s on structural and other critical components during the MLAS boost phase.



Artist conception of the A-3 test stand at Stennis Space Center. (Inset) The J-2X subscale diffuser elbow at the E-3 test stand at Stennis Space Center.

Space Operations Engine Cutoff Sensor (ECO): In response to an NESC call for support, the SSC Data Acquisition Team devised a technical solution that allowed the processing, formatting and displaying of critical test data taken from the STS-122 External Tank ECO Sensors. This was the first complete and successful processing of the data captured in a very large file, with format issues. Furthermore, the SSC team assisted the NASA Technical Fellow for Avionics and the senor test team by processing specific areas of interest to facilitate the isolation of the ECO sensor problem.

NESC Awards

The SSC Data Acquisition Team received an NESC Group Achievement Award for their efforts in support of the Space Shuttle Program. Their outstanding technical abilities and dedicated service supported timely decision-making by the technical and management teams and ultimately the successful launch of STS-122.

SEE ALSO: *MLAS, Page 14*

Dr. Nancy J. Currie
NESC's Chief
Engineer at JSC

White Sands Test Facility

White Sands Test Facility (WSTF) scientists and engineers have assisted the NESC in addressing important issues in NASA programs and projects. This year, testing and analysis centered on hypervelocity impacts, chemical oxygen generators, Composite Overwrapped Pressure Vessels (COPVs), technology requirements for the High Pressure Oxygen Generator Assemblies, pyrovalve failures, and a proposed method for treating hydrazine and monomethylhydrazine.

Space Operations

A chemical oxygen generator explosion aboard a UK Royal Navy (RN) submarine resulted in crew fatalities and extensive damage. Since similar chemical oxygen generators provide backup oxygen on the International Space Station (ISS), the NESC sponsored a cooperative agreement for scientists and engineers from NASA and RN to work together to conduct a root cause analysis, chemical modeling, laboratory analysis, and field testing that resulted in a series of full-scale tests at WSTF. The findings have increased fundamental knowledge of the mechanisms of chemical oxygen production and have led to operational changes and improved safety onboard RN submarines.

A project focusing on research and development of the technology required for a High Pressure Oxygen Generator Assembly (HPOGA) was started this year. The HPOGA is a high differential pressure water electrolysis cell stack that uses water to produce oxygen gas at up to 3000 psi without the need for a mechanical compressor. The oxygen tanks on the ISS are currently resupplied with high pressure gaseous oxygen by using space shuttle oxygen. When the Space Shuttle is retired the HPOGA is being explored as one option to meet ISS oxygen needs. Personnel from WSTF, Hamilton Sundstrand, and JSC are performing testing on HPOGA simulators.

WSTF supported an NESC evaluation of a proposed method for treating hydrazine and monomethylhydrazine-contaminated equipment with alpha-ketoglutaric acid (AKGA). The tests were prompted by suggested cost and operational benefits to NASA for flight hardware and ground support equipment decontamination, treatment of liquid waste, spill remediation, and possibly vapor control. The NESC and WSTF developed a quick-response team with Dr. Thomas Giordano from CH2MHILL to further examine the treatment processes proposed by CH2MHILL.

Science

Cables on the James Webb Space Telescope will be directly exposed to micrometeoroid impact in the Earth-Moon L2 environment. WSTF's Remote Hypervelocity Test Facility conducted hypervelocity impact testing, some at cryogenic temperatures, to support the NESC assessment of cable vulnerability and shielding requirements. WSTF personnel continued to assist the NESC assessment into ground test failures of pyrotechnically operated valves that are used in numerous NASA spacecraft. A novel approach to analysis of the heat transfer mechanisms inside the pyrovalve primer chamber assemblies was performed using a combination of computer analysis and test data. Recommendations for reliable operations were shared with NASA projects and programs such as the Solar Dynamics Observatory, Mars Science Laboratory, Phoenix Mars Lander, and Orion.

Ben Gonzalez, GeoControl Systems Inc., and Brooks Wolle, Jacobs Technology Inc., perform radiograph inspection of COPV weld anomalies at WSTF.

Chris Keddy, Jacobs Technology Inc., verifies measurements on a sectioned COPV against a structural model generated in GENOA, a virtual testing and analysis software.

General

WSTF has supported the NESC Composite Pressure Vessel Working Group (CPVWG) in evaluating the effectiveness of nondestructive evaluation techniques for detection of manufacturing flaws and vessel aging indications and applied Raman spectroscopy for measurement of strain condition. WSTF has also developed a library of material properties and stress rupture data on carbon and Kevlar fiber materials.

SEE ALSO: *JWST electrical cables, Page 23*

Astronaut John Young, Apollo X command module pilot, participates in simulation activity in the Apollo Mission Simulator at the Kennedy Space Center.

Risk-Driven Design Approach for CEV

Electrical systems enable the crew and ground to control critical spacecraft functions. Balancing competing needs and requirements, infusing new technology, and meeting tight mass and power constraints argues for a top down risk informed design approach to achieve an optimized system.

– Michael Bay, Bay Engineering

Iterative Risk Driven Design Approach for CEV Avionics

Michael Bay, NASA Engineering and Safety Center (NESC)
Avionics Technical Discipline Team, BEI
Mitchell Davis, NESC Avionics Technical Fellow, NASA
Blake Putney, Principal Risk Analyst, Valador

Abstract - An agency wide team led by the NASA Engineering and Safety Center (NESC) utilized an iterative, risk informed, build up design approach to decide where to apply mass resources to balance safety, performance, and affordability for Crew Exploration Vehicle (CEV) Avionics. The buildup approach started from a simple single string architecture to assure the solution was in the box, then identified weaknesses and risks to safety and mission success, considered operational alternatives to eliminate risks as well as the addition of backup systems and redundancy to restore adequate failure tolerance. The fundamental objective of the build up approach was to find the safest, most reliable and affordable system design by applying mass, power and other resources where they do the most good for safety and mission success.

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1. TEAM CHARTER

An agency-wide team led by the NASA Engineering and Safety Center (NESC) participated in a study chartered to assess driving requirements and consider alternative designs for the CEV that may reduce mass.[1] The Smart Buyer Team was challenged to assess driving requirements and offer alternative approaches to reduce mass without adversely effecting safety and mission success. One of the tasks involved a study of the Avionics configuration for the CEV with the express purpose of identifying safety, reliability, and mass drivers, and identifying how the avionics configuration effects vehicle mass. In addition the team was to identify the requirements that drove vehicle mass and how changes to those requirements may allow mass reductions. To search for innovative solutions, the Smart Buyer Team united technical expertise and experience of the human spaceflight, robotic and research centers.

2. BACKGROUND AND CHALLENGES

The CEV Smart Buyer Design Team (SBT) used the existing CEV design products as a starting point and was allowed the latitude to perform trade and design studies outside of the current baseline and to challenge the existing requirements if necessary. Several challenges guided the study effort:

Mass Constraints. The Lunar mission design poses severe mass constraints on the Crew Exploration Vehicle as do most missions to the Moon, Mars and elsewhere beyond LEO. The physics of traveling to the Moon and Mars involves the "pushing" of mass to the destination requiring significant propellant and supporting structure. Power systems introduce a multiplicative effect on mass as power must be collected, stored, distributed and then shed as waste heat by the thermal system. These multiplicative factors argue for the judicious control of power to allow the application of scarce mass resources where they do the most good.

Reducing Mass. The CEV design had proceeded through several design cycles. The link between mission objectives and the required functions were masked by a large number of lower level derived requirements including the application of two failure tolerance at a low level. The conceptual design had matured to the point that a significant number of derived requirements severely limited design options. The system was constrained to the point that alternative designs, even ones utilizing less mass, appeared to violate derived requirements.

Even after setting aside some derived requirements, the team found it hard to identify where to reduce mass and was not comfortable with "loping" off pieces of an existing system design without understanding how mass reductions would effect crew safety and mission success. The team was challenged to identify how to get the system back inside "the box". Figure 1 shows a notional box with Risk, Performance, and Cost / Schedule boundaries. Valid solutions appear as surfaces inside the box boundaries. If a system design results in parameters outside the box, it is hard to lop off pieces to get back inside the box without compromising the integrity and cohesiveness of the integrated system.

To avoid the drawbacks of loping pieces off the system, the study team started with a minimal system whose performance and cost parameters were well inside the box, and risk parameters outside the box. The team then proceeded to build up the system, add to the minimal system reducing risk along the way until a balanced closed solution was found.

<u>*Design Prescriptions and Rules*</u>. While evaluating alternatives, the team recognized that there is no predefined recipe or prescription for safety. There is no a priori prescription for the design of a safe human rated system. No single process or single rule such as two failure tolerance will by itself assure safety and mission success. Hazards exist in context of a design and an operational sequence and therefore are unique to each mission. When considering safety as the absence of uncontrolled hazards, we realize that we cannot write enough rules and requirements to preclude hazards and prevent latent defects. We cannot prove this "negative", i.e. that all hazards are controlled, or that there are no latent defects.

Success during mission operations is assured by following procedures and rules. Procedure and rule development starts by exploring and anticipating what may go wrong and what can and should be done about it. Decisions are captured in procedures and flight rules and are followed in a disciplined manner. During operations, procedures and rules tend to drive what is done which is the opposite from upfront work where mission objectives, an operational sequence, and critical functions drive design.

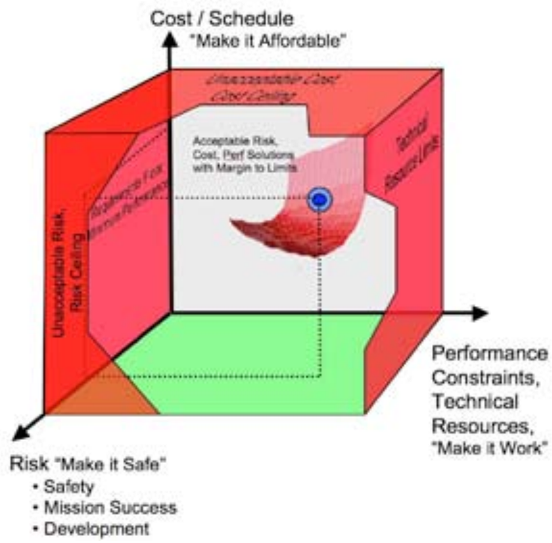

Figure 1 Box Defining Boundaries

Absent a prescription for a safe design, the challenge then is to design the system for the minimum risk at the integrated mission level.

Exploring alternate architectures along with their associated failure modes is critical to identifying the lowest risk and most robust solution. Upfront design work provides the most leverage in obviating or mitigating weakness and should result in an architecture with a predictable and coordinated response to failures threatening the critical functions necessary for safe crew return. A flexible iterative design loop is necessary to explore alternate designs and alternate operational approaches.

Success in the high risk business of manned space flight is grounded in providing sufficient capabilities for "safe crew return" should system elements fail. Teams need to explore system weaknesses, risks, hazards, etc, in context of the design's operation and its exposure to the natural and induced environments. An essential part of the risk evaluation includes identifying specific functional failure modes of system elements. When unacceptable threats are identified, ideally eliminate them from the design first and if that is not possible reduce the severity of the threats by decoupling the threats from the susceptible system. Finally, design the susceptible system to tolerate the threats with the minimal impact or essentially survive the consequences of the threat.

Top down and bottoms approaches are needed to explore and capture system weaknesses with an objective of finding safer alternates and or simple systems to preserve safe crew return. Not providing two failure tolerance, or not meeting a requirement is not necessarily a weakness of the system. Weaknesses exist in actual physical vulnerabilities of the end item rooted in the as built system acting in a manner that results in undesired consequences.

Two failure tolerance provides one mechanism to minimize risk but such an approach must be balanced against the added complexity and the utilization of scarce resources. Additional complexity intended to enable a system to survive a failure may result in a higher likelihood of system failures offsetting the improved failure tolerance.

Resources need to be applied where they do the most good for the total system. Once resources are consumed they cannot be used in other areas to improve their safety. Stated differently, a two failure tolerant system design should not result in a less safe system over other alternatives.

Requirements. The team operated under the assumption that requirements can inadvertently constrain the design and potentially eliminate safer or lighter options. A proliferation of requirements, rules, and other prescriptions can lead to the false confidence that compliance with those rules will result in a safe and proper system. The sheer volume of rules / requirements and the massive effort to show compliance with those rules can lead to the illusion that the system must be a good and safe one. The irony of all the rules and prescriptions is they can inadvertently reduce the discussions and exploration on the very risks that the rules seek to prevent, and can unintentionally remove the onus for a safe and reliable system from the designers and place it on the rule writers.

It was therefore important to distinguish between requirements establishing program needs and objectives from derived requirements intended to constraint the solution space. The team identified the requirements establishing needs and objectives that if met make the program worthwhile. These served as the validation bases for subordinate derived requirements. The derived requirements were candidates for change and could be solidified later after a design reference mission and a design approach has been considered and evaluated from a risk standpoint.

Safety and Mission Success. For the purposes of the study, a distinction was made between Safety (loss of crew) and Reliability (mission success). This distinction was important since a human rated vehicle fundamentally preserves safe crew return over mission success. Safety and reliability objectives often work together, but can also compete. The two work together when margins are added to the system to ensure its continued operation from both safety and mission success perspectives. They compete when safety objectives seek to prevent a hazardous condition that also interrupts mission success. For example, a human rated system would set safety limits prior to the point of failure to allow a crew abort scenario. An early or false abort may occur at the expense of mission success. Such limits preserving abort are not present in unmanned vehicles.

Complexity. Complexity is often the antithesis of safety and reliability as complexity can obscure unintended and unexpected interactions and coupling of system elements.[2]

Robustness is achieved by knowledge of how the system responds to intended actions or faults and complexity obscures the predictability of the system's response. A robust system is predictable, and does not produce surprises. A complex system with a large array of interactions and stimuli will harbor unexpected and undesirable responses.

Interactive complexity threatens to obscure safety risks. The system can become so complex that there are "no obvious" safety risks. Complexity should therefore be limited to the minimum necessary to accomplish the mission objectives.

Complexity is a relative term as no meaningful absolute scale exists. Complexity must be linked to the ability to predict the systems' response and is not necessarily related to part count. Finding the correct level of complexity is the hard part and requires good systems engineering. To determine the minimum complexity the team established a minimal floor for the system design as driven by the critical functions necessary for meeting mission objectives.

A large part of the systems engineering effort involved identifying where separate pieces were necessary to support critical functions, where they should be separated and decoupled, and then integrating those pieces into a cohesive whole.

A driving consideration in minimizing the complexity of space systems design involves balancing centralized versus distributed architectures with respect to safety. Due to complexity, systems are centralized so a single element can orchestrate the integrated vehicle. However from a failure standpoint systems are decentralized to limit the coupling and the cascading of failures from one subsystem into others and to allow the crew to utilize backup systems and simple manual methods to control critical vehicle functions.

3. Assembling an Integrated team

The study effort expanded the term "Avionics" to the more global "Electrical Systems". The electrical systems team included representatives of all subsystem elements that control the flow of electrons as well as software, mission design, and operations. The electrical system was defined to include all electronics components on the spacecraft, from where the current or voltage is generated in a sensor or a power source to where the current or voltage ends in an actuator, or the signals leave the spacecraft. This broad view enabled a holistic understanding of the complete system and rapid appreciation and evaluation of risk and alternatives.

The team also included Reliability, Safety and Risk analysts who provided a skeptical "what can go wrong" mindset complementing the engineer's optimism in expecting the design to work.

The electrical systems team included representatives from Electrical Power, Command & Data Handling, Communications & Tracking, Guidance Navigation & Control, and Software disciplines as shown in Figure 2.

For the crew interface, Environmental Control And Life Support System & thermal, a clearly defined interface was established to the electrical systems allowing independent evaluation of the non-electrical systems. Representatives of the electrical systems team worked closely with the Systems Engineering and Integration to coordinate issues that crossed discipline boundaries.

The electrical system team's study efforts relied heavily on a risk driven cyclic loop to attack risk drivers in a systematic top down

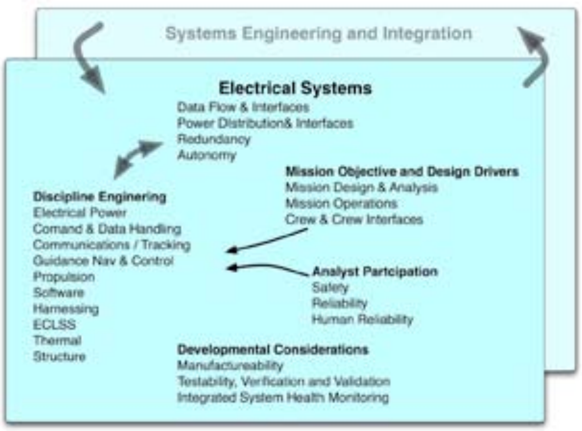

Figure 2 Electrical Systems Team Members

fashion as shown in Figure 3 and described in the rest of this paper.

Each functional element of the electrical system was assigned to a team member and team members were encouraged to communicate and collaborate to ensure individual system elements combine into a cohesive integrated system. Functions and interfaces were established with minimal overlap and without holes. The well-coordinated electrical systems design team was guided by the following objectives:

- Establish an integrated view of electrical components, sensors to actuators
- Identify where common designs reduce box count and complexity
- Identify where common cause failure threatens safety and reliability
- Identify design overlaps and holes in design
- Provide a clear and integrated interface to Safety and Reliability Analyses
- Integrate results with the overall vehicle systems engineering team

Safety and reliability analysts were also part of the team providing a "skeptical" view and seeking to continually encourage "what can go wrong" type questions along with analyzing the system design. A key contribution of the reliability team is the linkage of the design reference mission to the design, to identify system level failure and recovery scenarios that are used to evaluate back up redundancy alternatives. This helps designers to envision the role of their system in its entire context beyond the written requirement, allowing

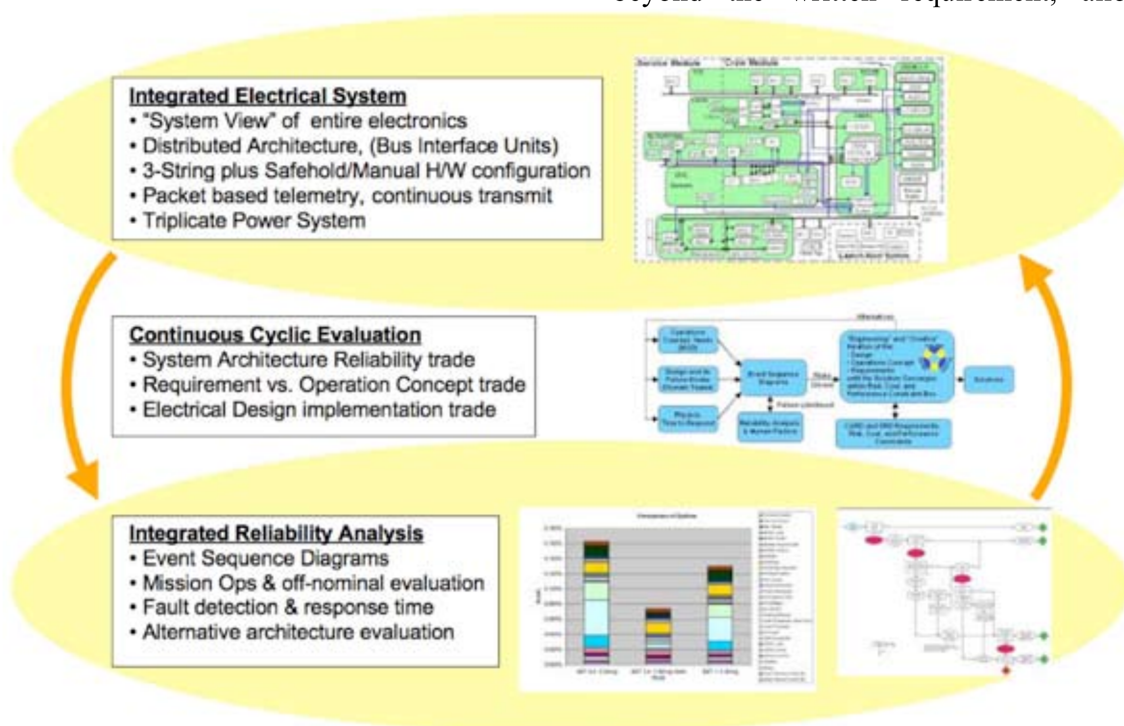

Figure 3 Electrical Systems Risk Driven Design Loop

them to conceive of designs that achieve high reliability with maximum simplicity.

4. Description of the Design Approach with Example

A buildup approach was fundamental to the performance of the study.[3,4] The approach started with the minimal incarnation of the system to:

a. provide rationale for the system design including efficient utilization of scarce mass and power resources,
b. identify whether the system has any hope if being “in the box”,
c. establish a “floor” for the complexity of the system.

In this case the minimal system was single string. Building up the system from this baseline provides rationale for every system element, every watt, and every kilogram of mass based on system weaknesses and risk. The single string system provides a direct link between the required functions and performance requirements without the complexity of redundancy. The addition of backups, redundancy, and failure tolerance was addressed later after assessing weaknesses and risks of the single string system.

A secondary objective of establishing a minimalist system was to make sure the simplest solution is in the box, if it is not, then alternate designs or even alternate mission objectives and constraints maybe necessary. If the minimalist system is in the box, then margin to box limits were available to improve safety and mission success based on risk drivers.

Figure 4 shows the systems engineering approach starting with mission needs and objectives driving the identification of an operational sequence and critical functions that in turn then drive an iterative design loop.

An iterative design loop was necessary to assure the requirements, the system design, and the design reference operations concept mission are developed in a cohesive manner assuring consistency.

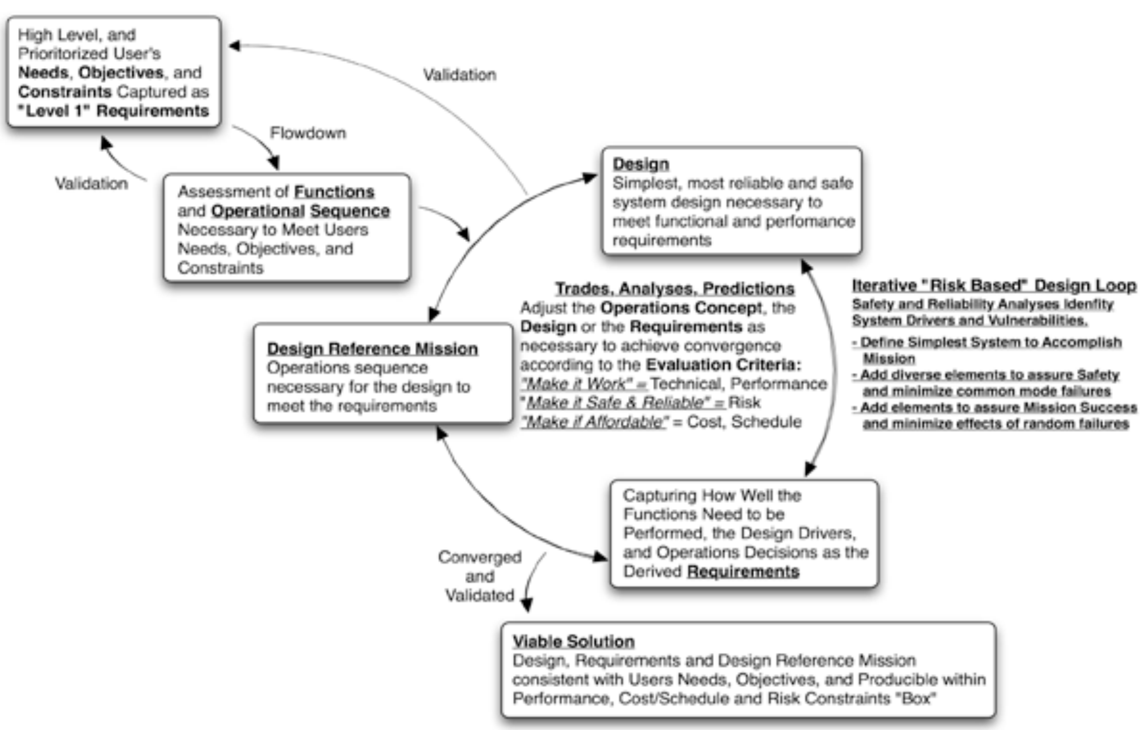

Figure 4 Systems Engineering Approach

Identify high level driving requirements. The study started with the identification of those requirements that establish program needs and objectives as distinguished from derived requirements that specify solutions. Due to the overall goal of reducing mass, the team had the flexibility to question requirements and identify those that if changed would result in mass savings.

Capture the concept of operations in a design reference mission. Understanding the operational sequence as captured in the design reference mission was critical for the subsequent work. The time ordered sequence of activities necessary to meet mission objectives, their time criticality, and sequencing constraints became design drivers.

Identify Critical Functions. The time ordered sequence of activities helped define not only the critical functions necessary for accomplishing mission objectives but also the critical functions for safety returning the crew. Critical functions for both safety and mission success were defined and tracked separately.[5]

Safety critical and mission critical functions were then used to identify the simplest design capable of implementing the functions. During the risk analysis described below, alternative approaches including back ups were identified to protect these critical functions.

4.1 Identify the simplest design of the system, "Make it Work".[6] For the purposes of this study the system was reduced to the simplest system that performs the critical functions necessary to accomplish the mission objectives. In this case a single string system with one computer was selected. It was recognized that such a simple system would not be "flyable". However establishing a minimal system was critical for establishing a floor for the minimum complexity of the system and determining whether a solution existed within box boundaries. Starting with a simple system also serves to identify the system's weakest links as well as those elements whose failure response is inconsistent with the system's critical functions.

The following considerations were important for the configuration of the single string design and balancing a distributed versus centralized approach:

Network for Internal Communications – drivers were reliability (the simplest, lowest data rate necessary), low power, robust to failures (fail high, low, blabber mouth), along with upgradeability and extensibility. Limiting bus data rates below the 100 – 200 MBbs range minimizes power consumption and dissipation at all the network nodes. Additionally, limiting these rates significantly reduces the complexity of testing the system. Any interfaces requiring higher data rates were hardwired point to point as necessary.

Method for connecting to the network – through a robust terminal with low power interfaces that interface to the bus on the front end and to the user at the back end through digital, serial and analog input and output interfaces.

Computer System Architecture – A central computer was chosen to orchestrate functions performed by network terminals while balancing central control and limiting coupling and interactions should terminals fail. The design solution assigned safety critical functions to appropriate terminals, Bus Interface Units (BIU,) and subsystem electronics boxes. The BIU design would provide predictable end item functionality in the event of communication loss with the main computer, thus increasing the independence (robustness) of the subsystems. Additional computational power necessary for Automated Rendezvous and Docking was provided by an Auxiliary computer that can be added as part of a mission kit when needed along with sensors.

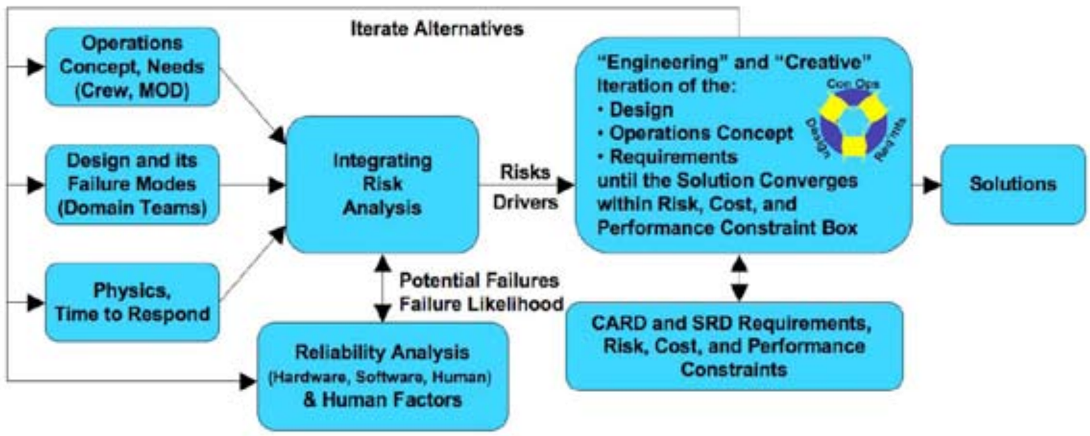

Figure 5 Integrated Risk Analysis Flow

Separation of Functions – Care was exercised to limit the coupling of disparate functions. A driving consideration for isolating functions was to limit collateral damage in the presence of failures and to allow simple backup control of only the function that failed. The central computer was not given control over low level functions, rather the BIU defaulted to a predictable and known operational mode that maintained low level functionality. Balancing centralized control with distributing low level functions allows simple backup or manual controls to only replicate the failed higher level function.

4.2 Explore risks to safety, and then "Make it Safe". This step in the buildup approach was designed to identify aspects of the design that protects safety critical functions necessary to meet mission objectives. The set of safety critical functions identified in the previous steps were used to guide safety risk assessments. Risk assessments evaluated the basic single string design along with candidate design approaches seeking to obviate or mitigate risk through alternatives that eliminate the risk, utilize system elements already on-orbit in different ways, point design solutions such as backups, or additional like redundancy.

Integrated risk analysis. An integrated risk analysis brought together the operations sequence from the design reference mission, the system design, the physics applicable for the situation, and safety and reliability analysis results as shown in Figure 5. Event Sequence Diagrams were used as the mechanism for capturing specific scenarios and the resulting effects of failures. Failure Modes and Effects Analysis (FMEA) were performed from a top down functional standpoint as actual design details were not yet complete. Historical failure rates were used for bottoms up reliability analysis to represent the general likelihood of the type of system component and as a representation for the complexity of the design. Engineering fears and threats based on historical data and engineering judgment were also used to evaluate weaknesses of the simple system. Critical to this process was the collection and ranking of all risks from all sources. This sorting and ranking part of the process is critical for systematically considering and attacking the biggest risk drivers first.

As risk drivers are attacked, alternative approaches to the operations sequence and or the design were fed back into the loop for reevaluation.

It is important to note that this type of analysis performed early in the project's life cycle focuses more on a functional level than on a hardware level. It was too early in the program to rely on "bottoms up" reliability analysis alone. Without an actual design that would exist at CDR time, it is difficult to identify all the physical failures that can result in loss of crew. As the design matures specific failure modes of the exact design will replace functional failure modes.

Component based models that only assume hard failures may overlook important system failures that surface when individual components and software interact in unforeseen and adverse ways. The more complex the system becomes, the harder it is to anticipate all the ways it can fail especially this early in the design. It is for this reason that it is advantageous to look for the simplest most robust and easiest to understand solution that attacks each weakness and preserves critical functions. The team identified what functions might fail so that the system can protect those functions.

The team also recognized that there are significant error bars, up to a factor of 10, around any predictive analysis. So the team needs to be careful when relying on failure rate estimates beyond the first significant figure. Thus the analysis provided the means to rank the different architectures relative to each other without focusing on the absolute failure prediction of any given architecture. At this point the objective of the numbers is to help in the ranking and sorting of risks from all sources.

The risk analysis started with the end of the mission, safe crew return, and sequenced backwards to launch. Four critical mission phases were evaluated "Entry, Descent, and Landing", "Critical Burn", "Lunar Loiter", and "Ascent" and captured in event sequence diagrams. Figure 6 provides an example of the type and format of the Event Sequence Diagrams that were created for each of the critical mission phases. The event sequence diagram helped to visualize the responses and

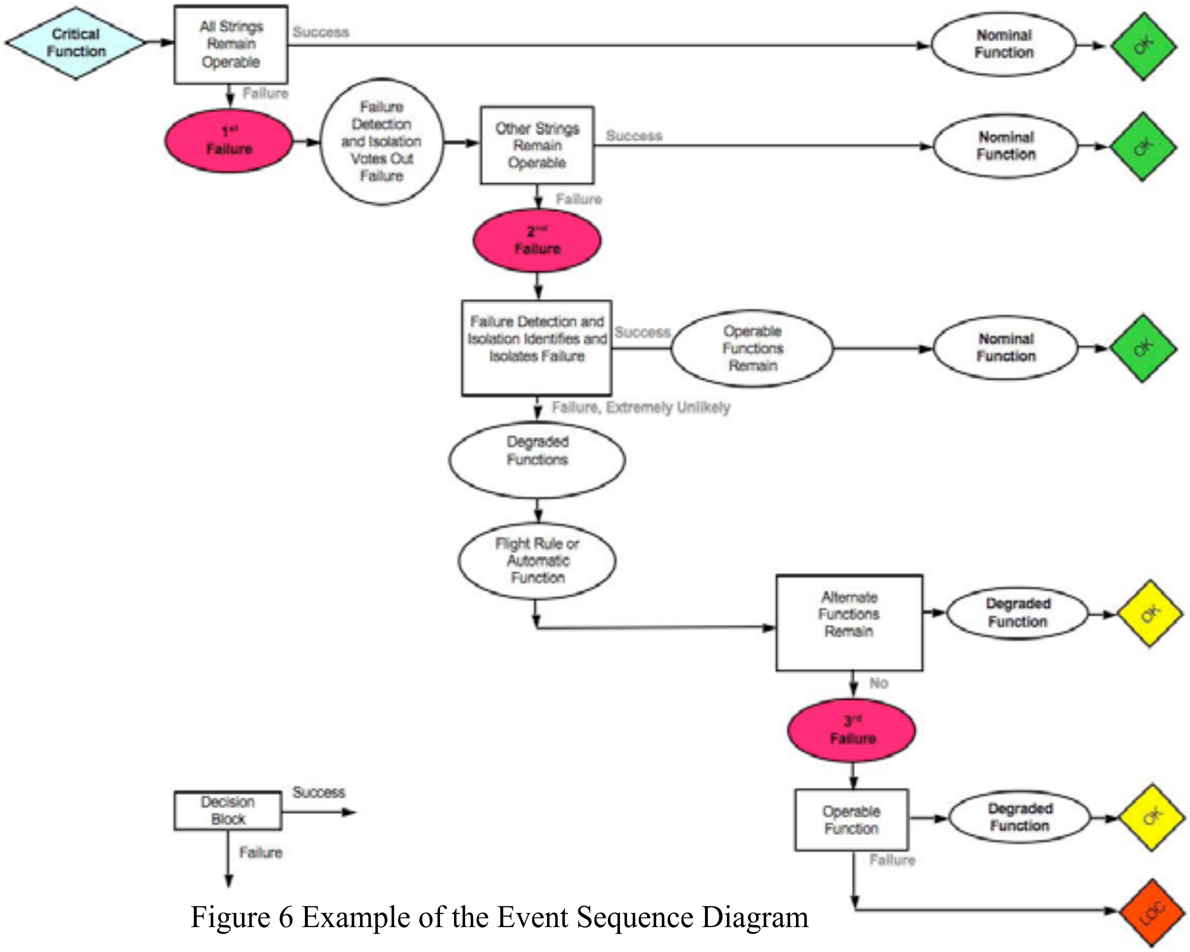

Figure 6 Example of the Event Sequence Diagram

downmodes that could protect the crew. The iterative risk analysis loop, shown in Figure 5, along with the event sequence diagrams, Figure 6, allowed an exploration of risk along the operational sequence and an evaluation of alternatives that eliminate the risk, designs that inherently should not fail, utilize system elements already in orbit in different ways, point design solutions, or redundancy.

Exploring alternatives for mitigating each risk was critical and requires creative "engineering" and compromise among often competing needs. The team looked for the most mass efficient method to reduce risk. Some alternatives mitigate more than one risk, and finding these synergistic solutions attacking multiple risks was important. The team looked at all the risk on the table and let the risks drive solutions and design decisions.

The integrating risk analysis identified major drivers that resulted in the following three additions to the simple single string system:

a) a simple manual control while crewed,
b) a simple “safemode” to protect a power positive and stable vehicle attitude while uncrewed, and
c) a low power mode to enable an Apollo 13 style manual, minimal power return.

It is significant to note that the first elements added to the minimal single string vehicle were not additional strings of like full performance redundancy. The team sought to add simple diverse systems for manual control while crewed and simple safemode while uncrewed to protect safe crew return at reduced, but adequate performance. Figure 7 provides a functional diagram for the Safemode and Manual System. Manual control or providing simpler systems to control actuators is utilized on modern aircraft such as the 777. Simple systems or “safemodes” protecting health and safety are often utilized on unmanned spacecraft to provide time and opportunity for the ground to apply appropriate corrective action.

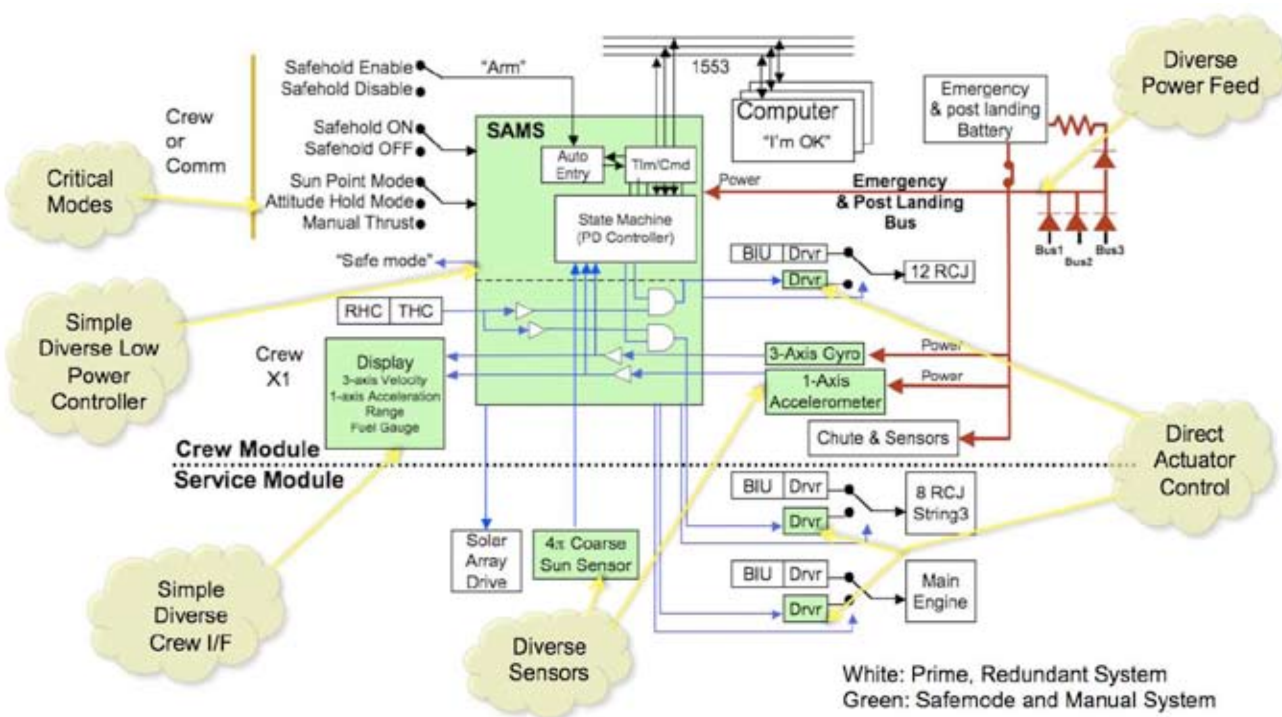

Figure 7 Safehold and Manual System Functional Diagram

An uncrewed safemode also provides a last line of defense, a "never give up" function preserving the vehicle health and safety should the primary system fail. Safemode provides a power and thermal safe attitude as well as a stable attitude for Lunar Ascent Module Docking using simple coarse sensors and a gyro controlled by a simple hardware based controller.

Safemode was focused on assuring crew safety through robustness enabled by an alternate means to control critical vehicle systems. This independent system becomes even more powerful from a reliability perspective if it remains simple containing fewer parts and fewer connections. The simple safemode is lower performance than the prime system, although it has the requisite performance to enable safe crew return. Simplicity in the dissimilar system can also significantly mitigate the cost burden of having to design, certify and maintain full performance "backup" systems. The goal is to achieve a significant improvement in overall reliability for a fraction of the cost of the primary system. Simple systems are more easily manufactured and tested due to their lower complexity and are more reliable due to fewer failure modes and better test coverage.

Safemode provided a Sun Pointing Mode, an Attitude Hold Mode and worked in conjunction with manual crew control. In addition, some critical subsystems such as power and ECLSS had enough local "smarts" in the BIU to control battery charging, load shedding, and control of the breathable air and temperature autonomously. Communications with the ground are via 4 pi Omni antennas that did not require any onboard switching logic to achieve a minimally functioning forward and return link.

With the safemode added to the system, failure of the central computer or its network had minimal immediate effect on system health and safety. The vehicle can enable safe return of the crew using simple low power systems even under an Apollo 13 type or ISS Computer Loss scenario after primary systems suffer unexpected failures.

Safety improvements to power generation and distribution systems considered the coupling between power and data functions to assure that failures in the power strings minimize collateral damage, i.e. coupling, to other subsystems. For example, power and data paths were defined such that failures in a data path would not couple into power distribution and failures in power generation and storage would limit the effects on data paths. For example, failure of a power feed switch results in loss of the load's function and needs to be tracked that way. Safety critical functions were protected from switch failures by diverse or alternate power feeds. The Safemode and manual control function was given a separately powered safemode and emergency power bus with its own emergency battery.

Uncrewed operation also required a certain number for "special" hardware decoded commands that enable reset, recovery, and reconfiguration of the primary system without requiring the primary system to do so. The team provided recovery methods such that prime system failures do not prevent utilization of redundant and safemode systems.

The team utilized a litmus test for assessing the "independence" of prime system elements from the systems protecting the capability to safely return the crew. The test involves encircling system elements on a system block diagram that are necessary for crew return using the prime system and then encircling elements necessary for safemode. Any overlaps, or circling of common elements between the prime system and the safemode system warns the system designer of the potential for common cause failures that need to be addressed.

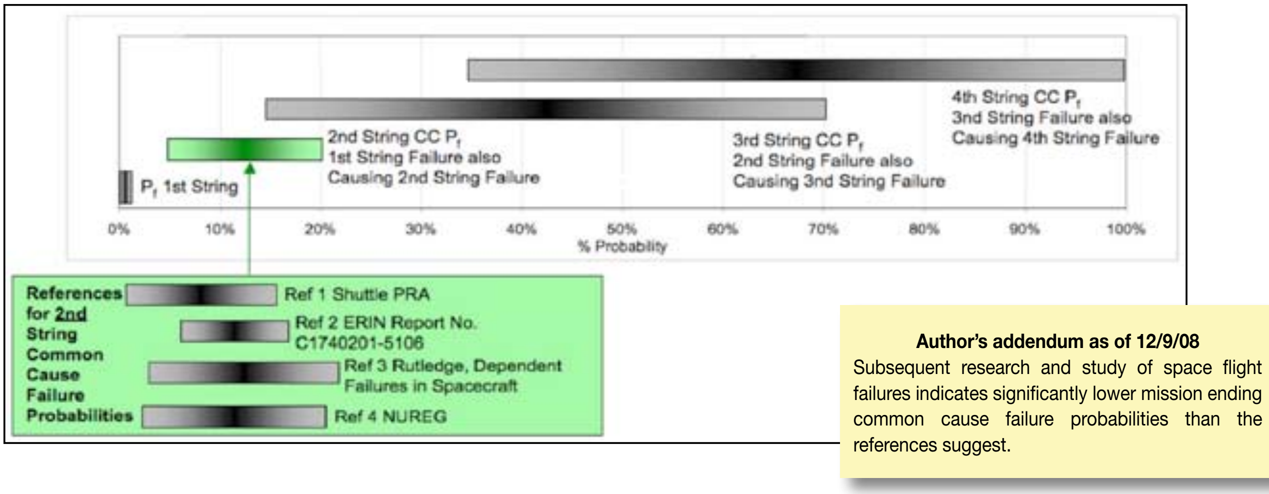

Figure 8 Conditional Probabilities of Multiple Failures in Identical Components

Risk Analysis Results. Reliability analysis supported the integrated risk assessments by providing failure rate estimates that were used to rank risk drivers. To thoroughly evaluate failure likelihood, two "knobs" were applied to the reliability models, one is the "statistically independent" or random failure rate and the other is the "dependent" or correlated / "common cause" failure rate.

Since system component selection and detailed design remains in flux, failure rates of similar hardware elements were used in the analysis. Failure rate sources included databases of Shuttle, ISS, and robotic spacecraft experience.

Common cause failure probabilities and uncertainties that were used in the reliability analysis are shown in Figure 8[7]. The lower left corner includes a notional probability that the first string will fail. The broad bands above the first string failure probability represent the estimates for the probability of a second string failing given that the first string has failed, the probability of a third string failing given that two strings have failed, and the probability of a fourth string failing given that three strings have failed, respectively. While there have been no studies that provide definitive estimates for these values for spacecraft components, some limited studies have been performed on Space Shuttle components, and other non-aerospace sources (see references Figure 8) that do offer insights particularly for second string failures. As shown in the green block a range was determined from each of these sources which are all in relatively good agreement to estimate a range for the second string avionics failures.

Many alternatives were evaluated during the course of the risk analysis. Results are summarized in Figure 9 providing a relative comparison of single string to quad redundant systems with common cause factors and component failure rate along with applied uncertainties[8]. Results show that common cause failures tend to limit the reliability improvements above 2 or 3 strings. A sweet spot is evident somewhere around 2 strings and 3 strings with a diverse safemode providing additional benefits. From a safety and reliability standpoint the team felt that an optimized "sweet spot" exists in a 2 to 3 string prime system with a diverse independent safemode as depicted in Figure 8. Adding a second prime string does significantly improve the system failure rate with a relatively low contribution from common cause failure and appears mass efficient for the reliability benefit. Adding more than 3 strings for the purpose of reducing the random portion of the failure rate does not appear necessary and brings with it a significant common cause contribution that does not make it mass efficient. There are other reasons to add multiple strings as discussed later. These reasons include voting out failures under time critical scenarios.

Figure 10 compares the failure contributors of a three string system, to a three string plus safemode, and a four string system. Examination of the figure shows that the safemode reduces the system failure probability by half. Failure modes that the safemode backs up essentially disappear (e.g. Crew Interface Displays) due to the credit for independent backup, while the failure rate contribution of other system elements that are not protected by the safemode (e.g. S/A Regulator) merely reduce. The benefit of adding a fourth string is limited relative to adding a safemode by the potential for common cause failures.

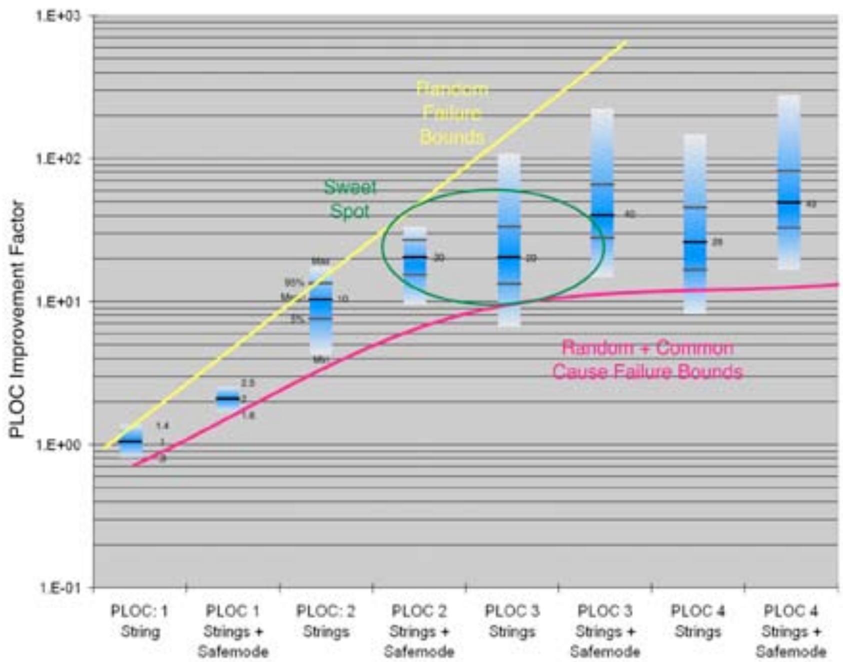

Figure 9 Example Comparison of Alternatives vs. Probability of Loss of Crew Improvement Including Uncertainty

4.3 ***Explore risks to Mission Success, and then "Make it Reliable".*** The set of mission critical functions, as opposed to safety critical functions discussed in 4.2 above, were used to guide the exploration of threats to mission success. These threats were captured and attacked from most significant to least significant. Many threats to mission success surfaced during the safety discussions and analyses described in the previous step and were addressed in this step. In general a second string of like redundancy was added to the prime system to improve the probability of mission success.

In general it appeared that two strings may provide sufficient reliability as indicated by the results shown in Figure 8, however identifying which of the two strings has failed may be difficult. Most failures could probably be isolated by built in self tests or by comparing inputs and / or outputs against expected results. However the possibility of dilemma cases requires a tie breaker. Use of the diverse safemode may aid in breaking a tie, although safemode's reduced performance may not provide sufficient precision and accuracy. Therefore a third string was added to resolve dilemma cases for time critical functions allowing a simpler voting scheme among three strings. There was a mass penalty for the third string, however modern low power and low mass components alleviated some of the inefficiency.

4.4 Look at resources including development costs and then "Make it affordable". Life cycle costs were factored into some of the decisions that were drivers. Cost drivers included nonrecurring software development as well as maintenance. Drivers from a safety and reliability standpoint included Fault Detection, Isolation and Recovery (FIDR) and Integrated System Health Monitoring (ISHM). A major supporting driver included the consideration of additional redundancy to enable voting over more extensive FIDR and built in test. In general the addition of a third string simplified software development by enabling voting algorithms.

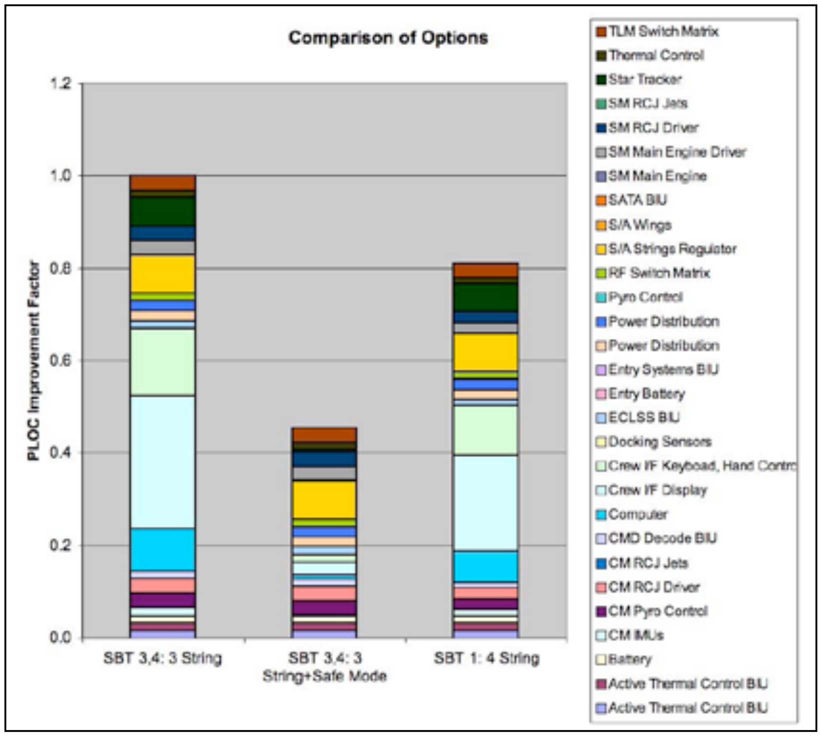

Figure 10 Example Comparison of Electrical Systems Element Contribution to PLOC

5. Conclusion

The Smart Buyer design effort was successful in identifying risk based design drivers, recommending requirement changes along with innovative design alternatives that could reduce mass while improving safety and reliability.

- Merging of technical expertise and experience of the human spaceflight, robotic and research centers was effective in identifying alternate concepts that reduce complexity, power and mass. In particular, techniques utilized by robotic spacecraft to keep the vehicle safe directly apply during the operational phases where the CEV is "uncrewed" in lunar orbit. Robotic spacecraft experience complemented the experience of the manned space flight centers in utilizing the crew's capabilities for enhancing mission success and safety. In addition, some low power and low mass technology routinely utilized by robotic spacecraft can be transferred to manned spacecraft.
- There are no a priori prescriptions taken by themselves that result in a safe design, therefore the design team must design for the minimum mission risk. Even a two failure tolerant design should not be chosen over a safer alternative. Minimizing risk centers around exploring system weaknesses and unpredictability in context of the operational scenario and then attacking those risks from highest to lowest.
- Designers must control complexity that may obscure hazards and unintentional interactions and coupling of system elements. Teams should avoid complexity that results in "no obvious safety risks". Early design and analysis work should focus

on preserving critical functions and introducing complexity only where it is necessary for safety and mission success.

- An effective approach to defend against interactive failures obscured by system complexity is through simple, easy to understand diverse systems that protect those functions critical for safe crew return.
- It is important that teams identify and collect risks in a systematic, top down fashion and assure they remain visible and are communicated to team members.
- A "build up" approach is effective in limiting complexity to the minimum necessary and providing a risk informed rationale for not only the system design, but also the rationale for the existence of every component and the utilization of power and mass resources. The buildup approach balances each risk in light of all the other risks present in the vehicle. Accepting risks is also balanced against the utilization of power and mass resources and increased complexity.

Severe mass constraints require the wise utilization of scarce mass resources to protect safety and mission success. Both the Crew Exploration Vehicle and the Lunar Access Surface Module projects are utilizing variants of the build up approach described above to not only design their vehicles but also balance risks. Additional information about this risk informed, systems engineering technique is available in the NESC Report RP-06-108_05-173, "Design, Development, Test, and Evaluation (DDT&E) Considerations for Safe and Reliable Human Rated Spacecraft Systems, Volume I" May 1 2007, http://www.nasa.gov/pdf/176245main_RP-06-108_05-173_DDT%26E_Final_04-30-07_(Vol[1]._1Master).pdf

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Julie Kramer White of NASA, (current CEV Chief Engineer,) NESC Discipline Expert in Mechanical Analysis, Reliability Lead during the performance of the Smart Buyer Study and the initial NESC DDT&E Report team lead.

Dawn Schaible of NASA, NESC Systems Engineering Office Manager, for her role as the Systems Engineering Lead for the study.

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Agency wide Smart Buyer Study Team.

References:

[1] "Crew Exploration Vehicle 'Smart Buyer' Design Team Final Report", NASA Engineering and Safety Center, May 2006

[2] Discussions with TK Mattingly

[3] Build up approach from manned spaceflight experience suggested by TK Mattingly Apollo 16 CM Pilot and Shuttle Mission Commander, Jerry Gilmore based on Apollo Guidance System design at Draper Labs, Joseph Fragola based on Apollo LM design techniques at Grumman

[4] Build up approach from robotic spacecraft experience: Bay, Michael, "MIDEX / MAP Project Reliability Program Overview", Sept 1997

[5] See "Safety and Mission Success" under section 2.

[6] Description of the build up approach as "make it work", "make it safe", and "make it affordable" from discussions with Joseph Fragola

[7] "Design Development Test and Evaluation (DDT&E) Considerations for Safe and Reliable Human Rated Spacecraft Systems, Volume I", NESC RP-06-108_05-173, May 1 2007, Figure 3.4-1.

[8] Adapted from data in "Crew Exploration Vehicle 'Smart Buyer' Design Team Final Report", NESC, May 2006, Section 4.1.

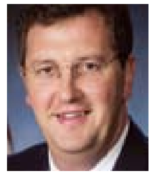
Tommy Yoder, Jacobs Technology at WSTF, places fiduciary markers on a large Kevlar® COPV being prepared for pressure testing.

Cross-Agency teaming:

"In my experience as a NASA researcher, cross-Agency teaming occurred only when self-initiated by researchers. The NESC brought team members with unique expertise together from seven Centers. I was impressed by how effectively they all leaned on and learned from each other."

— Dr. Terry St. Clair, Consultant Team Member, Retired Materials Research Branch Manager, LaRC

NESC Core Leadership



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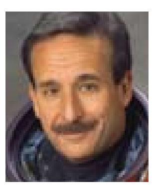

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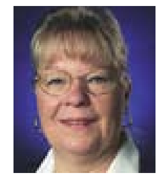

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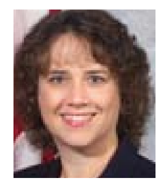

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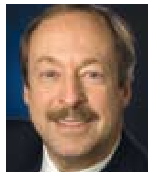

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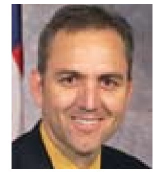

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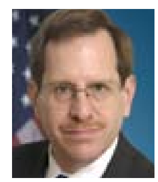

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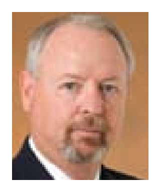

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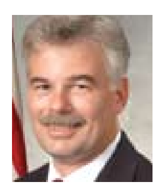

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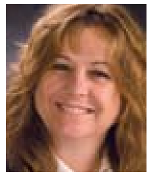

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Dr. Charles F. Schafer

NESC Chief Engineer

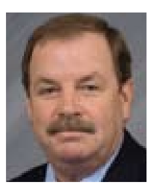
Dr. Charles F. Schafer is NESC's Chief Engineer at Marshall Space Flight Center (MSFC). Dr. Schafer came to the NESC from MSFC where he served as the Deputy Manager of the Propulsion Research Center of the Science and Technology Directorate. Dr. Schafer has over 42 years of experience in leading research 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 propellents.

Steven S. Scott

NESC Chief Engineer

Mr. Steven S. Scott is NESC's Chief Engineer at Goddard Space Flight Center (GSFC). Mr. Scott also serves 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 18 years experience in satellite software engineering.

Michael D. Smiles



NESC Chief Engineer

Mr. Michael D. Smiles is NESC's acting 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 23 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 21 years of engineering and management experience leading the development of space flight systems.

NESC Chief Engineers *Con't.*

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 42 years of management and technical experience leading missile and aircraft programs.

Clayton P. Turner

NESC Chief Engineer

Mr. Clayton P. Turner is NESC's Chief Engineer at the Langley Research Center (LaRC). Mr. Turner also serves as the LaRC Chief Engineer. He has over 18 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.

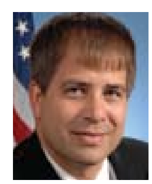
NASA Technical Fellows

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 32 years of experience on embedded software development.

Mitchell L. Davis



NASA Technical Fellow

Mr. Mitchell L. Davis is the NASA Technical Fellow for Avionics and is resident at the 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 26 years of experience in power and avionics.

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 28 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.

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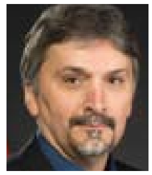
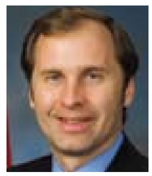
NASA Technical Fellows *Con't.*

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 17 years of experience in performing aerodynamic, hydrodynamic, and engine system design and analysis of rocket propulsion.

Dr. Curtis E. Larsen
NASA Technical Fellow

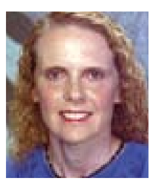


Dr. Curtis E. Larsen is the NASA Technical Fellow for Loads and Dynamics and is resident at Johnson Space Center (JSC). Prior to joining NESC, Dr. Larsen was the Technical Discipline Manager for Cargo Integration Structures in the Space Shuttle Program's Flight Operations and Integration Office. Dr. Larsen has over 28 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 27 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

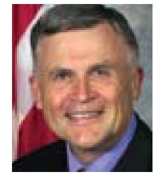


Dr. Cynthia H. Null is the NASA Technical Fellow for Human Factors and is resident at Ames Research Center (ARC). Before joining NESC, Dr. Null was a scientist in the Human Factors Division and Deputy Program Manager of the Space Human Factors Engineering Project. Dr. Null has 22 years of experience 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 20 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 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 24 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 21 years of experience in the field of ultrasonic and acoustic emission sensing techniques.

Dr. Ivatury S. Raju
NASA Technical Fellow

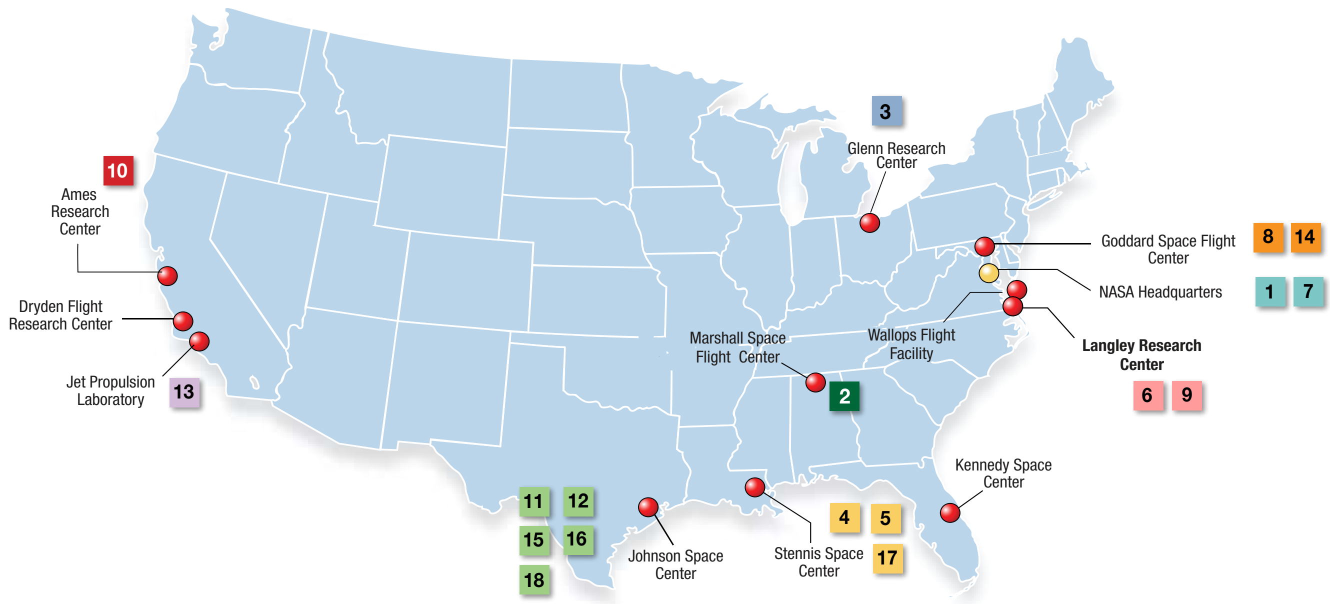
Dr. Ivatury S. Raju is the NASA Technical Fellow for Structures and is resident at Langley Research Center (LaRC). Dr. Raju was the Senior Technologist in the LaRC Structures and Materials Competency prior to joining the NESC. Dr. Raju has over 33 years of experience in structures, structural mechanics, and structural integrity.

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 41 years of life support and active thermal control systems experience during the Apollo, 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 30 years experience in the aerospace industry with expertise in aeroelasticity and integrated aerodynamic analysis.



Frank H. Bauer 1
NESC Discipline Expert for Guidance Navigation and Control (2003–04) Currently serving as the Exploration Systems Mission Directorate Chief Engineer at NASA HQ

J. Larry Crawford
NESC Deputy Director for Safety (2003–04) Left NESC to become Director of Safety and Mission Assurance at the Kennedy Space Center (KSC) and has since retired

Steven F. Cash 2
NESC Chief Engineer at Marshall Space Flight Center (MSFC) (2005) Currently the Manager, Shuttle Propulsion Office at MSFC

Derrick J. Cheston 3
NESC Chief Engineer at Glenn Research Center (2003–07) Left the NESC to participate in the Senior Executive Service Candidate Development Program (SESCDP)

Freddie Douglas, III 4
NESC Chief Engineer at Stennis Space Center (SSC) (2007–08) Currently the Manager, Office of Safety and Mission Assurance at SSC

Dr. Michael S. Freeman
NESC Chief Engineer at Ames Research Center (ARC) (2003–04), Retired

T. Randy Galloway 5
NESC Chief Engineer at Stennis Space Center (SSC) (2003–04) Currently the Director of the Engineering and Test Directorate at SSC

Dr. Edward R. Generazio 6
NESC Discipline Expert for Nondestructive Evaluation (2003–05) Currently a Senior Research Engineer, Research & Technology Directorate, LaRC

Dr. Richard J. Gilbrech 7
NESC Deputy Director (2003–05) Left the NESC to become the LaRC Deputy Center Director, in 2006 was named as the Stennis Space Center Director, and is currently the Associate Administrator for the Exploration Systems Mission Directorate

Michael Hagopian 8
NESC Chief Engineer at Goddard Space Flight Center (GSFC) (2003–07) Currently the Chief Engineer in the Engineering Directorate at GSFC

David A. Hamilton
NESC Chief Engineer at Johnson Space Center (JSC) (2003–07) Retired

Dr. Charles E. Harris 9
NESC Principal Engineer (2003–06) Currently the Director, Research & Technology Directorate at LaRC

Dr. Steven A. Hawley
NESC Chief Astronaut (2003–04) 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 (2005-06) Currently Associate Director for Management, National Institutes of Health

George D. Hopson
NASA Technical Fellow for Propulsion (2003–07), Retired

Keith L. Hudkins
NASA Headquarters Office of the Chief Engineer Representative (2003–07), Retired

Danny D. Johnston
NESC Chief Engineer at Marshall Space Flight Center (MSFC) (2003–04) 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) (2003–05) 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 (2003–07) Retired

Dr. Dean A. Kontinos 10
NESC Chief Engineer at Ames Research Center (ARC) (2006–07) Left the NESC to work a detailed assignment as the Technical Integration Manager of the Fundamental Aeronautics Program in the Aeronautics Research Mission Directorate at NASA HQ. Has since returned to ARC in the Office of the Chief Engineer

Julie A. Kramer White 11
NESC Discipline Expert for Mechanical Analysis (2003–06) Currently the Chief Engineer, Crew Exploration Vehicle Office at JSC

Steven G. Labbe 12
NESC Discipline Expert for Flight Sciences (2003–06) Currently the Chief Engineer, Constellation Program Office at JSC

Matthew R. Landano 13
NESC Chief Engineer at NASA's Jet Propulsion Laboratory (JPL) (2003–04) Returned to his assignment at JPL as the Director of Office of Safety and Mission Success

David S. Leckrone 14
NESC Chief Scientist (2003–06) Currently the Senior Project Scientist for the Hubble Space Telescope at GSFC

John P. McManamen 15
NASA Technical Fellow for Mechanical Systems (2003–07) Currently the Chief Engineer, Shuttle Program Office at JSC

Brian K. Muirhead 16
NESC Chief Engineer at NASA's Jet Propulsion Laboratory (JPL) (2005–07) Currently the Program Systems Engineer in the Constellation Program's Systems Engineering Office at JSC

Dr. Paul M. Munafo
NESC Deputy Director (2003–04) 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 (2003–04) 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 17
NESC Chief Engineer at Stennis Space Center (2005–06) Currently the Deputy Director of the Engineering and Test Directorate at SSC

Jerry L. Ross 18
NESC Chief Astronaut (2004–06) Currently the Chief of the Vehicle Integration Test Office at JSC

John E. Tinsley
NASA Headquarters Senior Safety and Mission Assurance Manager for NESC (2003–04) 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

2008 NESC Honor Award Recipients:

From left (back row): Ralph Roe, Jr. (NESC Director/Presenter); Norman Knight, Jr. (General Dynamics); Erik Weiser (LaRC); Jon Haas (WSTF); Jerry Stuart (Northrop Grumman); Lawrence Pelham (MSFC); David Dawicke (AS&M, Inc.); David Roberts (LaRC); Walter McCabe (ATK); **From left (front row):** Kenny Elliott (LaRC); Kenneth Hodges (JSC); Erik Tyler (AMA); Michael Dube (GSFC); Anna Jackson (LaRC); David Shemwell (independent consultant); Darcy Miller (KSC); James Beaty (LaRC); William Sipes (independent consultant); Raymond Lanzi (WFF); George Slenski (ATK Space); Ivatury Raju (NESC); Henning Leidecker (GSFC); James Fesmire (KSC); Kenneth Cameron (NESC Chief Astronaut/Presenter); Tim Wilson (NESC Deputy Director/Presenter). Not pictured: John Graf (JSC)

NESC DIRECTOR'S AWARD

Michael J. Dube
In recognition of technical excellence in the support and resolution of anomalies for NASA projects across the Agency including the Space Shuttle, International Space Station, and multiple robotic spacecraft.

Kenny B. Elliott
In recognition of technical excellence in the load redefinition and redirection of the Max Launch Abort System flight test vehicle.

John C. Graf
In recognition of technical excellence in the investigation of the Self Contained Oxygen Generator explosion on a British Royal Navy submarine.

NESC LEADERSHIP AWARD

Larry I. Pelham
In recognition of outstanding leadership of a diverse team of Agency and industry experts to design and manufacture the NESC composite crew module full and subscale hardware.

NESC ENGINEERING EXCELLENCE AWARD

Raymond J. (Jim) Lanzi
In recognition of exceptional technical support in the fundamental design of the NESC's Max Launch Abort System flight test vehicle.

James R. Beaty
In recognition of exceptional technical support in flight mechanics stability and control engineering for the NESC's Max Launch Abort System Flight Test Vehicle system concept development.

David S. Dawicke
In recognition of exceptional technical support in the testing of the Ares I-X Upper Stage Simulator welds.

Kenneth L. Hodges
In recognition of exceptional technical excellence in the design, development, and implementation of state-of-the-art nondestructive techniques for the composite crew module project.

Norman F. Knight, Jr.
In recognition of exceptional technical excellence in the analyses contributions to the Ares I-X Upper Stage Simulator Critical Initial Flaw Size.

Walter Thomas McCabe, Jr.
In recognition of exceptional technical excellence in the manufacture of the composite crew module.

David M. Shemwell
In recognition of outstanding technical leadership in the investigations into innovative crew seat concepts for the Orion Crew Module and alternative approaches to occupant impact tolerance modeling.

George A. Slenski
In recognition of exceptional technical expertise in the failure analysis of the STS-115 fuel cell motor anomaly.

Jerry L. Stuart
In recognition of exceptional technical excellence in the design and manufacture of the NESC composite crew module.

Erik D. Tyler
In recognition of exceptional technical excellence in the computational aerodynamics and structural analysis of Max Launch Abort System concepts enabling efficient development of the flight test vehicle.

Awards *Con't.*

NESC GROUP ACHIEVEMENT AWARD

Self Contained Oxygen Generator Failure Mechanisms Investigation Team
In recognition of outstanding efforts in reproducing the Self Contained Oxygen Generator mishap, successfully identifying the contributing factors, and developing effective corrective actions (award accepted by Jon Haas on behalf of the team).

8% Max Launch Abort System Model Team
In recognition of outstanding efforts in designing, fabricating, and testing the 8% Max Launch Abort System model (award accepted by David Roberts on behalf of the team).

External Tank Intertank/LH2 (Liquid Hydrogen) Flange Y-joint Evaluation Assessment Team
In recognition of outstanding technical support for the External Tank Intertank/ Liquid Hydrogen Flange Y-joint evaluation (award accepted by James Fesmire on behalf of the team).

Human Factors Pathfinder Core Team for Ground System Designers
In recognition of outstanding contributions to the engineering excellence of Constellation ground systems through the human factors engineering pathfinder activity (award accepted by Darcy Miller on behalf of the team).

Ice Mitigation Approaches for Space Shuttle External Tank Team
In recognition of technical excellence to develop, test, and successfully demonstrate two innovative solutions that mitigate risks posed by ice liberating from the external tank (award accepted by Erik Weiser on behalf of the team).

Langley Research Center Mission Support Team
In recognition of exceptional service, dedication and a proactive approach to providing the mission support services which have enabled the NESC to accomplish critical mission objectives (award accepted by Anna Jackson on behalf of the team).

NESC Ares I-X Upper Stage Simulator Critical Initial Flaw Size Analysis Team
In recognition of technical excellence in the analysis and engineering guidance for the design, development, and manufacturing of the Ares I-X Upper Stage Simulator (award accepted by Ivatury Raju on behalf of the team).

Pyrovalve Y-PCA (Primer Carrier Assembly) Assessment Team
In recognition of outstanding contributions investigating the Pyrovalve Y-PCA booster failures (award accepted by William Sipes on behalf of the team).

Space Shuttle Program Engine Cut-Off System Investigation Team
In recognition of technical excellence in the evaluation of the operational anomalies and reliability improvements associated with the Space Shuttle Engine Cut-Off system (award accepted by Henning Leidecker on behalf of the team).

IN MEMORIA

Paul D. Guy, recipient of the 2007 NESC Engineering Excellence Award for his leadership and contributions to the independent review for the Phoenix Project, unexpectedly passed away in November 2007.

Dr. Gopal M. Rao, a key contributor to NESC's NASA Aerospace Flight Battery Program, also passed in May 2008.

Both are missed and will be remembered for their significant contributions to the NESC and Goddard Space Flight Center.

Reports

ET Ice Mitigation	TM-2008-215324 & 215325
Prebreath Protocol for Extra-Vehicular Activity Technical Consultation Report	TM-2008-215124
Eight-Foot High Temperature Tunnel (HTT) Oxygen Storage Pressure Vessel Inspection Requirements	TM-2008-215316
ISS Fiber Optics Workmanship	TM-2008-215525
Engine Cut-Off (ECO) Sensor Reliability Testing	TM-2008-215332
CMG1 Root Cause Analysis	TM-2008-215329
Design Development Test & Evaluation (DDT&E) Considerations for Robust and Reliable Human Rated Systems	TM-2008-215126
Conax Y-PCA (Primer Chamber Assembly) Booster Anomaly Investigation	TM-2008-215548
External Tank (ET) Foam Thermal Analysis Project	TM-2008-215102
Composite Crew Module Pressure Vessel	TM-2008-215125
Crew Launch Vehicle (CLV) Project Reaction Control System (RCS) Thrust and Propellant Weight Sizing	TM-2008-215101
ISS S-Band Corona Discharge Anomaly	TM-2008-215100
ET Bipod Bolt Locking Feature Verification	TM-2008-215099
CEV LAS Aero Evaluation	TM-2008-215098
Feasibility of Conducting J-2X Engine Testing at the GRC Plum Brook Station B-2 Facility	TM-2008-215104
DC/DC Converter Unit Investigation	TM-2008-215352 & 215354
Ares I-X USS Fracture Analysis Loads Spectra Development	TM-2008-215335
Ares I-X USS Stress Analysis	TM-2008-215339
Ares I-X USS Material Testing	TM-2008-215338
Ares I-X Upper Stage Simulator Structural Analyses Supporting the NESC Critical Initial Flaw Size Assessment	TM-2008-215336
Ares I-X USS Weld Residual Stress Analysis	TM-2008-215339
Constellation Mass and Performance Independent Assessment	TM-2008-215326

Presented Papers

GN&C Engineering Best Practices for Human-Rated Spacecraft Systems TM-2008-215106

The NASA Engineering & Safety Center (NESC) GN&C Technical Discipline Team (TDT):
Its Purpose, Practices and Experiences TM-2008-215128

Guidelines for Reliable DC/DC Converters for Space Use, J. Plante, Components for
Military and Space Electronics, February 10-14, 2008, San Diego, California

Guidelines for Reliable DC/DC Converters for Space Use, J. Shue, J. Plante,
MAPLD 2008, September 15–18, 2008, Annapolis, Maryland

Rescuing EDL Data , Elmain Martinez, Adrian Tinio, Mike Gangl, Robert Powers,
Keith Shackelford, Alan Wood, Russel Westbrook, International Planetary Probe Workshop,
Atlanta, Georgia, June 23-27, 2008

NASA Experience with Pogo in Human Spaceflight Vehicles, C. Larsen, NASA Johnson
Space Center, United States, AVT-152 Symposium on Limit Cycle Oscillation and Other
Amplitude-Limited Self Excited Vibrations, North Atlantic Treaty Organization

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