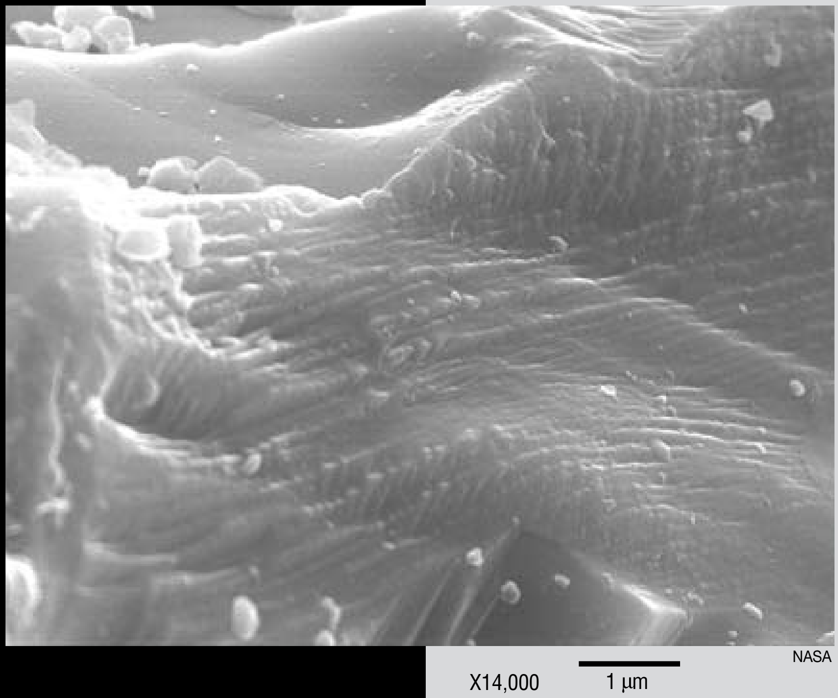
National Aeronautics and Space Administration

NASA ENGINEERING & SAFETY CENTER

NESC 2007

TECHNICAL UPDATE



Lunar dust grain surface etched by solar wind; such surfaces have a high density of crystal dislocations and are presumably very reactive. The NESC held a workshop on lunar dust to bring together the scientific and engineering communities to discuss the known hazards of lunar dust on humans and mechanical systems. Strategies to mitigate the effects of lunar dust on our next generation of explorers will be needed to enable a permanent return to the lunar surface.

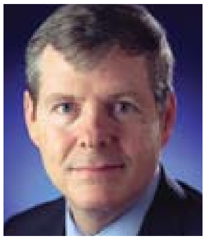
"The NESC is an exemplary model for rapidly, effectively and proactively applying the best talent we have to the toughest and most urgent operational challenges at NASA. In doing so, the NESC continues to gain recognition as a steward of technical excellence and as an invaluable resource to the Agency's highest priority programs."

— **Dr. Michael D. Griffin,** NASA Administrator

Christopher J. Scolese Associate Administrator

We at NASA are fortunate to be at the forefront of efforts to explore and utilize the air and space environment for the benefit of civilization. Our missions range from improving air traffic control, to tracking forest fires from UAVs and spacecraft, to sending humans into space, to understanding the Earth, to robotic missions at other planets, to observing and understanding our Universe. The NASA Engineering and Safety Center continues to be a valuable resource for all of these NASA missions and even for other Agencies. This year the NESC became the home institution for our NASA Technical Fellows. These individuals represent the best individuals in their technical field. They are capable of advancing the field through their leadership, training the next generation of leaders in their field, guiding the agencies activities in their specialty, building teams to solve the most difficult problems we face, and representing NASA to the broader aerospace community in the USA and internationally. NESC was the logical home for our Technical Fellows because it already has the broad NASA perspective and already engages our entire technical and project communities. A sign of effectiveness is the degree to which other organizations ask for your services. Given this metric the NESC is probably one of the most effective organizations around. It continually receives requests from NASA and other agencies to solve problems that require the use of skills or facilities not readily available to a single institution. The NESC continues to be effective at doing this and most importantly they accomplish their tasks in an inclusive and collegial manner. In closing, the NESC continues to demonstrate its value to NASA by solving some of the most difficult problems we face and in the future will serve to further enhance our technical excellence through the leadership of the technical fellows.

Bryan O'Connor NASA Chief Safety and Mission Assurance Officer



In its fourth year, the NESC has shed all of its new-guy-on-the-block image of the past. It is clearly a recognized agency asset, one that people are deferring to and depending upon. People in the programs and institutions no longer need to be reminded of the existence of the NESC, they know it's there, and to a greater degree than ever, they are leaning on the NESC for help on the Agency's toughest issues. In addition, at the request of the NASA Administrator, we are now establishing a NASA Safety Center in Cleveland. The NSC will lead technical excellence initiatives for Safety and Mission Assurance. Key to the success of the NASA Safety Center will be close coordination with NESC on their assessments and technical excellence work.

Dr. Michael Ryschkewitsch NASA Chief Engineer

While I am new to the job of Chief Engineer, the NESC is one part of the activities of the Office of the Chief Engineer with which I am very familiar. I was part of the original team asked to "stand-up" the NESC. Over the ensuing years, the NESC has fulfilled its promise and more. A very strong leadership team and a superb staff have demonstrated the value of the NESC. The term "One-NASA" applies and NESC has again and again assembled the best talent from across NASA to attack the most critical problems and had tremendous impact on everything from earth observations to astrophysics missions to planetary missions to shuttle safety to ISS operations to preparing for the future of humans in space. It is hard to think of a tough problem with which the NESC and its people have not been involved and had a major positive impact. Perhaps as importantly, the alumni of the NESC have gone on to some of the most important jobs in the Agency, a recognition both of their talent and the value of the NASA-wide experience base they acquired in their NESC work. I look forward to working even more closely with the NESC team than I have in the recent past and to supporting its mission as we go forward into a bright future with lots and lots of engineering challenges ahead of us.

LEADERSHIP TEAM INTRODUCTION

The fourth year of operation brought about a number of changes as the organization evolved to meet the needs of the Agency — while remaining true to our core mission of providing value-added independent assessments, testing and analyses in support of the Agency's high-risk programs and projects. This year, we have seen a marked increase in support to the Exploration Systems Mission Directorate and have undertaken a number of proactive assessments to generate new knowledge, expertise and data that can be used by the Constellation Program in making critical design decisions in the future. We have continued to provide support to the Space Shuttle and International Space Station Programs, often engaging in real-time mission critical decisions. In addition, we have also contributed to the Science Mission Directorate through our participation with the Dawn, Phoenix and SOPHIA Missions. In all of these activities, our strength remains our ability to bring together diverse teams of technical experts from across NASA, industry and academia in our pursuit of engineering excellence. The NESC is also working closely with our partner organization, the NASA Safety Center, to provide the Agency with a robust technical and mission assurance resource to address the most critical, high-risk problems. In April of the year, the existing twelve NESC Discipline Experts were transitioned to NASA Technical Fellows. An additional seven NASA Technical Fellows will be added to the NESC over the next few years. The NASA Technical Fellows have been charged with providing technical leadership and stewardship of their disciplines and to proactively address their discipline's most urgent issues. A number of these discipline advancing activities are described in this Technical Update. Again this year, our Technical Update will highlight our accomplishments, broadly applicable lessons learned, Center contributions, and NESC Honor Award recipients. The NESC Leadership Team is pleased to provide you with this Technical Update for 2007 as we look forward to our fifth year of operation.

NESC

(Back row from left) Kenneth Cameron – Deputy Director for Safety, Patricia Dunnington – Manager of the Management and Technical Support Office, Dawn Schaible – Manager of the Systems Engineering Office, Dr. Charles Camarda – Deputy Director for Advanced Projects. (*Front row from left)* Ralph Roe, Jr. – Director, Timmy Wilson – Deputy Director.

Great deeds are usually wrought at great risks. — Herodotus

Improving Safety Through Engineering Excellence

NASA's unique and extraordinary achievements have only been realized after committing to endeavors that have a substantial component of risk. The role of the NASA Engineering and Safety Center (NESC) is to identify and mitigate that risk and maximize safety by taking advantage of one of NASA's strengths — engineering excellence. Formed in the wake of the Columbia accident, the NESC has grown into an important and respected organization by following the strategy that the path to mission success is safety, and safety is achieved through engineering excellence.

NESC

The NESC Leadership Team meets regularly as the NESC Review Board (NRB) to review all engineering reports prior to their publication. The NRB peer review process is a critical step for maintaining engineering excellence in NESC products.

NESC

The NESC is a unique resource, which helps solve challenging technical issues and proactively works to prevent problems from occurring. The independent nature of the NESC allows it to address issues as an objective voice—separate from the Agency's programs and projects. The NESC exploits the depth of knowledge within the Agency by tapping into the far-reaching talent pool at NASA, and further increases that range by engaging with other Government agencies, industry, and academia. Organized into NESC Technical Discipline Teams (TDTs), there is always a ready pool of engineers and scientists from 15 separate disciplines. But the breadth of experience in the NESC is equally important. The vast background and experience base is leveraged through the NESC Review Board (NRB), ensuring all results, recommendations and decisions are sound and supported with technical justification *(pictured above right).*

NESC Mission

The NESC carries out its mission in a variety of ways. The formal, structured activities that are pursued by the NESC are called assessments. They can be either in response to a request or generated from within the NESC as a directed or discipline enhancing task. The level of participation 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. Because the NESC has the ties to a vast human knowledge base, experts can be easily found to participate in NESC assessments as well as other activities such as mishap investigations, technical reviews, and program-sponsored tiger teams. Furthermore, because the NESC is an Agency resource, it is a leader for Agency-wide initiatives, standards, and working groups such as the Data Mining and Trending Working Group. The NESC has also begun issuing technical bulletins. These are concise articles distributed NASA-wide illuminating a specific problem or concern that has been addressed or discovered by the NESC and may be relevant to NASA programs.

The NESC is also well-suited to provide the organizational structure for large, non-NESC initiatives that require assembling a large team of personnel with a wide variety of skills and located across multiple locations. An example of this is the Crew Exploration Vehicle (CEV) Smart Buyer Design Team, which designed an alternative proposal for the CEV (later renamed Orion) using a widely distributed network of NASA engineers

The structure of the NESC is geared toward maintaining a diverse and broad base of knowledge, keeping informed and engaged with each Center and the Agency's major programs, responding efficiently to requests for assistance, and retaining a high degree of independence. Leadership of the NESC is provided by the Director's Office, which, with the Director and Deputy, includes the Deputy Director for Safety, Deputy Director for Advanced Projects, Chief Astronaut, and Chief Scientist. The discipline-specific technical teams of readily available experts, the TDTs, are drawn on to address technical issues as they arise. All but three of the TDTs are led by the NASA Technical Fellows. The exceptions are the Human Space Flight Operations TDT, led by the NESC Chief Astronaut; the Robotic Missions TDT, led by the NESC Chief Scientist; and the Systems Engineering TDT, led by the Manager of the NESC Systems Engineering Office. To help coordinate the facilities and resources of each Center when required to support NESC assessments, each Center (including Headquarters) has a resident NESC Chief Engineer (NCE), a role fulfilled at some Centers by the Center Chief Engineer. The Chief Engineers are engaged with their Center's activities and provide insight into the programs and projects that impact their Centers.

The Principal Engineers (PE) have the primary responsibility of leading assessments — especially when the assessment has a broad scope and encompasses more than one discipline area. Some assessments with a more focused scope may be led by Technical Fellows or NCEs. The NESC also has a Systems Engineering Office (SEO), which performs a variety of functions such as dispositioning requests as they come in, performing proactive trending analysis and problem identification, and providing NESC support for Agency-wide initiatives and working groups. The business responsibilities of the NESC belong to the Management and Technical Support Office (MTSO), which attends to the contracting, budgeting, and management of the NESC's infrastructure.

These elements come together to form the heart of the NESC — the NESC Review Board. The life cycle of every formal activity performed by the NESC requires approval of the NRB. The NRB brings a diversity of thought to the decision-making process as it is an amalgam of experts representing different Centers, programs, and engineering backgrounds.

People

More than just a unique, independent organization unto itself, the NESC is a model framework for finding and taking full advantage of expertise available within NASA. The majority of technical positions within the NESC are temporary. This allows the employees to take their experiences and lessons learned back to their home Centers and organizations. And while there are approximately 60 NESC-badged employees, there are 10 times that many people who participate in NESC activities through the TDTs. These matrixed employees are from every Center

2007 Metrics Summary
(As of Nov. '07)

- Accepted Requests for Assistance.......... **55**
- Technical Assessments (Detailed independent analysis and test) **33**
- Technical Support to Project Teams....... **18**
- Special Studies **4**

and Headquarters and enjoy the benefits of working with and learning from their colleagues and the leaders in their fields.

Independent Objectivity

One of the defining characteristics of the NESC is its independence. The NESC is funded through the NASA Office of the Chief Engineer, so it is not in line with any program, project, or mission directorate either from a budgetary or organizational standpoint. In addition, the NESC has from its inception been closely aligned with the NASA Office of Safety and Mission Assurance (OSMA). All of NASA is encouraged to call upon the NESC and requests for NESC support are received from many sources: Agency senior management, program and project managers, NASA engineers and scientists, even the general public. The pie chart *(shown at right)* depicts the sources of requests that have been accepted for implementation as assessments.

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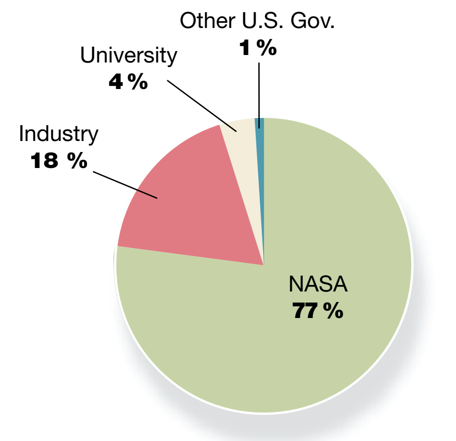
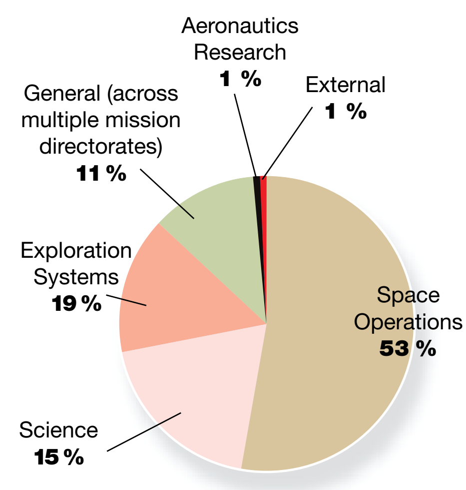
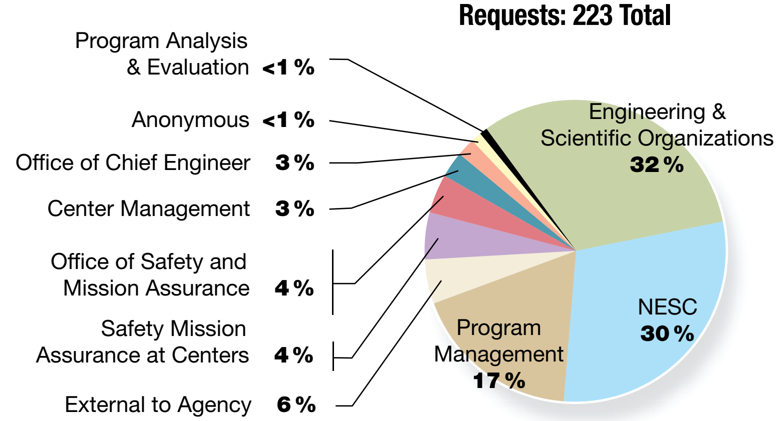
2007 Technical Discipline Team Composition



Accepted Requests by Mission Directorate: 223 Total



Source of Accepted Requests: 223 Total



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A formalized process has been instituted to address each request submitted to the NESC. Initially, each request received is vetted by the SEO, and then those that are approved by the NESC leadership are assigned a lead. The lead will act as a project manager and guide the assessment from the development of a plan through the completion of the final report. The results of each assessment are solution-driven preventative and corrective recommendations that are presented to the NESC Leadership Team and stakeholders of the assessment. The NESC strives to set the example for the Agency by providing full and readily applicable engineering reports for every activity. Along with each report, lessons learned are communicated to Agency leadership and to engineers through avenues such as NASA's lessons learned system and this Technical Update.

Partnerships

One of the keys to maintaining the effectiveness of the NESC is its capacity to build and nurture the partnerships that are vital to reach in-depth expertise, expand the range of available resources, and utilize the focused experience and skills that outside organizations have to offer. The MTSO ensures for the NESC that a broad set of contract vendors are in place and are readily accessible when needed. The NESC has formed working relationships with other government agencies such as the Federal Aviation Administration and the Navy and Marine Corps School of Aviation Safety. The NESC formed a partnership with the National Transportation Safety Board (NTSB) to provide NESC technical personnel formal training on managing or serving on mishap investigations. From this partnership, the NESC has gained immeasurable knowledge from NTSB investigators on how they solve some of the most challenging aviation mishaps and accidents.

The NESC has also enlisted the resources of national laboratories and independent research organizations such as Sandia and Lawrence Livermore National Laboratories, Southwest Research Institute, and the National Institute of Aerospace. Some of the partners from industry include: Alliant Techsystems, Boeing, Janicki Industries, Lockheed Martin, and The Aerospace Corporation. Within NASA, one of the NESC's developing partnerships is with the newly-formed NASA Safety Center (NSC)—an organization that has been created based on the NESC model to foster safety and mission success within the Agency in technical areas not directly within the scope of the NESC. The NSC will support the NESC (and other organizations) in disciplines including system safety, reliability and maintainability, quality engineering, software assurance, range safety, operational safety and aviation safety.

Available to anyone that needs independent testing, analysis, or assessment of NASA's projects, the NESC can be reached through the NESC Chief Engineer at each Center or by email at nesc@nasa.gov.

More contact information is available from the NESC website: www.nesc.nasa.gov.

NESC

Members of the NESC Composite Crew Module (CCM) Team provide NESC Review Board members with a periodic update. Mr. Michael Kirsch *(far right)* is a NESC Principal Engineer (PE) and CCM Project Manager. To his right is Mr. Paul Roberts, back-up NESC PE and Dr. Sotirios Kellas, Test and Verification lead for the CCM Team. *(Far left)* is Dr. Ivatury Raju, NESC Review Board member and NASA Technical Fellow for Structures.

NESC

Agency Leadership Appoints First NASA Technical Fellows

As its fundamental mission, the NESC strives to set the example for engineering and technical excellence within NASA. The NASA Technical Fellows, and their Technical Discipline Teams (TDTs), provide the collective knowledge base that enables the NESC to perform its primary service to the Agency of independent test, analysis and evaluation of NASA's most difficult problems. The Technical Fellows and their TDT members are specialists in diverse engineering disciplines pulled from the ten NASA Centers and from partner organizations external to the Agency.

Inspired by the overall success of the NESC organization, the 12 existing NESC Discipline Experts were named as the first NASA Technical Fellows, and recognized in a ceremony in Hampton, Virginia on April 11, 2007. The NASA Technical Fellows Program was established to provide leadership, stewardship, and role models for NASA discipline engineering communities, increase the focus on technical excellence Agency-wide, and provide technical consistency across NASA as members of the NESC in support of the Office of the Chief Engineer. Consistent with NESC practice, the Technical Fellows will remain resident and actively engaged at their respective NASA Centers.

NASA Technical Fellows are competitively selected using the Agency's ST (Scientific or Professional) criteria. The Technical Fellows include the following disciplines, patterned after the disciplines defined by the NESC: Guidance, Navigation and Control (GN&C); Nondestructive Evaluation (NDE); Propulsion; Avionics; Loads and Dynamics; Aerosciences; Mechanical Systems; Human Factors; Materials; Structures; Life Support/Active Thermal; and Software. Plans over the next several years include adding Space Environments, Electrical Power, Flight Mechanics, Passive Thermal, Cryogenics, Sensors/Instrumentation, and Systems Engineering to the list of Technical Fellows' disciplines. The need for additional disciplines will be evaluated semi-annually and reviewed by the Agency's Engineering Management Board.

The primary roles of the NASA Technical Fellows are to assemble, maintain and provide leadership for the TDTs and act as the stewards for their disciplines through workshops, conferences and discipline advancing activities. The Technical Fellows serve as the senior technical experts for the Agency. Some Technical Fellows may also lead Agency-wide working groups. The Technical Fellows are an independent resource to the Agency and industry to resolve complex issues in their respective discipline areas. They also coordinate

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(Above) NASA and NESC Leadership recognize the new NASA Technical Fellows – *(From left)* Ralph Roe Jr. – NESC Director, George Hopson – Propulsion, Mitchell Davis – Avionics, Cornelius Dennehy – Guidance, Navigation and Control, John McManamen – Mechanical Systems (former), Dr. David Schuster – Aerosciences, Henry Rotter – Life Support/Active Thermal, Dr. Curtis Larsen – Loads and Dynamics, Dr. William Prosser – Nondestructive Evaluation, Dr. Ivatury Raju – Structures, Dr. Robert Piascik – Materials, Dr. Cynthia Null – Human Factors, Michael Aguilar – Software, Timmy Wilson – NESC Deputy Director and Christopher Scolese – NASA Associate Administrator, former NASA Chief Engineer.

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with each Center's NESC Chief Engineer in the identification of potential discipline-related issues to be addressed proactively by the NESC. Other responsibilities include ensuring consistency between Agency-level standards and specifications and promoting the identification and incorporation of lessons learned into Agency processes.

Collectively, the TDTs form a deep technical resource that supports NESC independent assessment teams. Typically, the Technical

By drawing on the minds of the Technical Fellows and their TDTs, the NESC consistently solves technical problems, deepens its knowledge base, strengthens its technical capabilities, and broadens its perspectives ...

Fellows and their TDTs work together to define the discipline-specific resources (e.g., subject matter experts, tools, and test facilities) required to support assessment teams and other NESC activities. Members of the TDTs may fulfill those requirements, or the identified resources may be drawn from the various NASA Centers or from partner organizations. The Technical Fellows ensure that their TDTs are cognizant of all assessments that require the support of their disciplines, and they manage and coordinate discipline-specific resources required to support the NESC stakeholders.

Communications between the Technical Fellows and their TDTs is accomplished via periodic teleconference meetings and with annual face-to-face meetings, and the NASA community is apprised of the yearly activities of the TDTs when the Technical Fellows provide an annual State of the Discipline address to the NASA Engineering Management Board and other Agency leaders. By drawing on the minds of the Technical Fellows and their TDTs, the NESC consistently solves technical problems, deepens its knowledge base, strengthens its technical capabilities, and broadens its perspectives, thereby further executing its commitment to engineering excellence.

CIBER

NASA Technical Fellow for Materials, Dr. Robert Piascik holds a side discussion during the NESC's Academy course on Materials Durability.

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

Another important function of the NASA Technical Fellows Program is the NESC Academy.

The NESC Academy was established to ensure that the vast body of knowledge of the NESC's scientists and engineers remains viable and accessible to the current community of NASA professionals. The NESC Academy provides a forum through which this knowledge can be passed on to NASA's younger generation. Each Technical Fellow has, or will be, given the opportunity to deliver an Academy class focusing on their discipline. During the past year, the NESC Academy delivered courses in Materials Durability, Human Factors and Software Engineering.

Materials Durability

Understanding materials durability is critical to NASA's mission and to explore this, the NESC Academy class entitled, "Materials Durability: Learning from the Past and Looking to the Future", was offered July 30 – August 2, 2007 in Houston, Texas at the University of Houston, Clearlake. Dr. Robert S. Piascik, NASA Technical Fellow for Materials, and Dr. William H. Prosser, NASA Technical Fellow for Nondestructive Evaluation (NDE), and their colleagues from both of their TDTs, worked jointly on this effort. This course focused on understanding material damage modes as they relate to materials-environment interactions. Members of the Materials Technical Discipline Team shared their lessons learned as they related degradation mechanisms and described how analysis methods are used for assessing materials durability.

" This course has been excellent. It has given me an opportunity to meet with experts all across the Agency, academia, and industry."

Nate Green
Marshall Space Flight Center

Past NESC Academy classes available online

- Active Thermal Control and Life Support Systems led by Hank Rotter at the University of Houston
- Space Propulsion Systems led by George Hopson at Alabama A&M University
- Power and Avionics led by Robert Kichak at the University of Maryland
- Satellite Attitude Control Systems led by Neil Dennehy at the University of Maryland
- Human Factors led by Cynthia Null at George Mason University
- Software as an Engineering Discipline led by Michael Aguilar at George Mason University
- Materials Durability – Understanding Damage Modes led by Robert Piascik at the University of Houston

More information on the NESC Academy, including available classroom and on-line courses is available on our website at: http://www.nescacademy.org.

Human Factors

"...I was also interested in seeing how this applies to everything that we do everyday. I think its very exciting ..."

Linda Patterson
Johnson Space Center

The NESC Academy's fifth knowledge-capture course, "Human Factors: Learning from the Past and Looking to the Future" with Dr. Cynthia H. Null and colleagues, took place from December 5-7, 2006 at George Mason University. Dr. Null, the NASA Technical Fellow for Human Factors, assembled a diverse team of experts in the field of human factors. Topics included human characteristics and capabilities, development of in-space systems, engineering new systems, maintenance and manufacturing, and lessons learned from mishap investigations.

Software Engineering

George Mason University also served as the location for the NESC Academy class on Software Engineering. "Software Engineering: Learning from the Past and Looking to the Future" was held from March 13-15, 2007. Michael L. Aguilar, NASA Technical Fellow for Software, led the instruction and course content that included the history of software engineering and the development and application of CAD and CAM and CASE tools, Unified Modeling Language (UML), and state charts. Mr. Aguilar discussed NASA's software quality assurance program and lessons learned from space missions, and provided insight into newer software programs. Class activities included viewing a documentary on software engineering that showcased the applications of software in the design and manufacture of Boeing Aircraft's B-777, and a moderated discussion among seven guest speakers and students that sparked thought-provoking questions and debate.

"I found this class extremely helpful. I've been struggling with implementing the new NASA NPR software standards at my Center."

Stephen Jensen
Dryden Flight Research Center

CIBER

NASA Technical Fellow for Software, Michael Aguilar, and students discuss details of software engineering during the NESC Academy course.

SPACE OPERATIONS

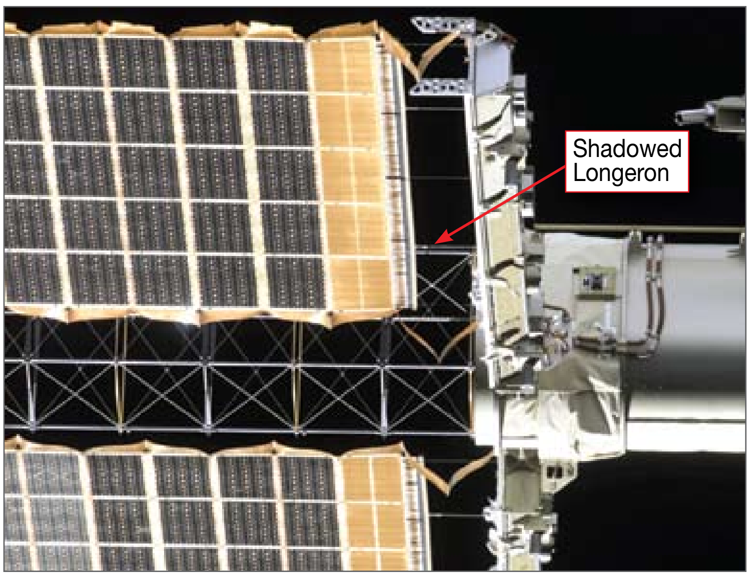
While anchored to the foot restraint on Canadarm2, astronaut Dave Williams helps relocate a 600-pound Control Moment Gyroscope (CMG) during STS-118 in August, 2007. The NESC has been involved in determining the root cause of a previous CMG failure.

International Space Station Solar Array Mast Shadowing

Problem: Operational conditions for the solar arrays of the International Space Station (ISS) have been identified in which partial shadowing of the 108-foot long support masts can occur. This partial shadowing induces differential heating between the sunlit and the shadowed portions of the mast structure and 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 for mast buckling if attitude control were lost for any considerable period of time. The ISS Program management requested that the NESC conduct an independent assessment of the thermal and structural analyses predicting the failure and 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. Thus, the NESC is preparing a ground test program to provide the best possible thermal and structural response data for correlation of the mast models. All other previous mast structural test data has also been reviewed for incorporation in the model correlation. The NESC has contracted with the mast manufacturer to design and fabricate a special mast test section that will be instrumented and exposed to a simulated space vacuum and solar environment in the Jet Propulsion Laboratory's 25-foot diameter Space Simulator facility. Buckling of the test article due to thermal strain will be demonstrated and the temperature, strain, and displacement responses of the test article will be recorded for use in subsequent model updating.

Results: The NESC will provide test-correlated thermal and structural models of the solar array masts, and updated predictions of the mast buckling failure load under the partial shadowing condition. In consultation with the ISS Structures and Mechanisms team, the NESC will recommend the appropriate mechanical loads to be considered simultaneously with the buckling loads and a time to effect buckle limit to be used as an operational constraint.



NASA

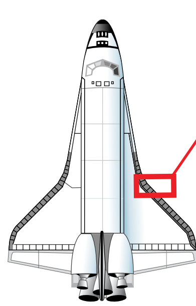
Example of solar array self shadowing event. The upper solar array blanket is placing one of the mast's four longerons in shadow, causing it to contract and potentially buckle the mast.

Orbiter WLE RCC Panel Subsurface Anomaly

Problem: Reinforced carbon-carbon (RCC) is used on the Space Shuttle orbiter wing leading edge (WLE) and nose cap to protect it from temperatures during entry that exceed 2300° F. Recently, the outer silicon carbide (SiC) protective coating of the RCC has shown reduced adherence to the underlying carbon substrate. Three instances have occurred where small fragments of SiC liberated from the RCC, and one case where a 30 inch-long subsurface region of reduced adhesion was discovered.

NESC Contribution: The NESC is working with the Leading Edge Structural Subsystem (LESS) Problem Resolution Team (PRT) to discover the root cause of the anomalies and to develop improved nondestructive evaluation (NDE) methods for inspecting the RCC. NASA Technical Fellows and members of the NESC's Materials, Structures and NDE technical discipline teams (TDT) have been involved with this effort. The NDE TDT has developed a new method of quantifying data from infrared imaging of the RCC panels to evaluate and compare indications that may represent loss of SiC adhesion.

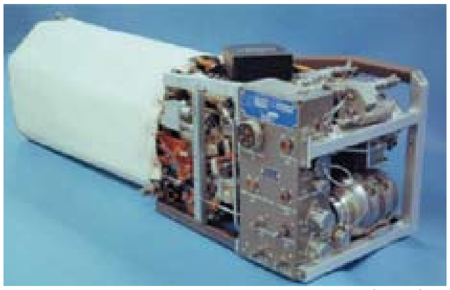
Results: The NESC has and will continue to assist the LESS PRT with RCC testing and analysis in pursuit of a resolution of this issue and to maximize safety of flight.



KSC

Damage to RCC panel 8R, post STS-114, found to have weakened SiC to carbon substrate adherence after excavation of a 30-inch long region. The NESC developed an improved imaging capability to better quantify this type of damage.

NASA



UTC Fuel Cells

Space Shuttle fuel cell

Fuel Cell Motor Two-Phase Operational Evaluation

Problem: The Space Shuttle is equipped with fuel cells that generate direct current electricity. The direct current is then converted into 3-phase alternating current and distributed throughout the spacecraft. Each fuel cell uses the 3-phase current to power two internal motors – a coolant pump and a hydrogen separation motor. Prior to launch, STS-115 experienced a momentary short on one of three phases in a fuel cell's electrical output power. The short was attributed to a failure of the coolant motor within the fuel cell. During the mission, the fuel cell's motors were operated on two phases and the launch proceeded without further fuel cell issues.

NESC Contribution: The NESC was asked to determine if the fuel cell's hydrogen separator motor was damaged by the two-phase operation. Consultation was also requested on what failure analysis was needed to understand the cause of the fuel cell motor anomaly and to make recommendations regarding the value of failure analysis on other motors inside the affected fuel cell. The NESC performed the requested damage assessment and participated on a project team for the anomalous motor failure analysis.

Results: The analysis indicated that the hydrogen separator motor was not significantly stressed by the two-phase operation. Testing showed that the failed coolant pump contained defects consistent with manufacturing irregularities, and thermal and mechanical stresses that have accumulated over the motor's 30 year life.

External Tank Hail Damage Repair Assessment

Problem: As a result of a severe thunderstorm which produced hailstones measuring up to 0.8 inches in diameter, the External Tank (ET) used on STS- 7 incurred extensive hail damage to its thermal protection system (TPS) foam insulation.

NESC Contribution: The NESC was asked to assess the feasibility of repairing the ET TPS and of conducting those repairs with the vehicle in a vertical configuration in the Kennedy Space Center Vehicle Assembly Building (VAB). The NESC participated in technical discussions surrounding the inspections, repair categorization, and the repair process and reviewed supporting planning, testing and analysis. A human factors assessment was performed of the VAB work environment and the adequacy of the process controls applied to standard and non-standard repairs of the TPS foam. Concern about the debris potential posed by undetected crushed foam remaining on the ET and the adequacy of various repair techniques were also addressed. The NESC evaluated flight rationale for the non-standard repair processes and the flight risk associated with prelaunch icing and thermal conditions during ascent.

Results: The NESC found that tests and analyses performed to substantiate repairs planned for the ET were well-formulated and provided an adequate foundation for flight rationale. However, some process catches (a problem found during normal processing) and escapes (a problem found after it should have been identified during normal processing) were observed. Trend analysis was recommended on both process catches and process escapes to maximize the potential for identifying and correcting process control issues in the future. Improvement of the repair processes could also be gained via a detailed Process Failure Modes and Effects Analysis and process sensitivity study. The repairs to the tank were completed and STS-117 was successfully launched.

KSC

United Space Alliance personnel, Nancy Lewis and Jessie Lawhorn, repair damage to the External Tank's foam insulation caused by hail damage while Atlantis was on the launch pad at KSC.

NASA

The NESC contributed realtime assistance to the ISS computer anomaly investigation team.

Russian ISS Computer Evaluation

Problem: In June , 2007, all five active computers in the Russian Segment went off-line and operation remained erratic. The Russian computers provide attitude control for the International Space Station (ISS) by operating reaction control thrusters. The US Control Moment Gyros provide only fine control and saturate at large rates. During the erratic computer behavior, the docked Space Shuttle was used to stabilize the mated ISS/Space Shuttle Configuration.

NESC Contribution: The NESC was asked to contribute expertise to assist in the resolution of the ISS computer shut-down and attitude control anomaly. As a result, on-site support was provided to the anomaly resolution process at JSC during the mission. The Russian computer system was analyzed and critical simulations and analyses needed to ensure a safe undock and separation of the orbiter from ISS were identified and executed.

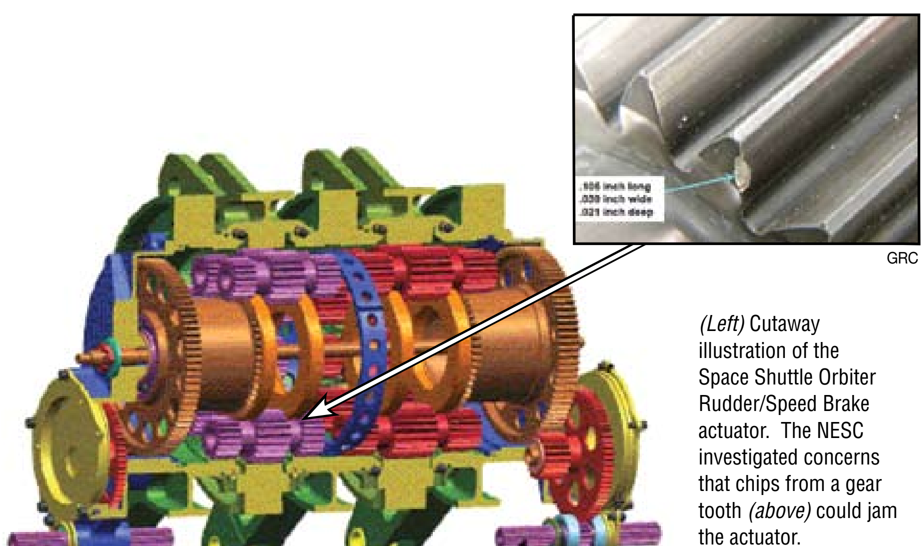
Results: Contamination or corrosion observed on a Russian BOK3 relay box connector and harness that contained on/off commands for the computers was identified as the cause for the computer shut-down anomaly. In addition, follow-on actions were completed to implement contingency attitude control plans for ensuring long term stability of the ISS in the event the Russian computer-controlled thruster-based system capability is lost.

Chipped Gear Anomaly in Space Shuttle Rudder/Speed Brake

Problem: During performance verification, damage was found on the planet gear teeth of a Space Shuttle Rudder/Speed Brake (RSB) actuator containing new build hardware. As a result, a concern existed that liberated debris could cause jamming or binding and degrade the performance of RSBs or Body Flap Actuators (BFA) containing the new build hardware. This issue presented a potential launch constraint for the STS-117 and STS-118 missions.

NESC Contribution: The NESC was requested to participate on a Tiger Team to support the damage assessment. Members of the Mechanical Systems Technical Discipline Team worked closely with the Mechanical Flight Controls Problem Resolution Team in developing tests designed to address the ability of the RSB and BFA hardware to tolerate debris. Testing included placing gear chips, obtained from actual planet gears, into specified gear and bearing locations in a RSB actuator to encourage jamming and binding. In no instance was jamming observed and in all cases, the torque spikes produced were within the torque capability of the actuator to drive through the debris. In addition, a RSB unit with the original chipped planet gear present was subjected to a full rotation ultimate load test with no jamming or binding resulting and no additional gear chipping observed. A successful system level test and subsequent Acceptance Test Review was performed for a total of 64 mission duty cycles on a RSB actuator with five chips present in the actuator. Members of the NESC team performed spur gear testing that demonstrated a linear relationship between the chip size and torque spike observed. Members of the NESC Engineering Statistics Team provided reliability and Weibull analyses, supporting the Tiger Team's finding. Based on the maximum power drive unit torque output available, acceptable torque margins were present in all gear and bearing locations tested.

Results: Flight rationale for upcoming missions based on testing and inspections was presented to the Orbiter Project Office. The root cause of the chipping was attributed to improper handling during a critical heat treatment phase of the manufacturing process when steel is most susceptible to handling damage. The failure itself was attributed to internal stress rupture resulting from a subsurface crack produced by the high residual stresses present in the material.



GRC

(Left) Cutaway illustration of the Space Shuttle Orbiter Rudder/Speed Brake actuator. The NESC investigated concerns that chips from a gear tooth *(above)* could jam the actuator.

EXPLORATION

Apollo 17 Mission Commander Eugene (Gene) Cernan next to the Lunar Roving Vehicle during Extra Vehicular Activity -3. Lunar dust interfered with the smooth operation of numerous mechanisms on the suits and infiltrated the Lunar Module cabin causing breathing irritation for fellow astronaut Harrison Schmitt.

Apollo 17 Mission Commander Eugene Cernan in the Lunar Module after the third moon walk. Lunar dust is evident on his pressure suit.

NASA

Lunar Dust Workshop for Exploration

Problem: Lunar dust may pose engineering, scientific, and medical issues relating to the exploration of the Moon, both crewed and robotic. While many different points of view on the issues and how to address them have been voiced, a clear consensus on a forward plan was needed.

NESC Contribution: The NESC sponsored a Lunar Dust Workshop in late January, 2007, at the Ames Research Center. The workshop brought together a diverse group of individuals from NASA Centers, academia, and industry. Participants included researchers who are currently studying lunar dust, as well as the designers and operators of the hardware that will function on the Moon.

Results: Discussions centered on four areas: basic research, mechanical systems, medical and health, and support systems. Workshop participants agreed that the characteristics (physical, chemical, mechanical) of lunar dust and the lunar plasma environment need to be better understood. This process can be started by mining existing data from Apollo, Lunar and Prospector missions and continued with in-situ measurements from robotic missions. A robust qualification test program based on approved understanding, sensitivities and mitigation should be developed and implemented. In order to carry out rigorous tests of the effects of dust on mechanical systems and on humans, realistic simulants of lunar dust must be developed and tested as returned samples of useful lunar dust are in short supply. Medical studies require a systematic framework beginning with in vitro and in vivo studies to understand the biological effects of dust, to determine the effects of acute versus chronic exposure to dust, and to find ways to predict individual responses to dust. Mitigation technologies must be designed, developed, tested, evaluated and selected to limit the exposure of astronauts to the dust and to prevent or limit the damage caused to mechanical systems by dust. Issues and potential solutions related to lunar dust are being compiled into an integrated Agency perspective on lunar dust. This will allow identification of proactive testing and analysis that should be conducted in the near term.

"I think dust is probably one of our greatest inhibitors to a nominal operation on the Moon. I think we can overcome other physiological or physical or mechanical problems except dust."

Gene Cernan
Apollo 17 Technical Debrief

NESC

The NESC held a workshop on Lunar Dust to focus efforts for the benefit of the Constellation Program.

NASA

(From left) Craig Newland of Northrop Grumman, Larry Pelham, NASA Manufacturing Lead, Nathan Oldfield of Northrop Grumman, and Terry Graham of ATK, lay-up the first ply of carbon epoxy fabric that will later become one of the sub-element test articles as part of the building block approach being used for the NESC Composite Crew Module Project.

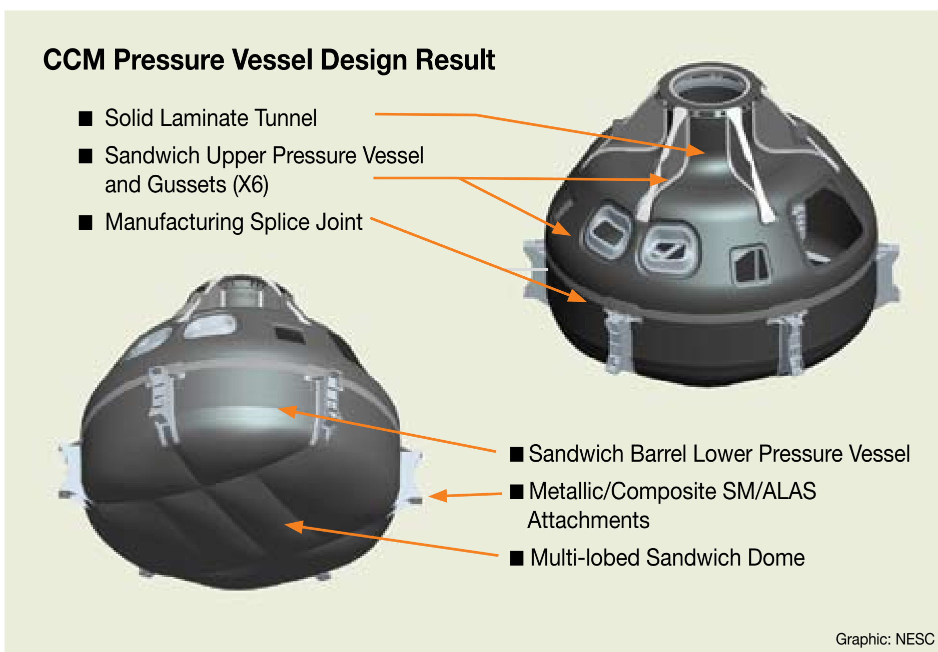
MSFC

NESC Composite Crew Module Design Project

Problem: In 2006, the NESC studied the feasibility of a composite pressure vessel for the Orion Crew Module (CM). The overall finding indicated that a composite crew module was feasible but that a detailed design would be necessary to quantify technical characteristics, particularly in the area of mass and manufacturability. Accordingly, the NASA Administrator, Associate Administrator for Exploration Systems, and the Constellation Program Manager chartered the NESC to design, build, and test a composite crew module with the goal of developing a network of engineers within the Agency who would have hands-on experience using composites on habitable spacecraft design.

NESC Contribution: The NESC Composite Crew Module (CCM) Project objective is to design, build, and test a structural test article of the CEV Crew Module primary structure. The project was chartered in January 2007, with the goal of delivering a test article for structural testing 18 months after project initiation. The project team is a partnership between NASA and industry and includes design, manufacturing, and tooling expertise. Partners include civil servants from ARC, GRC, GSFC, JSC, JPL, KSC, LaRC, MSFC, Air Force Research Laboratories and contractors from Northrop Grumman, Lockheed Martin, Genesis Engineering, Alliant Techsystems, Janicki Industries, and Collier Corporation.

Results: The CCM team constrained the design to match interfaces with the current Orion CM including the internal packaging constraints that utilize a backbone for securing internal components. During the first two months of the effort the team evaluated design solutions and focused in on a design that utilizes predominantly aluminum honeycomb sandwich and solid laminate material systems. One unique feature of the CCM design was the integration of the packaging backbone structurally with the floor and walls of the pressure shell. This provides a load path that accommodates load sharing with the heatshield for water landing load cases. An independent panel reviewed the initial concept and preliminary design. The project is currently conducting building block testing of critical areas and the results of the building block testing will be used to validate critical assumptions for the final design that will be independently reviewed again at the Critical Design Review (CDR) near the end of calendar year 2007.



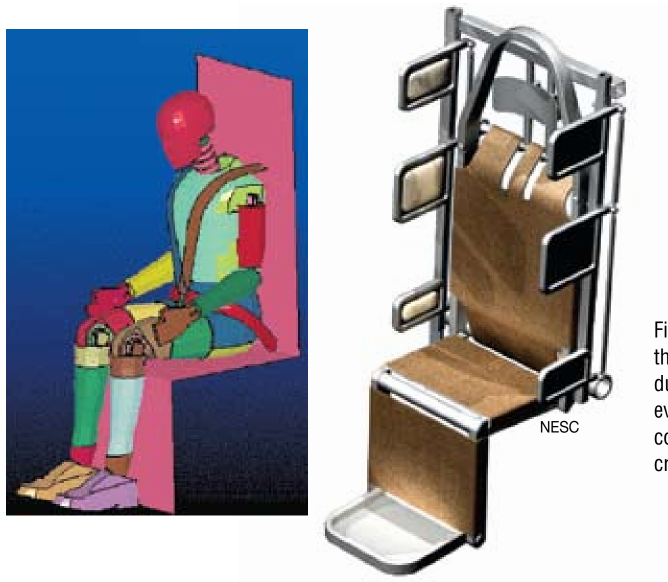
Graphic: NESC

CEV Integrated Landing and Recovery System Assessment

Problem: The Orion Project requested a risk comparison of the Integrated Landing and Recovery System (LRS) designs developed by NASA and the Contractor for the Orion Crew Module. Based on the results of this risk comparison, the NESC was further asked to evaluate risks identified by the Orion Project to risk reduction and mitigation strategies.

NESC Contributions: The NESC formed a comprehensive assessment team that included Apollo engineers and astronauts. The team first analyzed the LRS baselines and qualitatively evaluated the risk to the flight crew in each baseline. Configurations included water landing and land landing configurations Several areas of risk and mitigations that could improve crew safety in off-nominal situations were investigated.

Extensive analysis was performed using an NESC-developed tool to understand the number of landing opportunities over a period of time given a site's accessibility and availability. Accessibility was based on the site location, vehicle capabilities to reach the landing sites from International Space Station orbital trajectories, and operational procedures. Availability was based on the predicted winds at the landing site, vehicle horizontal wind limit, and day/night landing restrictions. This tool could prove useful in developing the Orion flight test program.



Finite element models of the Hybrid III crash test dummy were adapted to evaluate crashworthiness concepts for the Orion crew seats.

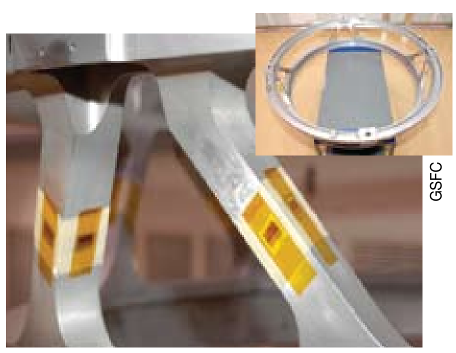
Alternative crew protection and crashworthiness concepts were investigated using finite element models of Hybrid III crash test dummies used in the auto industry. The models were modified by the NESC and evaluated/calibrated against the NASA standard human impact tolerance model used by the Orion Project. The NESC models were used to quickly evaluate the relative performance of crew protection concepts for areas of the human body where the NASA model could not provide sufficient injury prediction.

Results: The integrated risk analysis predicted the lowest risk for water landings while the landing site accessibility and availability analysis showed that land landing opportunities could be restricted to a few times per week in certain circumstances for preferred sites. The crew protection and crashworthiness concepts led to additional requests from the Orion Project for further, independent investigations of human impact tolerance modeling and crew protection mechanisms.

Flight Force Measurements to Improve Coupled Loads

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 dramatically impact the Orion Crew Module requirements and development.

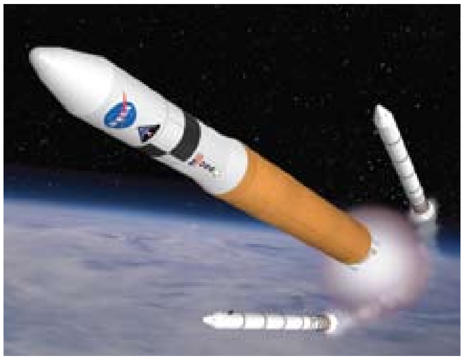
NESC Contribution: The Flight Forces Discipline Team is demonstrating the benefits of acquiring interface force measurements during flight. Ideally, this would be accomplished via force transducers. However, force transducers are in the load path and require significant integration effort and lead-time that is not



Testing of a concept: strain gages can be used to extract forces and moments from a complex payload adapter structure *(inset)* like the GLAST Test Payload Attach fitting.

available. A simplified approach will be used that involves mounting of strain gages near a spacecraft interface such 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. Methods will be demonstrated through analysis and testing of the trussed Payload Adapter Fitting (PAF) to be flown on the Gamma-Ray Large Area Space Telescope (GLAST) mission. The PAF design used on this flight is the most suitable test article for resolving forces based on strain measurements.

Results: GLAST is scheduled to be launched on a Delta II in 2008. Post-flight data analysis will be performed to reconstruct the flight loads and reconcile the predicted forces, document the benefits of force measurements and to make recommendations for further Agency action.



NASA

A concept image shows the Ares V cargo launch vehicle. The heavy-lifting Ares V will become NASA's primary vessel for safe, reliable delivery of large-scale hardware to space.

Assessing GN&C System Architecture Commonality for Constellation

Problem: Guidance, Navigation and Control (GN&C) systems for the Exploration Systems Mission Directorate (ESMD) and the Constellation Program stand out, among all the future spacecraft systems, as an area wherein commonality might be of technical and programmatic benefit. Commonality between exploration system hardware and software elements may offer the potential to increase sustainability by reducing both non-recurring and recurring cost/risk.

NESC Contribution: The NESC team is working to assess the potential for GN&C system commonality across the emerging new generation of space vehicles that will be designed and built for the exploration of the Moon and Mars. The team is performing an independent, systematic and comprehensive study on the problem of optimizing GN&C architectures across exploration space vehicles in terms of crew safety, reliability, robustness, minimum complexity, commonality, testability, ease of operation, sustainability, extensibility and affordability. The task leverages analytical methods developed at the Massachusetts Institute of Technology as part of their program in Technical System Architecture, as well as their specialized analysis tools/methods used to support the ESMD Concept Exploration and Refinement study. Preliminary results will be available in 2008.

Human Factors Workshop

Problem: The induced acceleration and vibration environments that will be experienced during Orion-Ares launch, abort, reentry, and landing phases of flight pose specific and significant challenges for maintaining the health and performance of the astronaut crew. Gaps in our knowledge concerning acceleration and vibration loading may impact NASA's ability to design safe and effective space systems for operation during these phases of flight.

NESC Contribution: The NESC conducted the AGILE (Assessment of Gravito-inertial Loads and Environments) Project workshop, which was held in October 2007. The workshop brought together over 60 NASA and contractor members for the Orion and Ares projects, external (military, academia and industry) subject matter experts, and present and former astronauts for plenary talks and breakout working sessions. During these sessions, crew health and performance concerns and Constellation Program system development for these induced environments were discussed.

Results: Two significant Constellation Program gaps were identified at the workshop: 1) incomplete and, as yet undeveloped, models and test data for induced acceleration and vibration environments and system structural response, and 2) incomplete knowledge of expected crew-system interactions during these induced environment phases of flight. Orion and Ares attendees acknowledged the meeting heightened their awareness of the interrelation between these induced environments and crew health and performance, and of the absence of pertinent data and models.

A review of the open literature and of non-public archives on the impact of acceleration and vibration loading on human health and performance is continuing. The final AGILE product will be a comprehensive report that captures the workshop output and ongoing literature review, identifies and prioritizes critical knowledge gaps, and proposes a path to close those gaps that represent significant risks to the Constellation Program cost/schedule and mission success.

ARC

Former astronauts Dr. Joe Kerwin *(left)* and Capt. John Young *(right)* discussing gravity and vibration loading during simulation, training, and flight with AGILE Workshop attendees.

EXPLORATION

Alternative Launch Abort System (ALAS) Solution for Orion Crew Module

Problem: The Orion Project identified a significant technical and programmatic risk related to large aeroacoustic loads predicted during nominal Orion/Ares 1 launches and aborts. This risk identification coincided with the presentation of the NESC ALAS feasibility study team's initial results in December 2006, that showed significant aerodynamic performance benefits for ALAS configurations. The Orion Project requested the ALAS Team refocus their efforts on evaluating the aeroacoustic benefits of the ALAS design concept, and to perform higher fidelity aerodynamic and ascent performance assessments, and high-fidelity abort stability and control evaluations.

NESC

Dr. Charles Camarda, NESC Deputy Director for Advanced Projects *(left)*, and Dr. Stephen Scotti, ALAS Study Lead, display an ALAS wind tunnel model. The NESC led a multi-Center effort to develop a fairing concept for the Orion CM that reduces aerodynamic drag and aeroacoustic pressure levels. The ALAS shape *(right)* is now being used by the Orion Project.

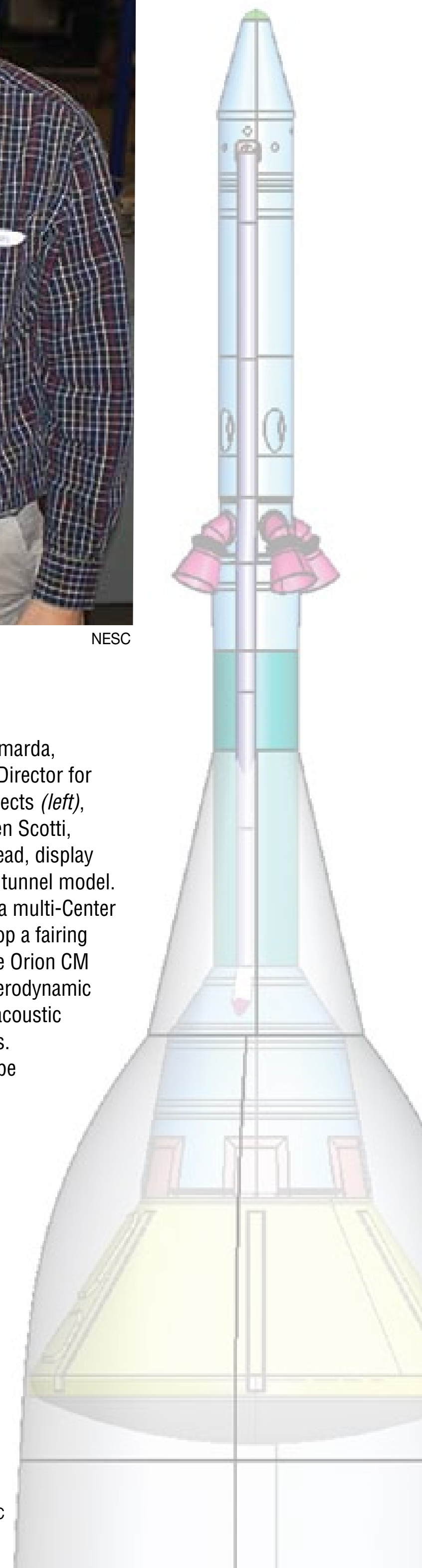
NESC Contribution: The NESC expanded the ALAS Team to include participation from multiple NASA Centers. The team created a family of ALAS configurations for study and evaluated the ALAS benefits through higher fidelity computational fluid dynamics (CFD) simulations, a wind tunnel test focusing on launch stack aerodynamics, two wind tunnel tests to evaluate launch abort vehicle stability and control forces/moments, an acoustic wind tunnel test to determine local fluctuating pressure/aeroacoustic loads, and dynamic stability and control simulations for pad and maximum dynamic pressure abort cases. Study results were presented to the Orion Project and the Orion contractor staff. The ALAS Team was asked to continue their efforts through support of a Project-led study of ALAS

Results: The Orion Project assessment largely confirmed the NESC ALAS Team's results, and the significant acoustic loads reduction obtained for the ALAS configurations led to adoption of ALAS as an integral element of the "point of departure" configuration for the Orion Preliminary Design Review (PDR).

Two significant findings from this study benefited the Orion Project:

1) The improved launch abort vehicle (LAV) aerodynamics of ALAS configurations allowed for safer pad abort performance since downrange and altitude constraints could be readily met by the ALAS LAV due to its higher lift and lower drag characteristics.

2) The original understanding of the Orion Crew Module (CM) aeroacoustic noise sources was that they were due to the wakes from exposed LAV nozzles and the large flow separation regions on the Orion Service Module. Wind tunnel testing with various nozzle shroud configurations, with nozzles removed, and with various outer mold line geometries, proved that the nozzle wake had only a secondary effect on the acoustic loads. A strong oscillating shock due to the Orion CM bluntness was discovered to be a previously ignored source, and the ALAS configurations that weakened this shock were the best aeroacoustic performers. Therefore, study of shock structures using static CFD computations were found to be excellent design aids in defining low noise vehicle configurations and reduced the amount of iterative testing of vehicle configurations.



NESC

Shell Buckling Knockdown Factor Proposal

Problem: High-performance aerospace shell structures are inherently thin-walled because of weight and performance considerations. Reliable, validated design criteria for thin-walled shells are required, with buckling being an important and often critical consideration in the design of these structures. Currently, aerospace shell structures are designed using buckling criteria established in the 1960s based on experiments with metallic shells. Buckling design allowables were used with the shell analyses to "knockdown" the analytical predictions that were observed to over predict failure loads. This approach to shell design remains prominent in industry practice, as evidenced by the extensive use of the NASA space vehicle design recommendations. In more recent times, significant improvements in nonlinear structural analysis codes and advanced experimental-response measurement systems have uncovered new insights into the complex behavior of thin-walled shells. The tools and understanding now exist for developing high-fidelity, analysis-based shell-buckling knockdown factors for shells of general shape and material composition and for combined mechanical and thermal loads. Thus, high-fidelity analyses and selective structural testing can be used to determine refined, reliable design criteria for shell buckling that are not overly conservative like the approaches currently being used.

NESC Contribution: The NESC is developing new analysis-based shell buckling knockdown factors for the Ares-I Upper Stage LH2 tank structure that would reduce design conservatism and enable significant weight savings. The NESC has assembled a team of discipline experts from MSFC and LaRC to define a program that involves specimen fabrication and testing for knockdown factor validation. Initial results will be available in 2008.

The Ares I-X Upper Stage fuel tank shown covered in orange insulation foam.

GRC

GRC workers monitor a critical lift of an Ares I-X Upper Stage simulator section. Each section of the inert mass simulator is being manufactured at GRC.

Critical Flaw Size Analysis for Ares I-X Upper Stage Simulator

Problem: The Ares I-X is a development flight test vehicle which will gather performance data of the first stage for Ares I. Ares I-X includes an inert Upper Stage Simulator that is composed of segments bolted together through welded flanges. The flange-to-skin welds are in the primary load path, which makes any cracks or defects in the weld region critical. The Ares I-X Project requested an independent assessment and prediction of the minimum weld defect shape and size which could grow into a critical crack. This information was required to determine the weld inspection threshold and to establish weld repair criteria.

NESC Contribution: The NESC Team worked jointly with the Ares I-X Project and established a set of loads for the structural analysis. Using these loads, the NESC Team assessed the Ares I-X Upper Stage Simulator stresses and critical initial flaw sizes for the flange-to-skin welds using state-of-the-art analytical tools that are readily available within NASA. The team is also performing crucial tests to develop appropriate material property values for the specific weld joint configurations and different weld types.

Results: The NESC Team will provide test results to the Ares I-X Project for use in further analysis. The NESC team will also make recommendations regarding critical initial flaw size that can be tolerated by the structure and specific crack sizes and shapes that should be considered unacceptable.

Lesson Learned: When using new materials, materials property characterization tests need to be performed as soon as possible.

Lunar Surface Access Module (LSAM) Design Support

Problem: The Constellation Program requires a lunar lander vehicle capable of supporting crewed and cargo missions to the lunar surface. As a result, the Program established a Lunar Lander Project team that has begun conceptual design studies of lunar lander configurations. The challenge is to develop unique and innovative design concepts that are mass and packaging efficient and, at the same time, satisfy lunar mission architecture requirements. An LSAM Structures and Mechanisms Design Team was set up by the Project Lunar Lander to conduct studies of an LSAM capable of supporting crewed and cargo missions to the lunar surface.

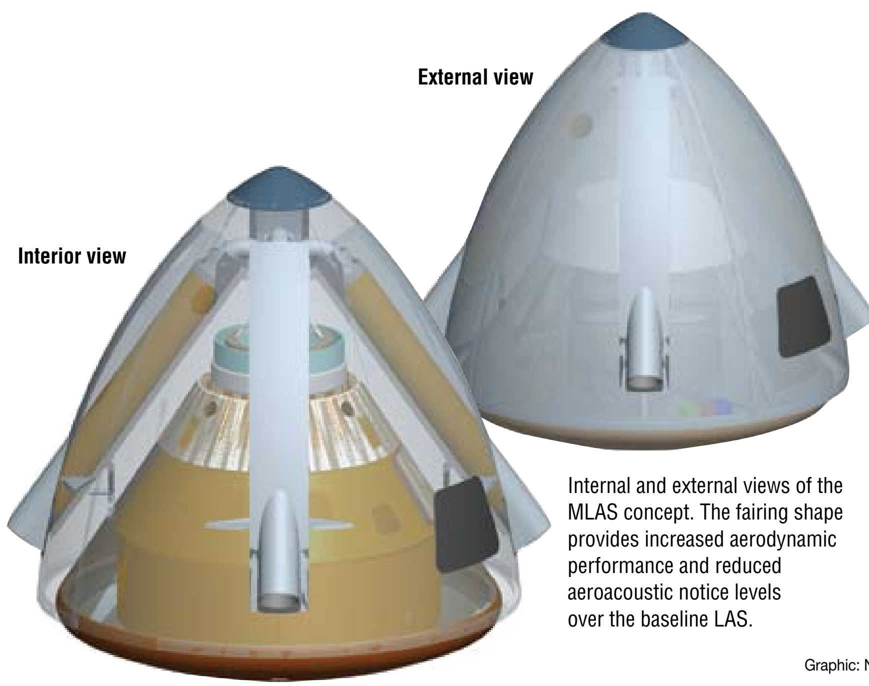

NASA
Illustration of an early concept investigated for the LSAM. The design will evolve over multiple design analysis cycles.

NESC Contribution: The lander design team consists of a strong contingent of experts derived from the NESC Composite Crew Module (CCM) Team, along with other engineers from across NASA. Experience and lessons learned (both technical and procedural) from the NESC CCM team have been useful in facilitating and developing a model for LSAM design work. The team is conducting its work through regular co-locations and web-based virtual design sessions.

Results: Preliminary results for "Lander Design and Analysis Cycle One" (LDAC-1) included detailed design concepts, finite-element models, and initial mass estimates. The work also included the development of detailed loads models, mechanisms, and landing-gear design options. The team is now working on modifications to the first-look lander design that optimized the configuration for cargo-only missions. The NESC will continue supporting the LSAM Structures and Mechanisms design team to ensure that the Agency-wide expertise assembled for CCM will be leveraged to the maximum extent possible by the LSAM team.

Max Launch Abort System (MLAS) Development

Problem: The NASA Administrator and the former Associate Administrator of the Exploration Systems Mission Directorate tasked the NESC to design, develop and test an alternate concept Launch Abort System (LAS) for the Orion Crew Module (CM) as a risk mitigation for the Orion Project's LAS development. Having an effective means for the crew to escape in an emergency during launch is critical in establishing launch system reliability and crew safety for the Ares-I launch vehicle. An alternate LAS design could reduce overall schedule risk by providing the Constellation Program management with a fallback design concept. Due to LAS complexity, a flight demonstration is necessary to validate design and performance assumptions in a safety-critical system such as the LAS. An alternative LAS must also meet all performance requirements of extracting the Orion CM from the launch vehicle at any time from crew ingress at the launch pad through staging and successful ignition of the second stage of the Ares-I.



Internal and external views of the MLAS concept. The fairing shape provides increased aerodynamic performance and reduced aeroacoustic notice levels over the baseline LAS.

Graphic: NESC

NESC Contribution: Using an intra-agency technical team and working with industry partners, the NESC is developing a launch abort concept that can be used for all launch abort conditions and for a nominal launch consistent with Constellation Program requirements. The concept is known as the Max Launch Abort System (MLAS), and will be designed to lift the Orion CM from the launch pad to an altitude high enough and with enough distance downrange to permit the CM to execute a nominal landing. MLAS performance will be evaluated through an actual Pad Abort test.

Results: The NESC is currently in the design analysis cycle process and procuring the hardware necessary to demonstrate a full-scale Pad Abort test of MLAS in Fall, 2008, at the Wallops Flight Facility.

LOCKHEED MARTIN

Design, Development, Test and Evaluation (DDT&E) for Safe and Reliable Human Rated Spacecraft Systems

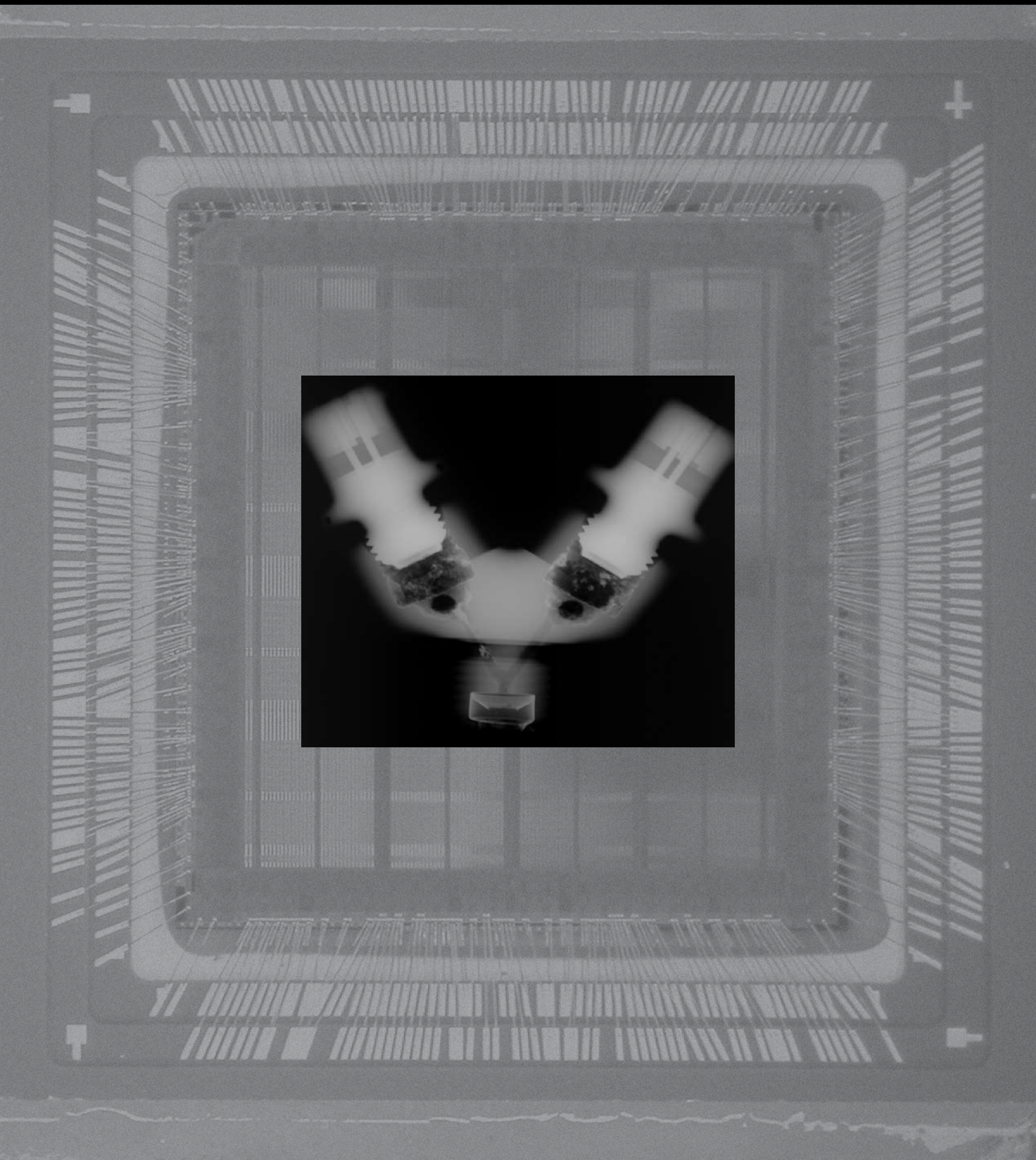
Problem: NASA is designing the next generation of human-rated vehicles that will take astronaut crews to the Moon and beyond in the next two decades. To support this endeavor, the Johnson Space Center (JSC) Astronaut Office asked the NESC to take a fresh look at the fundamental principles for developing safe and reliable human-rated spacecraft systems that should be considered during the formative phase of the Constellation Program.

NESC Contribution: A multi-disciplinary NESC team collected methodologies for developing safe and reliable human-rated space systems and identifying the drivers that provide the basis for assessing safety and reliability. Using a wide variety of resources including historical systems, subject matter experts, and contemporary engineering practice, the team identified techniques, methodologies, and best practices to assure that NASA can develop safe and reliable human-rated systems.

Results: The NESC published a two volume report on Design, Development, Test, and Evaluation (DDT&E) Considerations for Safe and Reliable Human Rated Spacecraft Systems. Volume I contains the overall systems engineering process along with three top level conclusions and seven guiding principles. Volume II contains expanded detail in nine discipline-specific sections.

Lessons Learned: The lessons learned by the NESC team are captured in the three top level conclusions. First, history indicates that no subsystem, component, or system element is immune from failure. It should be assumed that failures will occur and they should be planned for. Second, there is no single requirement, method, or process, which by itself assures the “right stuff” for safety and reliability. Cookbook approaches should be avoided and multilayered defenses should be used. Third, system level safety and reliability are achieved by maintaining a focus on these attributes throughout the DDT&E life cycle and during spacecraft operations. Potential problems should be anticipated by keeping a mindful preoccupation with failure, a reluctance to simplify interpretations, and a sensitivity to operations.

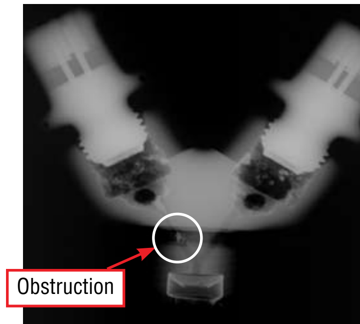
GENERAL



Conax Y-PCA Pyrotechnical Valve Assessment

Problem: The Solar Dynamics Observatory (SDO) Project requested the NESC perform an independent assessment of a "non-firing" pyrotechnic valve issue which was experienced in two shock test failures of baselined Conax Y-PCA pyrovalves. Another occurrence of the anomaly was later reported in a Lockheed military program and reproduced by Conax engineering in troubleshooting of the Lockheed anomaly. All four of these failures were of similar configuration and operation. This device is broadly used by NASA, commercial, and DOD missions; near-term NASA missions include Solar Dynamics Laboratory (SDO), Phoenix and Mars Science Lab (MSL).

NESC Contribution: The goals of the activity were to determine the root cause of the anomaly and to develop a clear understanding of how the device works with particular emphasis on ignition requirements at the booster interface. Test and analysis challenges were compounded by the small size of the device, the short timescales involved, and extreme environment during operation. The assessment included a series of "confidence" tests using live boosters, which attempted to duplicate the dual simultaneous fire anomaly, and single fire tests to demonstrate booster ignition margin. Other tests to understand the physics of device operation used novel techniques to measure temperature and pressure time histories, as well as combustion product distribution.



WSTF Technician Brooks Wolle prepares a Conax Y-PCA for an X-ray scan. An obstruction in one arm of the initiation path is evident *(above)*.

WSTF

The NESC team has provided guidance to programs already committed to using the device and has suggested improvements to the design.

Results: The NESC provided interim observations and findings to the SDO, Phoenix and MSL programs. That information included rationale for using the device in single fire operation, while highlighting likely contributors to the failure.

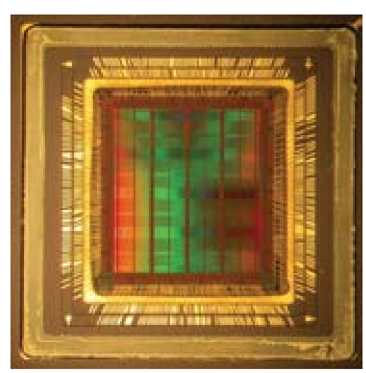
The SDO and Phoenix programs continue to baseline the use of the Conax Y-PCA for their upcoming missions, consistent with the operational recommendations and rationale the NESC provided. The MSL program, whose schedule allowed some investigation of PCA redesign, continued to develop and test an alternative design, which took into account many of the NESC observations and suggestions. Based on discussions with NESC, the new design is now baselined for MSL.

RTAX-S FPGA Risk Reduction

Problem: The NESC is conducting a risk reduction activity to reveal undocumented "design features" that pose a risk to flight programs that use the latest version of Radiation Tolerant Axcelerator - Space (RTAX-S) Field Programmable Gate Arrays (FPGA). The activity was initiated after numerous issues were discovered with the previous version of FPGAs. RTAX-S FPGAs are currently baselined for a number of Agency missions including Lunar Reconnaissance Orbiter, James Webb Space Telescope, Geostationary Operational Environmental Satellite, Mars Science Lab and the Orion Crew Module.

NESC Contribution: The NESC is working in collaboration with six NASA centers (GSFC, LaRC, GRC, MSFC, JSC and JPL), John Hopkins Applied Physics Lab and The Aerospace Corporation to develop a test plan for FPGAs and to peer review results of testing.

Results: NESC support is an important element in the development of a critical body of knowledge on RTAX-S FPGAs that will enable informed decision making and improved reliability.



NASA

RTAX-S FPGA showing package cavity, die, and wire bonds.

GENERAL

DC/DC Converter Investigation

Problem: Hybrid DC/DC converter flight failures have been observed or are suspected to have occurred on several NASA missions including GRACE, Hubble Space Telescope, and the International Space Station. In addition, numerous flight projects, both crewed and robotic, sustained severe pre-launch cost and schedule impacts due to hybrid DC/DC converter quality and application issues. Improved interpretation and use of converter specifications are needed.

NESC Contribution: The NESC is conducting electrical testing of converters to develop recommended test methods for users. This will standardize the approaches and communicate among NASA Centers the most effective testing program. Leveraging upon many years of experience and the testing, the NESC will develop an Agency-level Guidelines Document to aid designers and engineers in the pitfalls when using these types of converters. The NESC will recommend changes for MIL-PRF-38534 hybrid specification to increase the acceptability of these parts.

JPL

Typical DC/DC converter with cover removed shows internal components *(top)* and radiographic image of components *(bottom)*. The NESC is investigating ways to improve device reliability on deep space missions.

Results: A DC/DC converter Usage Guidelines Document will be available in 2008. Test reports will be included in the Guidelines Document and available to projects for their use. A DC/DC converter usage and failure reference website will be created for NASA Projects. The NESC is also working with vendors to improve the data provided in specification sheets.

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

NASA Aerospace Flight Battery Working Group

Problem: Batteries are used in virtually every space mission, crewed or robotic. The differences in the mission application, mission duration, planned operations, and even NASA Center experience result in the use of a large array of batteries and, therefore, battery issues. Individual engineers communicate and consult with their known counterparts at other Centers; however, there is no coordinated NASA-wide approach to 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 of new technology such as Li-Ion batteries.

NESC Contribution: To address these issues, the NESC proactively initiated the Aerospace Flight Battery Program. This activity supports the validation and verification of aerospace battery systems for NASA missions with contribution from five different Centers, (MSFC, GRC, JPL, JSC and GSFC). The program is designed to enable the implementation and execution of critical test programs to reduce risk by addressing wide-ranging technology issues. The issues affect the safety and success of future NASA missions. The final products include Battery Procurement Guidelines, Guidelines for Wet Life of Ni-H2 Batteries, and Guidelines for Li-Ion handling, safety, qualification and material availability.

GRC

GRC

(Above) The Battery Working Group meets to work issues with existing batteries and to develop next generation batteries. *(Right)* GRC developed and validated designs for nickel hydrogen (Ni-H2) cells that have been adopted for NASA missions and employed by cell manufacturers and satellite companies.

WSTF

A large Composite Overwrapped Pressure Vessel (COPV) is heavily instrumented for testing *(left)*. Numerous composite pressure vessels will be used in the Orion Crew Module *(below)*.

Composite Pressure Vessel Working Group

Problem: The use of and emphasis on light weight composite pressure vessels throughout the Agency by both human and robotic space programs is growing. As such, a NASA-wide multidisciplinary effort is required to understand the technology, to act as a technical resource to assist NASA Programs in solving current and future technical issues, and to stimulate advancements in the technology.

NESC Contribution: To address these issues, the NESC formed the Composite Pressure Vessel Working Group (CPVWG). An Agency-wide resource, the CPVWG is responsible for understanding composite pressure vessel design and analysis methods, standards and testing requirements and methods for existing, new and emerging technologies related to current and future needs of NASA Programs. Oversight of the CPVWG is provided by the NASA Technical Fellows disciplined in Materials, Structures, and Nondestructive Evaluation and membership includes technical experts from across NASA.

Results: The initial emphasis of the CPVWG is to support NASA's human space flight related programs that involve composite overwrap pressure vessel (COPV) technical issues. The CPVWG is developing a materials data-base that will include all available data associated with carbon fiber stress rupture. Relevant data will be used by ISS and Constellation Programs for stress rupture life prediction analysis. The CPVWG is also developing an understanding related to the long term use of COPVs and the nuances associated with testing efforts required to fully characterize long term stress rupture. Results of this ongoing effort have led to direct input to the Orion Project team working on COPV stress rupture testing requirements. The working group is also developing state-of-the-art life prediction and mechanics models that will be required to understand and predict the long term use of COPVs. A physics-based understanding of existing stress rupture reliability models is being developed so that the true capabilities of COPVs is understood when considering COPV reliability predictions.

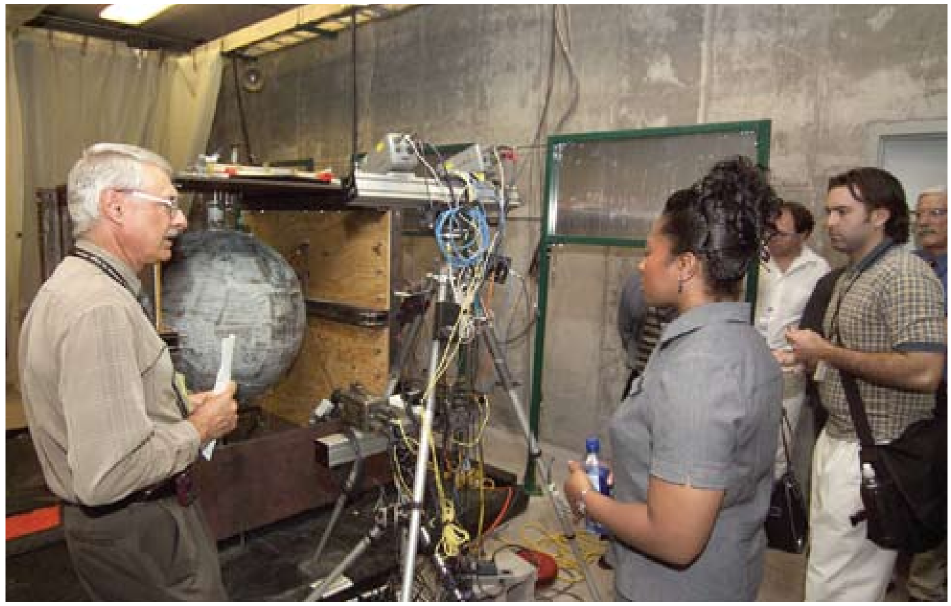
As no fracture mechanics-based methodology exists that can be reliably used to predict the fracture behavior of plastically deformed thin wall metal liners, proactive work is being conducted to develop a standard test methodology. The methodology could be used to obtain the low cycle crack growth data in the biaxial stress state field of a responding COPV metal liner. The CPVWG is also conducting a study to understand state-of-the-art associated with large composite tanks. Industry perspectives will also be captured. The output of this effort will be a comprehensive report that describes the current technology. The CPVWG is developing an Agency-wide expertise for standards by interacting with organizations that develop and maintain standards for use of pressure vessels.

Composite Overwrap Pressure Vessel Technical Issues

Problem: The NASA Chief Engineer requested an integrated technical summary of concerns associated with composite overwrap pressure vessels (COPVs) to assess if there are systemic issues with the COPV design, test, and operation. The activity was requested as the result of recent COPV issues including the inspection of a spare Space Shuttle Orbiter Main Propulsion System COPV and the detection of irregularities on the liner inner surface.

NESC Contribution: The NESC utilized the Composite Pressure Vessel Working Group (CPVWG) and other subject matter expertise to identify the principal observations associated COPVs. The NESC did not identify systemic issues with the design or application of COPVs that would suggest incipient failure of any pressurization system in service. The NESC team could not identify any common causes for the noted design, analysis, fabrication, inspection, test, or operational issues.

Results: The NESC delivered a technical report that summarized critical aspects involved with the industry standard for COPV design, analysis, and test; COPV failure modes and damage mechanisms; relevant COPV anomalies; and a summary of current COPV and related investigations.



WSTF

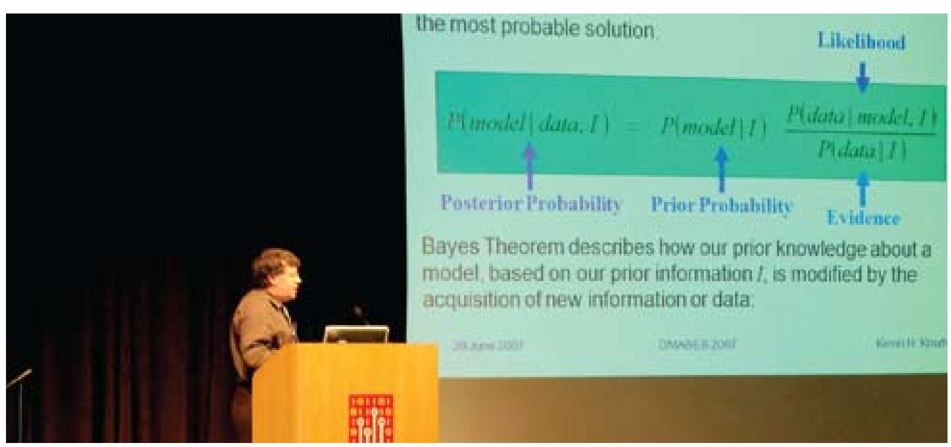
WSTF Project Manager Regor Saulsberry briefs Assistant Associate Administrator Christyl Johnson of NASA HQ on the 40-inch Kevlar COPV testing.

Data Mining and Trending Response Team

Problem: The NESC is currently leading the Agency's efforts to perform independent data mining and trend analysis to identify unknown indicators of future problems. One of the NESC goals is to strengthen the Agency's capabilities to perform data mining and trending, both within and across programs and projects.

NESC Contribution: The NESC is leading the Agency's Data Mining and Trending Working Group. The working group is comprised of experts from across the Agency, as well as from industry, academia and other government agencies, such as the Federal Aviation Administration, Department of Homeland Security, National Transportation Safety Board and the Institute of Nuclear Power Operations. This year the working group established a Data Mining Response Team to provide expert data mining analytical capabilities to programs, projects and institutions The goal is to both address the specific data mining problems and needs, while also providing an opportunity for the requesting organization to learn how to apply a tailored approach to data mining in their domain.

Results: The NESC's collaboration with other organizations has enabled the exchange of ideas, particularly regarding methodology and lessons learned. The group 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. In addition, the response team has undertaken tasks for the Crew Exploration Vehicle (CEV) Test and Verification Team to explore and analyze International Space Station data needed to support the system-level environmental acceptance testing approach and development process for CEV.



ARC

Professor Kevin Knuth presents his work on sampling and heuristics at the 2007 data mining conference.

NSI Firing Current Independent Review for Phoenix

Problem: An incorrect minimum current requirement for the cold temperature firing of NASA Standard Initiators (NSIs) on the Phoenix spacecraft was discovered. The circuit was designed to deliver 3.5 amps (with positive margin) whereas 5.0 amps is recommended at temperatures below -65°F. There were four pyrotechnic events of concern with the coldest event occurring at -173°F. Two of these events were mission critical. The Phoenix Project performed testing and analysis and determined that the design had sufficient current to fire the NSIs, although the recommended 5.0 amp current was not met.

NESC Contribution: The NESC was asked to review testing and analysis. A subset of 20 units from the actual Phoenix NSI lot were tested and showed an "all fire" current limit of 4.1 amps with 90% system reliability using a 10 millisecond pulse current at -211°F. The NESC team found that the circuit analysis predicted, in worst case, the spacecraft circuitry would deliver a minimum current of 4.47 amps (almost an amp of design margin). Additionally, the flight circuit uses a 20 millisecond pulse current (twice that required) and the worst case predicted temperature is -173°F. This results in positive margin in the current, time and temperature.

Results: The NESC team concurred with the Phoenix Project's circuit analysis predicting sufficient current to fire the NSI's.

JPL

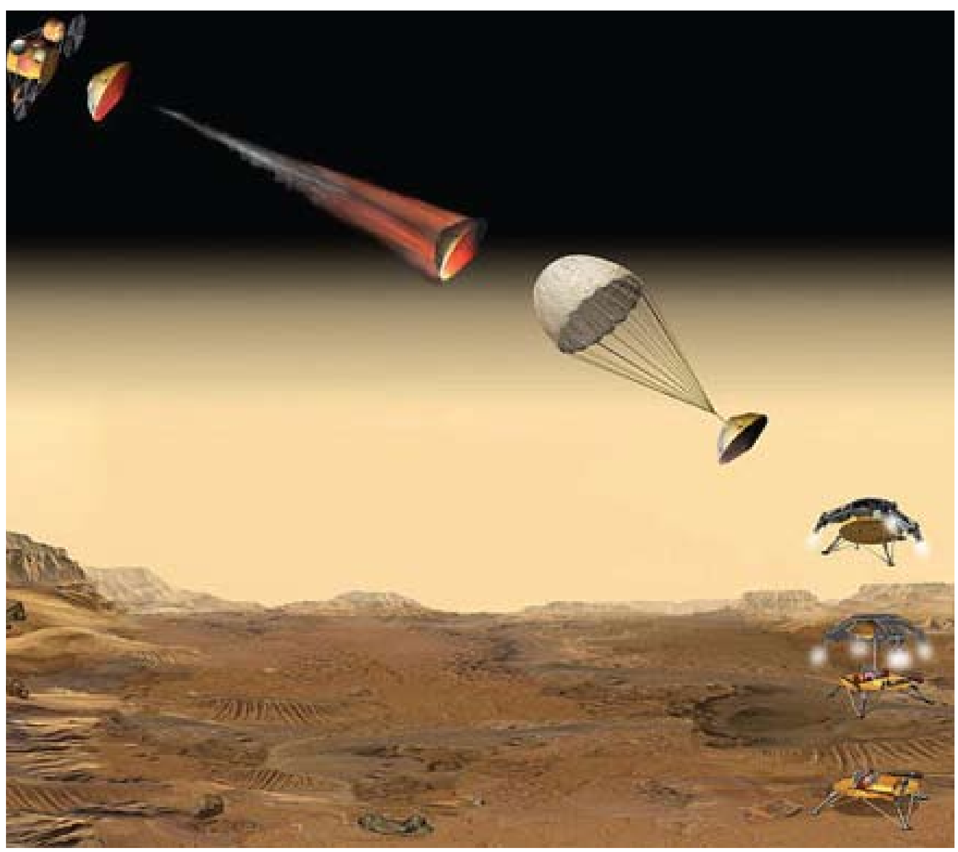
Dozens of NSIs are used throughout the Phoenix spacecraft to initiate pyrotechnic events. The NESC agreed with the Project that the NSI firing circuit design was adequate.

Entry, Descent, and Landing 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.

NESC Contribution: In response to this problem, the NESC is focusing on two aspects: to locate, collect, and digitize NASA technical and engineering EDL material and to develop a secure, web-based repository.

Results: The EDL Repository is in the process of being created, and initial EDL material from a prioritized set of missions is being stored. Upon completion, the repository will be delivered (FY09-10) to a NASA-selected Center for continued growth and maintenance.



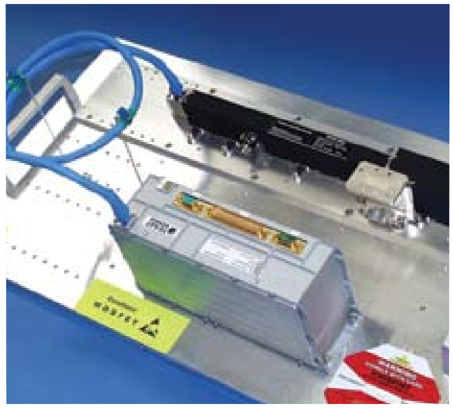
JPL

Modeling of the EDL sequence for the proposed Mars Sample Return mission would benefit from a single comprehensive source of historical EDL data to improve modeling accuracy.

Dawn Mission TWTA Venting Independent Assessment

Problem: A concern was raised regarding when the Dawn Mission Traveling Wave Tube Amplifier (TWTA) would be activated to establish the post-launch communications downlink. The mission plans called for TWTA activation one-hour after launch, but the spacecraft contractor typically requires a venting period of 24 hours due to potential failures that can occur from corona and/or breakdown of the high voltage microwave components in the TWTA. Breakdown can occur due to the presence of small physical gaps between conductors that carry a high radio frequency (RF) voltage in the presence of partial atmospheric pressures or outgas constituents. The NESC Chief Engineer at JPL requested an independent review of JPL TWTA venting analysis for Dawn.

NESC Contributions: The NESC conducted a thorough review of existing literature regarding RF breakdown in a low pressure environment to understand the state of knowledge regarding this phenomenon. All critical areas of the TWTA electronics were analyzed for adequacy of venting from the spacecraft during ascent to orbit to ensure that pressures at TWTA activation would be well below what is required for RF breakdown to occur.



JPL

The Dawn Mission required that the main communication system amplifier be activated soon after launch. The NESC reviewed and concurred with a JPL analysis that concluded that the system could be safely activated according to the mission timeline.

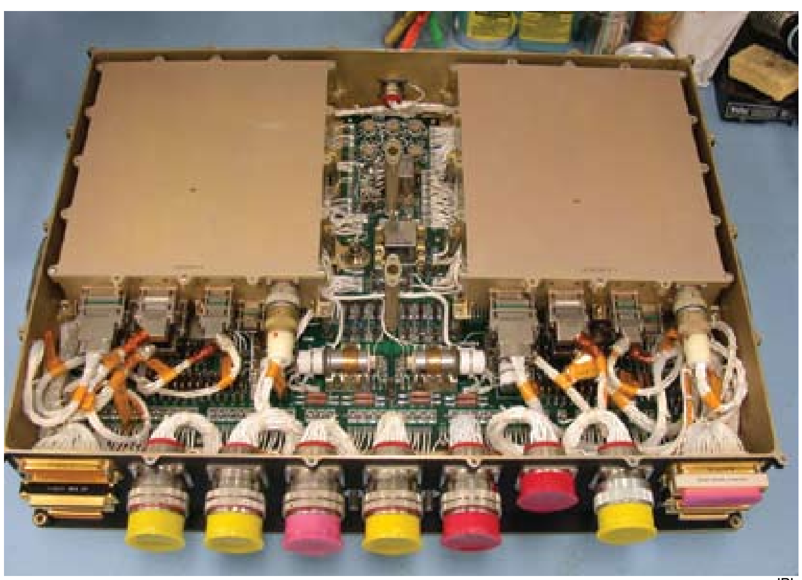
Results: The NESC concurred with the JPL venting analysis which concluded that adequate margin existed to activate the TWTA in accordance with the mission time line and no evidence was found to support the 24-hour waiting period. This finding was critical because a 24-hour delay in communications could have jeopardized mission success. Dawn was successfully launched in September, 2007.

Lessons Learned: To mitigate risk on future missions, the activation of the communications equipment should be considered during spacecraft thermal vacuum test pump down to support validation of venting analysis and system performance.

Dawn Mission HVEA Failure Analysis Independent Review

Problem: After a failure encountered on the Dawn High Voltage Electronics Assembly (HVEA) during Assembly Test Launch Operations, the Dawn Project requested an independent NESC review of the available failure related data, subsequent activities and corrective actions taken by the project. The review was requested to ensure proper post failure actions were assigned and resolved as well as to provide additional recommendations for consideration, if applicable.

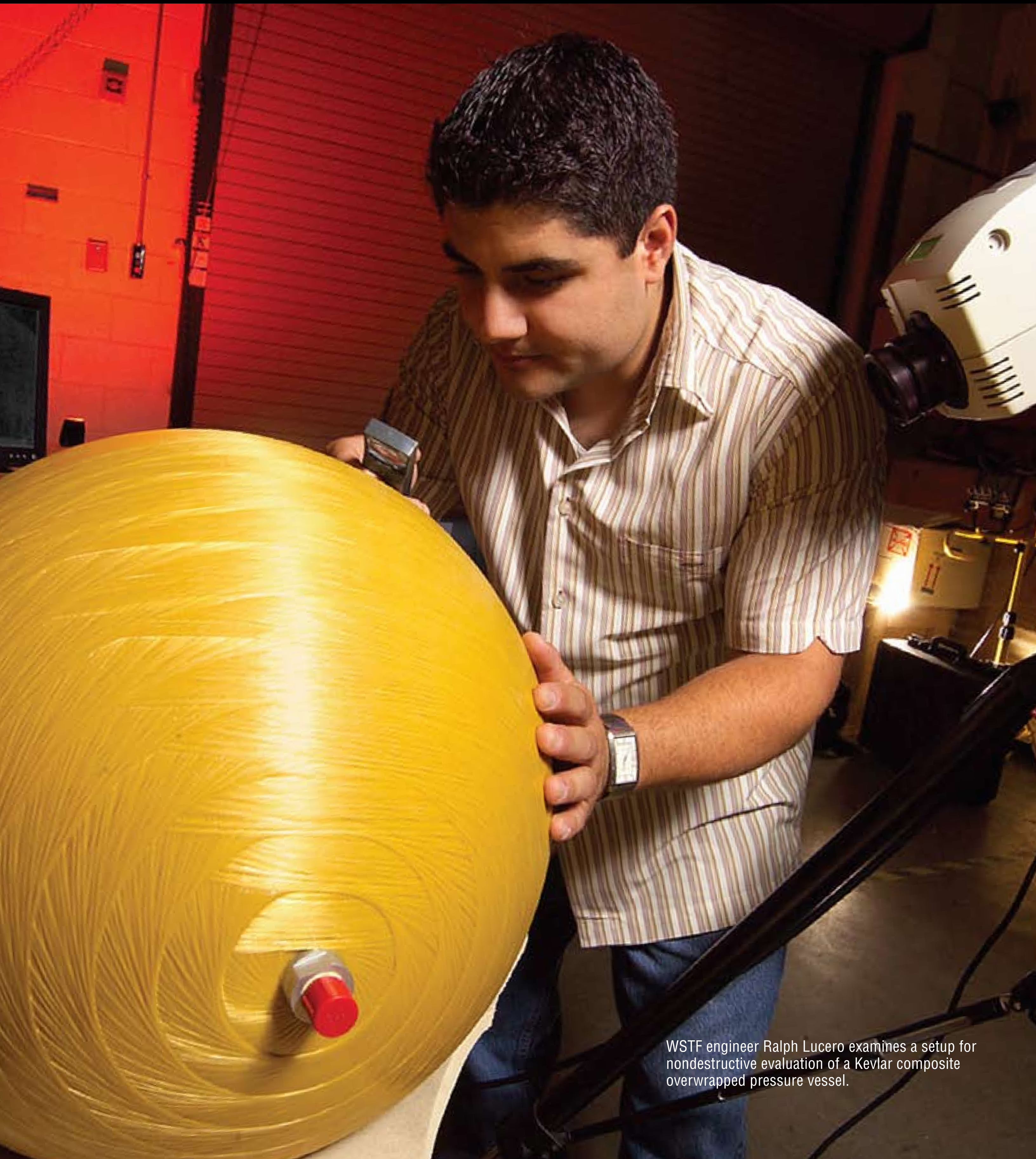
NESC Contributions: After reviewing the available data related to the observed failure and working with the project team, the NESC Review Team determined that the cause of the Dawn HVEA failure was understood by the Dawn Project and occurred primarily as a result of operator procedural error that did not prepare the HVEA for Solar Array Simulator activation. The error resulted in high in-rush currents that were beyond the capability of the HVEA.



JPL

The Dawn High Voltage Electronics Unit sustained damage due to excessive current during spacecraft testing. The NESC reviewed and concurred with the results of the JPL mishap investigation and made recommendations for the project's consideration.

Results: The Dawn Project implemented the HVEA repairs and actions recommended by the Review Team. Dawn was successfully launched in September, 2007.



WSTF engineer Ralph Lucero examines a setup for nondestructive evaluation of a Kevlar composite overwrapped pressure vessel.

AMES RESEARCH CENTER

The NESC efforts this year at Ames Research Center (ARC) included Aeroacoustic Noise Reduction for the Crew Exploration Vehicle and data mining methodology for the response team. Dr. Tina Panontin, the ARC Chief Engineer, was also named the NESC Chief Engineer at ARC and will perform both roles. The NASA Office of the Chief Engineer also named Dr. Cynthia Null, an NESC employee resident at ARC, as the NASA Technical Fellow for Human Factors.

Crew Exploration Vehicle (CEV) Aeroacoustic Noise Reduction

The NESC collaborated with the CEV Aerosciences Project Aerodynamic Testing Team to perform wind tunnel tests of three Alternate Launch Abort System (ALAS) configurations. The NESC examined the acoustic benefits from the alternate configurations. Empirical predictions showed that the baseline CEV Launch Abort System (LAS) would generate up to 172 dB local pressure fluctuations during a nominal ascent. For an ascent abort, the levels are expected to be as high as 17 dB. Protecting structure and systems from these very large pressure fluctuations is expensive and carries a significant weight penalty. The NESC effort led to an improved aerodynamic shape that has been adopted as the new baseline for the CEV. This new shape resulted in reducing the fluctuating pressure levels on the CEV with cost and weight savings for the CEV Program.

NASA

Nate Burnside, ARC's Principal Investigator of the Fluid Mechanics Laboratory, cleans a nozzle after the 50-AS testing was completed. The baseline 605-068 LAV, ALAS-2, and ALAS-11 models are in the foreground.

Data Mining Response Team

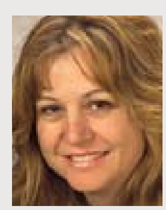
This year, the Data Mining Response Team established a data mining methodology; and solicited, reviewed, and started work on several activities. The team completed an analysis of the International Space Station (ISS) Problem Reporting and Corrective Action (PRACA) reports in support of a JSC-led Orion spacecraft acceptance test study. The task was to gather and analyze historical failures for evidence of the effectiveness (or lack thereof) of system level acceptance testing for manned spacecraft. From an initial set of over 4000 reports, the team isolated 27 reports that had a direct bearing on potential Orion acceptance test issues.

The Data Mining in Aeronautics, Science, and Exploration Systems (DMASES2007) conference, sponsored by the NESC, Aeronautics Research Mission Directorate (ARMD) Integrated Vehicle Health Management (IVHM), and the Science Mission Directorate (SMD), provided the data mining community with an opportunity to share recent advances in data and text mining, machine learning, and statistics across the larger communities of engineers and scientists working in aeronautics, aerospace, and science.

NESC Awards

Mr. Ian Fernandez received the NESC Engineering Excellence Award for his contributions to the NESC Composite Crew Module Project.

"With access to experts within and outside of NASA, the NESC has contributed to the success of a number of Ames activities, from capture of Stardust aerothermal entry data, to peer review of CEV aeroscience efforts and aeroacoustics of the SOFIA aircraft modification. In similar fashion, Ames experts working in the NESC have brought their expertise to bear on Agency engineering challenges, in particular in the areas of TPS, composite design, data mining, and human factors. ARC is strongly committed to supporting future interactions with the NESC."



— **Dr. Tina L. Panontin,** *Ames Research Center Chief Engineer and NESC Chief Engineer*

WSTF

DRYDEN FLIGHT RESEARCH CENTER

Dryden Flight Research Center (DFRC) scientists and engineers have contributed to the NESC's multi-discipline teams that are helping to address some of the Agency's biggest challenges. The NESC has also supported NASA projects and programs at DFRC.

NESC Technical Discipline Team Support

DFRC has supported the NESC in the area of non-destructive evaluation (NDE), and structural health monitoring. That latter area includes an NESC workforce augmentation for a task supported by NASA's Non Destructive Evaluation working group. Research is being conducted at a basic level to quantify and interpret the various contributions of the measurement response from fiber optic sensors embedded in composite overwrapped pressure vessels (COPV) when subjected to pressure loading. Testing of coupons with embedded fiber Bragg gratings parallel and perpendicular to the structural fiber direction is currently under way. DFRC is also supporting the NESC Loads and Dynamics Technical Discipline team through the efforts of Dr. Kajal K. Gupta, who has supported the NESC Ascent Loads Analysis system development.

John Carter, DFRC SOFIA aircraft project manager *(left)* and NESC Chief Engineer at DFRC, Dr. James Stewart, discuss the SOFIA Cavity Door Drive System Independent Review Team results and report that was supported by the NESC.

DFRC

Stratospheric Observatory for Infrared Astronomy (SOFIA) Project Support

The SOFIA Project continues to be a key area of collaboration between the NESC and Dryden representatives. This year, DFRC supplied mechanical and avionic experts to support a SOFIA Cavity Door Drive System Independent Review Team. SOFIA team leaders asked for assistance in identifying experts in thermal insulation, an area in which the NESC made a contribution. In addition, SOFIA program managers requested that the NESC support other SOFIA reviews conducted this year. The reviews played a key role in a safe and successful initial flight test series and safe transition of the SOFIA aircraft to Dryden as well as in flight readiness for the next flight test phase.

NESC Awards

Several Dryden engineers who have supported NESC activities during past years were recognized with awards for their contributions. Dryden Associate Director for Operations Larry Schilling and Dryden NESC Chief Engineer Dr. James Stewart recently presented NESC awards to Vicki Regenie for the NESC Design, Development, Test and Evaluation Considerations for Robust and Human-Rated Spacecraft Assessment. Since gaining experience on this NESC team, she has been assigned as Dryden Deputy Exploration Mission Manager. Also recognized were Martin Trout, Doug Baker and William Brockett who received awards for their efforts on the Stardust Hypervelocity Entry Observing Campaign. Dr. Kajal Gupta received an NESC award for his support of NESC External Tank Liquid Hydrogen Tank Ice Frost Ramp Redesign.

Dr. James Stewart
NESC's Chief Engineer at DFRC

DFRC

(Above left) Dryden Associate Director for Operations Larry Schilling presented an NESC achievement award to Vicki Regenie for efforts on the DDT&E assessment. *(Above right)* Dr. James Stewart presents an NESC Group Achievement award to Martin Trout for his efforts in the Stardust Hypervelocity Entry Observation Campaign.

GLENN RESEARCH CENTER

The Glenn Research Center (GRC) engineering and scientific community participated in a wide range of NESC activities. The support from GRC consists of using matrixed GRC personnel and contractors as members of NESC assessment teams and NESC Technical Discipline Teams (TDTs). The NESC Chief Engineer (NCE) at Glenn represented the NESC as a member of the internal Engineering Management Council and major reviews of Center projects. The NCE provides GRC senior management status updates on NESC on-going activities.

Exploration Systems

The Glenn community has supported the near and far-term objectives of the Constellation Program through the NESC. GRC personnel planned and led sessions of the Lunar Dust Workshop held at Ames early this year and continue to perform key risk mitigation activities associated with lunar dust identified at the workshop. Other contributions included further evaluation and comparison of land and water landings for the Orion reentry, conceptual development of a composite crew module design and evaluation of thrust vector control architecture alternatives for the first-stage CLV. The NESC has worked along side the Ares I-X Upper Stage Simulator Project to independently assist in development of weld inspection criteria for the critically loaded welds in the structure.

Derrick Cheston
NESC's Chief Engineer at GRC

Space Operations

GRC supported the independent assessment of the Orbiter Wing Leading Edge Reinforced Carbon-Carbon (RCC) panel subsurface anomaly and the development of data to support flight rationale for STS-117. GRC scientist, Dr. Elizabeth Opila, was recognized for her contributions to this team. GRC has also participated on the tiger team assessment of the root cause and potential effects of a chipped gear tooth observed on a qualification unit of orbiter rudder/speed brake actuator.

Additionally, GRC scientists have continued to play a particularly key role in establishing and communicating effective guidelines for development, test and use of composite pressure vessels for both the International Space Station and the Orbiter Project. GRC NDE team members including Dr. Don Roth are now summarizing NESC efforts over the last 3 years to develop and validate new NDE methods for the Space Shuttle external fuel tank foam.

GRC

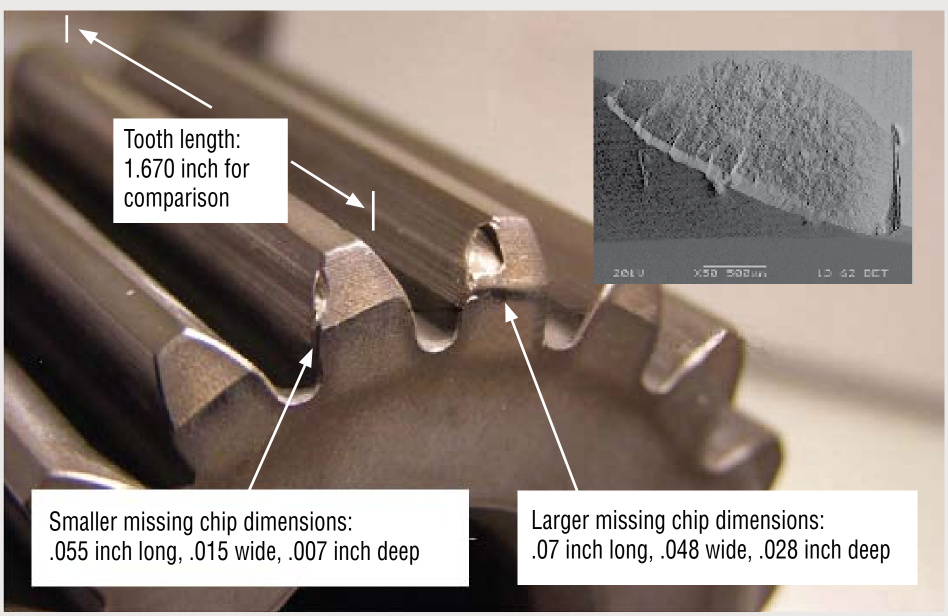
The GRC is designing and manufacturing the 11 Upper Stage Simulator segments for the Ares I-X flight demonstration. The largest segments are 10 feet high, 18 feet in diameter and will weigh up to 18,000 pounds.

Cross-Enterprise Proactive Risk Reduction

Aerospace Battery Working Group: GRC leads a multi-Center team tasked to reduce and/or quantify some of the unknowns associated with battery life and performance in aerospace applications. The efforts of this team will lead to increased knowledge which will better inform designers and operators of aerospace flight systems which rely on battery technology.

Computational NDE: Computational non-destructive evaluation is a promising advanced technology for analytically predicting "inspectability" of a test article based upon a CAD solid model geometry file. Glenn scientists will assist the validation of this technology for the Agency through initial funds provided by the NESC.

Design/Use Guidelines for Composite Pressure Vessels (CPVs): Dr. James Sutter of GRC and Dr. Lori Grimes-Ledesma of JPL together have provided leadership for the Agency's Composite Pressure Vessel Working Group, which shares invaluable lessons learned, best practices and limitations associated with design and operating CPVs. The working group is a resources for all programs that are currently or are considering the use of these advanced vessels.



GRC

Multiple chips were found in an Orbiter Rudder/Speed Brake qualification unit. *(Inset)* Backscattered electron micrograph showing general overall appearance of chipped region in topological mode.

GODDARD SPACE FLIGHT CENTER

The NESC continues to utilize the best talent from across the Agency to resolve NASA's toughest issues. Goddard Space Flight Center (GSFC) personnel have contributed to numerous NESC assessments this year while GSFC projects and programs have also benefited from this same dynamic when they secured NESC support. The NASA Office of the Chief Engineer named the following as Technical Fellows: Mitchell Davis, Avionics; Cornelius Dennehy, Guidance, Navigation and Control; and Michael Aguilar for Software. All are NESC employees resident at GSFC.

GSFC

Jeff Stewart/Mechanical Engineering Branch *(left)* and GSFC Director of Engineering Orlando Figueroa examine a model of the Composite Crew Module.

Technical Discipline Team Support

Goddard's involvement in the NESC technical activities has primarily focused on the competency areas of GN&C and software. GSFC personnel serve as deputies to NASA Technical Fellows for Mechanical Systems and Mechanical Analysis who are resident other Centers.

Michael Hagopian
NESC's Chief Engineer at GSFC

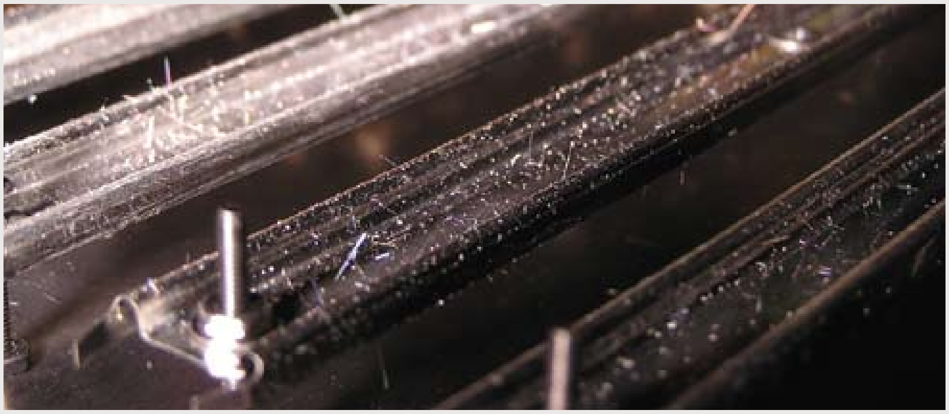
Exploration Systems Support

Goddard's competency in mission systems engineering has continued to evolve as an important NESC resource in support of the Constellation Program. GSFC personnel are now supporting Constellation-wide GN&C and Avionics architecture trade studies. GSFC is also currently hosting focused development activities on other NESC activities including the Composite Crew Module Pressure Vessel at GSFC and the Max Launch Abort System flight demonstration at Wallops Flight Facility.

Space Operations Support

Goddard personnel were key participants in numerous NESC activities in support of the Space Shuttle Program including the Rudder/Speed Brake Chipped Gear Tooth and Power Drive Unit Motor Dry Film Lubrication Bolt Issue assessments, Fuel Cell Motor Two-Phase Operation evaluation, ET Ice Mitigation studies, and the Space Shuttle Tin Whiskers consultation.

Goddard supported a variety of ISS activities including the Space Shuttle Power Transfer System risk evaluation, Rotor Joint Motor Controller Anomaly consultation, Control Moment Gyro Failure investigation, the use of Loctite®, S-Band Forward Link Anomaly, and Attitude Control Anomaly issues. Some of these problem-solving activities were performed in "real-time," during the course of a mission.



GSFC

Optical Photograph of Tin Whiskers on Tin-Plated Beryllium-Copper Card Guides Removed from Space Shuttle Avionics Boxes in 2006.

Science Mission Support

GSFC personnel have also led several NESC assessments in support of science missions, including the Conax Y-PCA Pyrovalve assessment for several science missions; and the Phoenix NASA Standard Initiator and Robotic Arm Brush Motor Failure reviews.

Proactive Efforts

The NESC proactive work, intended to prevent problems by addressing issues common to multiple programs, has also benefited Goddard missions. The NESC has funded Field Programmable Gate Array reliability studies including an RTAX-S Risk Reduction program. The NESC is currently working on a DC/DC Converter users guide, supporting a NASA/Aerospace Flight Battery program, and studying the benefits of using Flight Force Measurements to Improve Coupled Loads determination and reduce design/qualification requirements.

NESC Awards

Dr. Daniel Polis received the NESC Director's Award and Jeffrey Stewart received the NESC Leadership Award for their contributions to the NESC Composite Crew Module Project. Mr. Paul Guy received the NESC Engineering Excellence award for his contributions to the NESC independent review of the Phoenix Project. Mr. Robert Cherney accepted an NESC Group Achievement Award on behalf of the ISS to Shuttle Power Transfer Open PRACA Team.

JET PROPULSION LABORATORY

In 2007, JPL participated in numerous NESC studies for the Science, Exploration Systems and Space Operations Mission Directorates.

Science Mission Support

JPL personnel engaged in independent NESC assessments of the Mars Phoenix Lander to evaluate an issue related to the firing of NASA Standard Initiators (NSIs) on the spacecraft. At cold temperatures the NSIs are recommended to use at least five amps as the current level with safety margin. Phoenix is supplying less current for several of the NSI circuits. The Phoenix Project testing and analysis shows that their levels are sufficient. The NESC concurred with the testing and analysis and supported the use of the NSI circuits as designed.

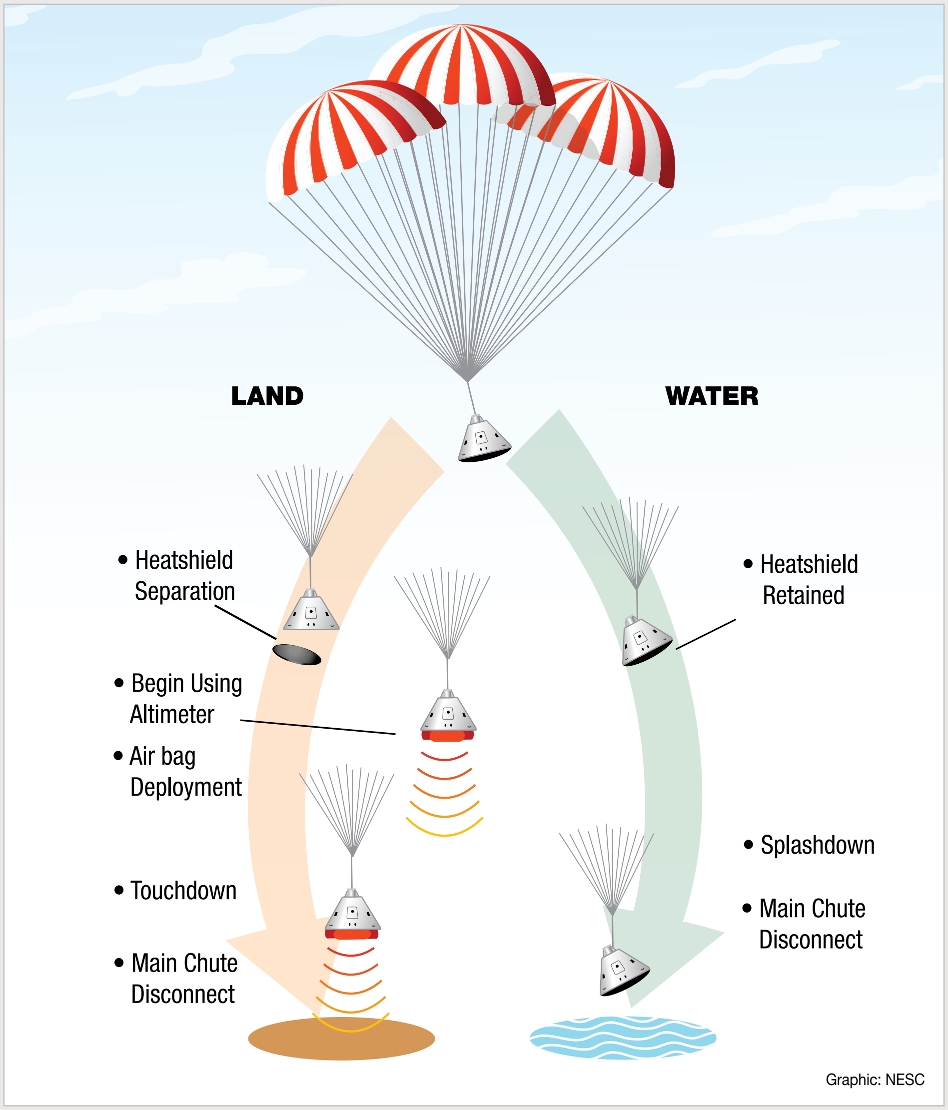
The Dawn Mission to orbit two of the solar systems largest asteroids, required analysis of its High Voltage Electronics Assembly (HVEA) which had a failure during thermal vacuum testing. Trouble shooting quickly identified several failed components.

R. Lloyd Keith
NESC's Chief Engineer at JPL

Evaluation of the repair approach and flightworthiness of the refurbished HVEA was conducted by the NESC and the system was accepted for flight. The Dawn Project also did an analysis that concluded that the Traveling Wave Tube Amplifier (TWTA) could be turned on within a very short time after separation from the launch vehicle. There was some residual concern that turning on a TWTA without waiting 24 hours could cause a failure due to insufficient venting of gasses from the chambers. The NESC independently reviewed the analysis to verify the assumptions and calculations and agreed with the JPL position.

JPL

The Phoenix Pyrotechnic Initiation Unit sends current pulses of precise magnitude and duration to the NASA Standard Initiators on the Phoenix spacecraft to start numerous actions.



JPL performed a risk assessment for land and water landing configuration options of an Orion Crew Module.

JPL has also been instrumental in the development of design and validation guidelines for next generation field programmable gate arrays used in many NASA and commercial spacecraft.

Exploration System Support

Using expertise gained through Mars entry, descent and landing (EDL), JPL engineers and scientists are also leading a follow-on study to evaluate the existing NASA and new contractor CEV landing and recovery architectures. JPL personnel led the risk analysis for the team that quantified risks to the crew, vehicle and public.

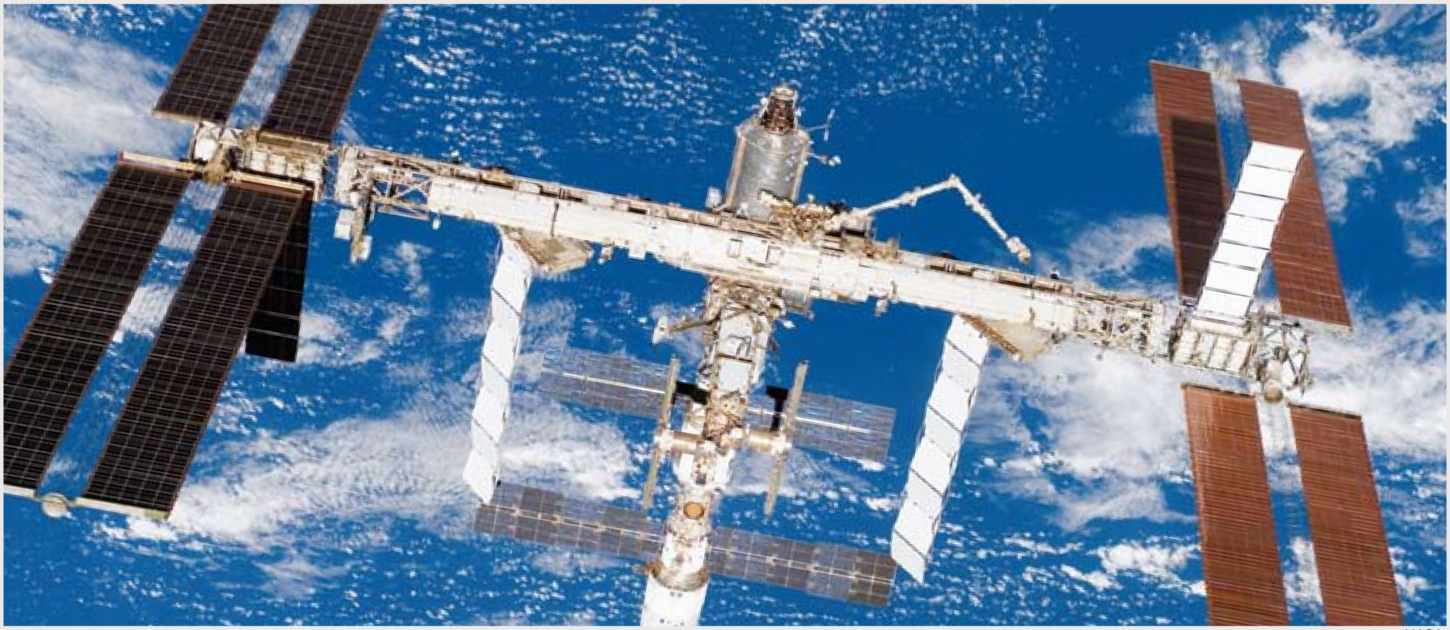
Space Operations Support

JPL continues to be engaged in the analysis of the long-term safety of COPVs. JPL is providing the joint leadership for the COPV working group sponsored by the NESC. JPL is also active in data mining and trending of existing problems. The Robotics Technical Discipline Team (TDT) led by JPL has also had 4 proactive proposals accepted to advance robotic exploration. The first of these led to a very successful Lunar Dust Workshop in January 2007. Sessions were conducted on issues in Human Health, Life Support, Mechanical Systems, and Research. The second task, DC/DC Converters, has developed a draft of guidelines for developers of power systems as well as test methodologies to be used. The last two, EDL Data Archiving and Wireless Avionics in Space are progressing well.

NESC Awards

Mr. John Baker accepted an NESC Group Achievement Award on behalf of the NESC CEV Water Versus Land Landing Study Team.

JOHNSON SPACE CENTER



NASA

The International Space Station (ISS) seen from the Space Shuttle Endeavour on STS-118. The NESC has supported several recent activities on the ISS.

The NESC at the Johnson Space Center (JSC) continued to support the Space Shuttle Program (SSP), the International Space Station Program (ISS), and Constellation Program (CxP) during 2007. The NASA Office of the Chief Engineer named JSC engineers Henry (Hank) Rotter and Dr. Curtis Larsen as the NASA Technical Fellows. Mr. Rotter for Life Support/Thermal/Fluids and Dr. Larsen for Loads and Dynamics . Former NESC employees who have returned to, or become a part of the JSC team, include John McManamen, SSP Chief Engineer, Steve Labbe, CxP Chief Engineer, Julie Kramer-White, Crew Exploration Vehicle (CEV) Chief Engineer; Brian Muirhead, Cx Program Architecture Office lead, Steve Hawley Astromaterials Chief, and Jay Legett as the ISS Systems Engineer.

Space Operations Support

The NESC supported the SSP through a number of assessments. Orbiter-specific analyses included: development of alternate Non-Destructive Evaluation (NDE) technology for inspection of the orbiters' leading edge Reinforced Carbon-Carbon panels; working with the Orbiter Project team to investigate/resolve issue of chipped gear teeth found in the rudder/speedbrake actuator; independent analysis following loss of phase A power on an Orbiter fuel cell pump for the STS-115 mission. External Tank (ET) — specific support included: support to the Ice Frost Ramp Redesign Team; participation with the ET Team in foam repair assessment engineering; developing a foam impact prediction algorithm of ascent debris release from the ET, debris transport, and orbiter thermal protection system impacts in order to perform an independent risk assessment; participated in the development and testing of the Shuttle Ice Liberation Coating which has shown reduction of ice adhesive strength on aluminum, foam, Kapton tape and film, and on Fire-X paint. The NESC also conducted an assessment of NDE options for the Crawler transporter shoes which have experienced cracking due to casting voids and associated slag inclusion. The NESC provided support to the ISS Program in several areas. The NESC investigated specific subsystem issues including: the effect of Solar Array Mast longeron shadowing, including thermal-vacuum testing at JPL; supported ISS Team to understand cause of the Rotary Joint Motor Controller failure in the robotic arm; investigated electrical nuisance trips of the Space Shuttle to ISS Power Transfer System and supported further study of the potential hazards associated with Control Moment Gyro bearing failure.

Dave Hamilton
NESC's Chief Engineer at JSC

More general ISS investigations included: assessment of the sensitivity of Loctite™ performance to fastener variables including diameter, thread class, thread finish, cleaning, primer, preload, cure, joint type, material and type of Loctite; support for ISS coolant chemistry testing and analyses in preparation for systems activation, and finally, established a multi-disciplinary team to address Composite Overwrapped Pressure Vessel issues, specifications, design practices, manufacturing, testing, and use for ISS, including the SSP, and future vehicles.

Exploration Systems Support

JSC employees engaged in numerous NESC assessments in support of CxP, covering a broad range of topics. CEV-related support to the NESC CEV Composite Crew Module Team; development of Alternate Launch Abort System concepts for CEV designed to reduce ascent drag with goal to increase weight to orbit and evaluation of injury/loss-of-crew risk factors for CEV water and land landing designs. Ares support included: independent study to identify minimum allowable flaw size in vicinity of structural welds on the new Ares launch vehicle utilizing the loads cycle spectrum to predict crack growth for assumed structural flaws; assessed the knockdown factor for structural shell buckling of booster walls to assess conservatism; conducted independent assessment of the NASA Plum Brook Facility for J2X engine testing, and supported the assessment of safe separation storage distances for the additional solid rocket segments at KSC required for the CxP lunar and Mars missions.

NESC Awards

Mr. Christopher Cerimele and Mr. Joel Broome received the NESC Engineering Excellence for their contributions to the NESC CEV. Water versus Land Landing Study. Dr. Eugene Ungar received the NESC Engineering Excellence Award for his contributions to various NESC efforts on the Space Shuttle External Tank.

KENNEDY SPACE CENTER

The Kennedy Space Center (KSC) continues to provide excellent support and expertise to a wide variety of NESC assessments and testing. The NESC team was well supported by more than 50 KSC civil servants and contractors of various disciplines who were active in NESC assessments and studies this year. Also, 26 NASA personnel at KSC are standing members of the NESC's Technical Discipline Teams. These discipline expert teams are the primary workforce the NESC calls upon when performing assessments and studies.

Space Operations Support

KSC researchers continued to support the NESC Shuttle Ice Mitigation assessment. This assessment is developing and testing a new compound called Shuttle Ice Liberation Coating which has been demonstrated to reduce the adhesive strength of ice on aluminum, foam, and Kapton® material. The Space Shuttle Program will begin qualification testing of this material for use on the Space Shuttle as early as next year.

Stephen Minute
NESC's Chief Engineer at KSC

KSC engineers provided assistance to the NESC in an important circuit analysis and circuit simulation for two key International Space Station issues as a member of the NESC Avionics & Electrical Technical Discipline Team.

Exploration Systems Support

In anticipation of increased amounts of solid propellant segment processing in the Vehicle Assembly Building (VAB) during the later Constellation Program campaigns, the NESC is partnering with KSC to assess safe separation distances surrounding the VAB. The NESC is modeling the ignition characteristics of the propellant and motor segments within the VAB and its internal structure while KSC is instrumenting and collecting solid rocket motor test data to anchor the models. Multiple NASA Centers, other government agencies and industry are partnering to perform this assessment.

NASA

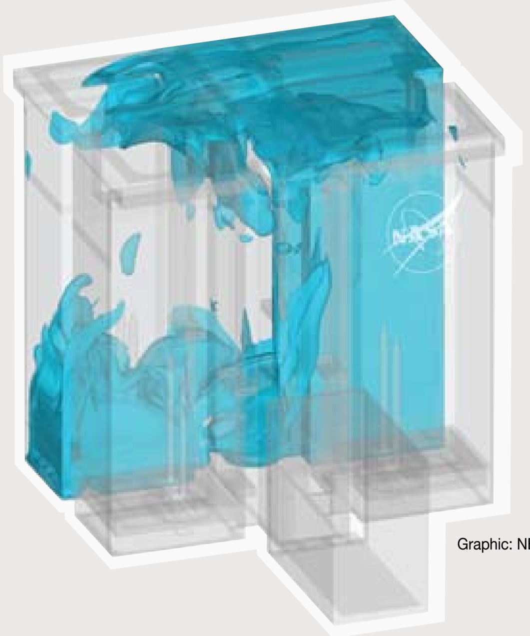
Joycelyn Harrison of LaRC Advanced Materials and Processing and Charles Stevenson of KSC Engineering discuss the practical application of SILC on the umbilical that feeds liquid hydrogen from the External Tank to the Orbiter's Main Propulsion System.

In January 2007, the NESC sponsored a Lunar Dust Workshop to gather leading experts from around the country and discuss the potential technical risks and mitigation strategies for humans, spacecraft, and equipment working in the lunar environment. KSC was well represented by several researchers performing innovative work in this field.

Science Mission Support

The NESC is actively working with KSC's Launch Service Program on a Flight Force Measurement project. This assessment will use flight measured strain data to resolve the actual flight forces at the spacecraft interface. The measurement system will be flown on the GLAST Mission. KSC personnel also contributed to the Conax Pyrotechnic Valve failure assessment.

NASA



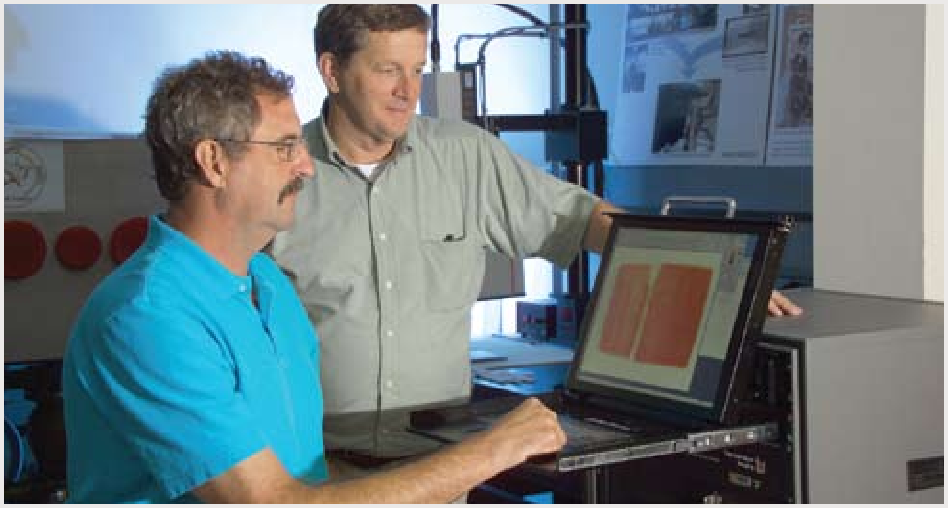
Graphic: NESC

VAB Burn Simulation

The NESC is assisting KSC and the Constellation Program by studying the possible effects of multiple Solid Rocket Motor segments burning in the VAB. The study is assessing the probability of an ignition event and the safe distance for personnel. The simulation shows the isosurface of a plume from burning segments in the VAB 52 seconds after ignition.

LANGLEY RESEARCH CENTER

Langley Research Center (LaRC) scientists and engineers continue to assist in the NESC mission in support of the Agency's high-risk programs and projects. LaRC has contributed technical expertise in areas of structures, materials, nondestructive evaluation (NDE), flight sciences, fabrication technology, loads and dynamics, computational fluid dynamics, mechanisms, guidance navigations and control, and avionics. LaRC continues to be the home Center for the NESC's' Directors Office, Systems Engineering Office and the Management and Technical Support Office. The NASA Office of the Chief Engineer also named Drs. Robert Piascik, William Prosser, Ivatury Raju and David Schuster as NASA Technical Fellows for Materials, Nondestructive Evaluation, Structures and Aerosciences respectively. They are resident at LaRC.



NESC

Dr. William Prosser, NASA Technical Fellow for Nondestructive Evaluation *(left)* and Dr. William Winfree review line scan thermographic data from an orbiter WLE RCC specimen. The new line scan data analysis methodology, developed by Dr. Winfree for the NESC, has proven invaluable at identifying imperfections under the SiC coating that provides oxidation protection for the RCC during re-entry.

Space Operations Support

The NESC is working with the Orbiter Project to discover the root cause of the anomalies in the orbiters' Reinforced Carbon Carbon (RCC) wing leading edge and to develop improved nondestructive evaluation (NDE) methods for inspecting the RCC. Thermography NDE systems from LaRC's Nondestructive Evaluation Sciences Branch (NESB) were used in an effort to identify regions where degradation of the interface between the silicon carbide (SiC) coating and the RCC substrate may have occurred. Microfocus Computed Tomography (CT) X-ray systems were then used to confirm the presence of defects such as delaminations at the silicon carbide coating interfaces in these RCC materials. Additionally, the computational facilities of NESB were used to analyze thermography NDE data previously acquired at KSC for all Space Shuttle RCC panels to determine if similar defects are present on RCC flight panels. Members of the NESC's Materials, Structures and NDE Technical Discipline Teams (TDTs) as well as the Technical Fellows who lead these TDTs have been involved with this effort.

Dr. Michael Gilbert
NESC's Chief Engineer at LaRC

Exploration Systems Support

LaRC personnel have also been members of NESC technical teams who are developing advanced technologies for consideration and possible use by the Constellation Program. The Alternate Launch Abort Systems (ALAS) study sponsored by the NESC evaluated the structural, thermal, acoustic, aerodynamic, aerothermodynamic, stability and control, and mission performance effects for an integrated launch abort motor and load carrying shroud for the Orion Crew Module. Aeroheating tests were performed using the LaRC Hypersonic Materials Environmental Test System arcjet to study material exposure effects from the launch abort motor plume. LaRC's fabrication experts developed the wind tunnel models used in the ALAS study. These efforts led to the adoption of ALAS as part of the Orion design. LaRC's Geometry Laboratory (GEOLAB) provided advanced capabilities to support research applications that require surface and grids for numerical simulations in Computational Fluid Dynamics and Computational Structural Mechanics. The NESC has used GEOLAB extensively for geometry modeling and grid generation for the ALAS and another alternate launch abort system referred to as the Max Launch Abort System (MLAS).

NESC Awards

This year four LaRC researchers received NESC Engineering Excellence Awards. Dr. Edwin Fasanella was recognized for his contributions to the NESC CEV Water versus Land Landing Study. Mr. Ray Rhew was recognized for his efforts on the NESC Solid Rocket Booster Roll Torque Study. Dr. Stephen Scotti was recognized for his contribution to the NESC ALAS Study and also accepted an NESC Group Achievement Award on behalf of the ALAS Team. Mr. Jeffrey Seebo was recognized his contributions to the NESC NDE of the Space Shuttle External Tank Thermal Protection System.

NESC

(From left) Dr. David Schuster, NASA Technical Fellow for Aerosciences, Dr. Charles Camarda, NESC Deputy Director for Advanced Projects, and Dr. Stephen Scotti, ALAS Study Lead, examine the shape of the ALAS wind tunnel model. LaRC personnel made up the majority of the NESC's ALAS Team.

MARSHALL SPACE FLIGHT CENTER

Marshall Space Flight Center (MSFC) employees have been supporting major NESC efforts across a broad range of activities. In addition, the NASA Office of the Chief Engineer also named Mr. George Hopson, resident at MSFC, as the NASA Technical Fellow for Propulsion.

MSFC

Thomas DeLay, is supporting the NESC as a member of the Composite Pressure Vessel Working Group. In this image, he is fabricating a series of lined and unlined composite test vessels used to understand the performance of fibers and matrix resins.

Space Operations Support

MSFC personnel continued in 2007 to participate in NESC assessments of flight and operations hardware for the Space Shuttle Program. Two of the largest efforts were in the Nondestructive Evaluation discipline. When a hail storm struck the vehicle on the launch pad prior to STS-117 there was extensive surface damage to the External Tank (ET). The NESC requested that thermography be used to inspect the nose cone. This was a process similar to that which was used to certify the hardware. Removing the nose cone was not feasible so a new technique was developed and tested at MSFC, showing that damage that might lead to a material failure could be detected. The ET was inspected in place at KSC and determined to be flight ready.

Dr. Charles Schafer

NESC's Chief Engineer at MSFC

Another NDE assessment sponsored by the NESC was the development of a Phased Array Ultrasonic Technique for inspecting the shoes of the Crawler Transporter used to move the mated vehicle to the launch pad at KSC. Working with LaRC and KSC, MSFC personnel developed this technique and the system to perform the inspections. This enabled detection of cracks or voids in the shoes, reducing the likelihood of failure while in transit to the launch pad.

As members of the NESC Technical Discipline Teams, MSFC engineers engage in other activities concerning the Space Shuttle and the International Space Station (ISS). Some additional contributions were in maturing NDE techniques for the ET Thermal Protection System and in the use of these methods to help quantify risk on the Ice Frost Ramp redesign, in fracture analysis of the pressure shell welds on ISS pressure vessels, and for the Orbiter rudder/speed brake bolt test.

Exploration Systems Support

The NESC efforts that began on the Space Shuttle Program have application to Ares and Orion. This includes development and certification of new NDE techniques. MSFC engineers are engaged in the NESC Composite Crew Module activity, in which a multi-center team is developing an Agency-wide design expertise for composite habitable spacecraft. This effort is intended to strengthen the Agency's experience in designing, analyzing, building, and testing composite structures and pressure vessels. Fabrication of all building block test elements has begun at MSFC in the National Center for Manufacturing facility.

MSFC engineers are contributing to the NESC working group for Composite Pressure Vessels in the area of materials, manufacturing, inspection, and damage tolerance. Information gained is being directly inserted into projects such as the First Stage and Upper Stage for Ares and the Launch Abort System on Orion. A major upcoming effort for this group is an assessment of the state-of-the-art in composite cryogenic tanks. MSFC engineers also worked, at the request of the NESC, on several other projects in support of the Science Mission Directorate. One of the tasks was in assessing damage done during acoustic testing to Aquarius hardware.

MSFC

(From left) Larry Pelham (MSFC), Dr. Dan Polis (GSFC), and Ron Schmidt (Lockheed Martin), fabricate Pi joints at MSFC that will be machined into pull-off and shear test coupons in support of the NESC Composite Crew Module Project.

STENNIS SPACE CENTER

"From my personal experiences in the NESC, I was always impressed with the depth and breadth of technical expertise the organization could bring to bear on some of NASA's toughest technical problems. Here at Stennis, I continue to see the contributions NESC makes across all of NASA's activities.

— Dr. Richard Gilbrech - *Associate Administrator for Exploration Systems and former Director of the SSC*

This year the Stennis Space Center (SSC) has continued to support NESC assessments with propulsion expertise in several areas in support of the Exploration Systems Mission Directorate (ESMD) efforts.

Since 1989, plume diagnostic engineers from the (SSC) technology laboratory have collected and analyzed more than three million data seconds of plume data from a variety of rocket engines. SSC is using this experience to support the NESC in the data collection and analysis efforts necessary to validate models of Solid Rocket Motor (SRM) Quantity-Distance Siting for the Vehicle Assembly Building (VAB) at Kennedy Space Center. The goal of the study is to determine the maximum number of SRM segments that can be safely stored in the VAB since the Ares boosters will use even more segments than the Space Shuttle.

Freddie Douglas
NESC's Chief Engineer at SSC

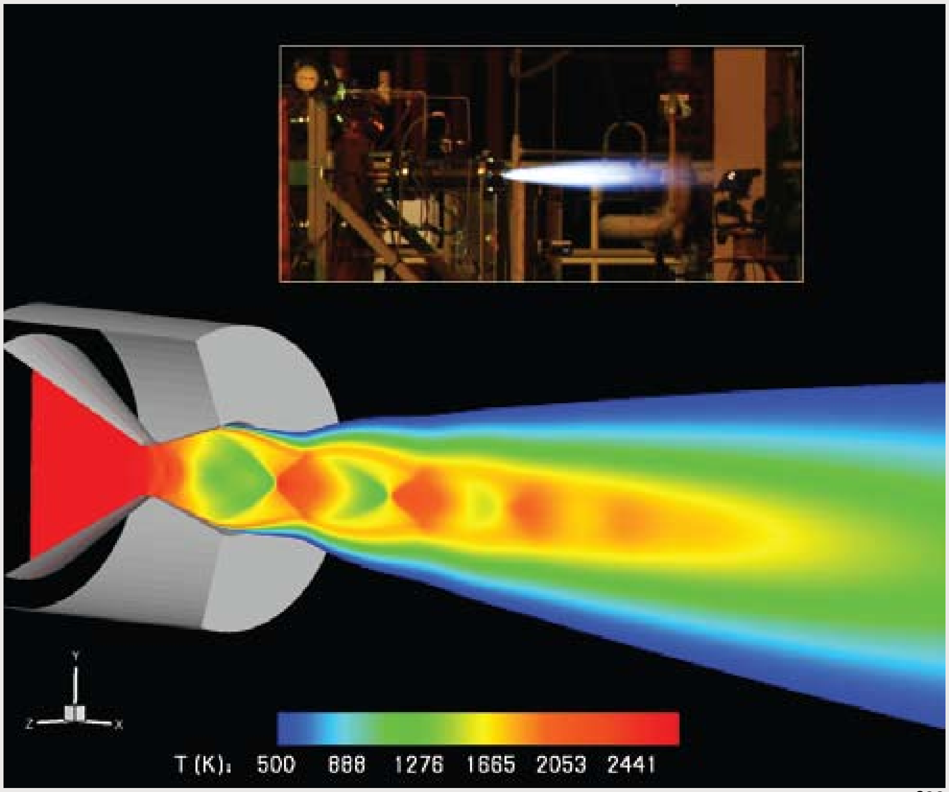
Traditional siting methodology assumes instantaneous combustion of all available propellant. However, analysis of the data acquired by SSC in August 2006 during an open-air disposal of a Titan IV segment proves the energy release, even for a single segment with a compromised motor case, is distributed over time.

The current effort is to establish validated physical models that accurately represent the conditions resulting from a fire involving Solid Rocket Motors in the VAB. SSC collected heat flux data from the plume of FSM-14 (Flight Support Motor) at ATK on May 24, 2007.

Through NESC funding, SSC also supports the Agency-wide development and implementation of NASA Technical Standard, "NASA-STD-7009 Standard for Models and Simulations." The goal of this standard is "to ensure that the credibility of the results from models and simulations (M&S) is properly conveyed to those making critical decisions." This is an important effort because SSC is also providing Computational Fluid Dynamics modeling of several engine test facilities in support of the Ares I and Ares V launch vehicles.

A uniformly applied standard is necessary to ensure the information gained through M&S are properly understood. SSC tested the usability of the M&S standard through a pilot study of the Computational Fluid Dynamics simulations as part of the Methane Technology Testbed Program. Using the credibility scale in the standard, the results of the M&S were evaluated to determine the extent to which project requirements were met.

In the near term, SSC will conduct subscale testing to support the design of the new A3 test stand. The test stand will be used to conduct altitude simulation tests for the Upper Stage J2X engine. The NESC involvement will include development of Computational Fluid Dynamics models for the subscale diffuser, as well as acoustical models to assess test stand and support facilities impacts. SSC's support of ESMD, in the areas of propulsion testing and M&S, will continue well into the future.



SSC

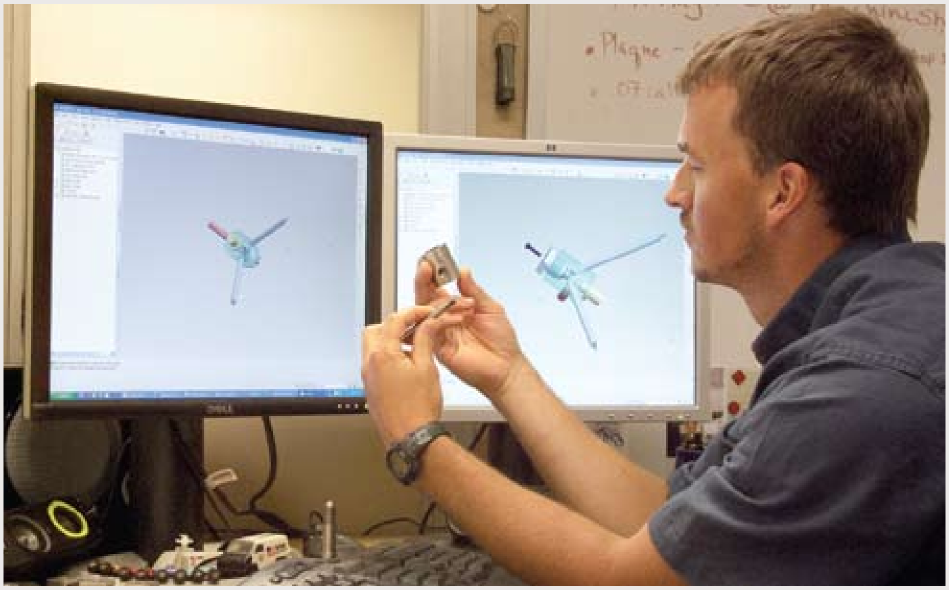
SSC modeled the operation of methane powered engine to support development of NASA Standard 7009 Standard for Models and Simulations

ATK

The plume diagnostic engineers at SSC measured the heat flux from the plume of a Space Shuttle solid rocket motor during a test firing.

WHITE SANDS TEST FACILITY

The NESC has continued to utilize the White Sands Test Facility (WSTF) in assisting important NASA projects and issues. These primarily assisted the Space Operations, Science, and Exploration Mission Directorates and addressed issues involving pyrovalves, many different aspects of Composite Overwrapped Pressure Vessels (COPVs), Orbiter ice mitigation, chemical oxygen generation, and special Nondestructive Evaluation (NDE) techniques development.



WSTF

Engineer Tom Hanson compares a fabricated test fixture with his original CAD design for pyrotechnic valve testing conducted at WSTF.

Space Science Support

WSTF personnel collaborated with personnel from other NASA Centers, the Jet Propulsion Laboratory, and Lockheed-Martin to help the NESC investigate five ground test failures of pyrotechnically-operated valves. Although none of the failures occurred in actual flight, the investigation was driven by serious concerns for several NASA spacecraft.

The investigation set a challenging goal of understanding the dynamic interactions between the initiators, the booster charge, and the Y-PCA. This required measuring high pressures and temperatures inside a very small enclosure in microsecond time frames. These requirements led to the development of several innovative measurement techniques and specialized test fixtures.

The fixtures often incorporated sapphire lens to allow temperatures to be measured by high speed optical sensors (pyrometers) as high dynamic pressures were measured. High speed video cameras (capable of up to 200,000 frames per sec) also captured video through the lens and were also used to measure flame front and particle velocities in open air.

WSTF

WSTF Engineer Tim Gallus aligns the laser used to ignite pyrotechnic valve booster charges.

To evaluate booster ignition temperatures, lasers were often used to rapidly heat Pyrovalve booster charges while the optical pyrometers measured the ignition temperature. Other specialized laboratory equipment such as X-ray Computed Tomography was used post-test to accomplish analyses. This technique allowed erosion and melting patterns inside actual Y-PCAs to be characterized without sectioning.

Dave Hamilton
NESC's Chief Engineer at JSC for WSTF

Space Operations and Exploration

WSTF personnel continued to assist the NESC by supporting Carbon and Kevlar COPV efforts for major NASA programs. WSTF also provided consultation on Constellation Program COPV designs and is performing data collection and establishing a data library for the newly formed NESC Composite Pressure Vessel Working group.

WSTF is supporting an investigation into potential failure modes of chemical oxygen generators, specifically the CAN-26 model which was chosen for the flight qualified BOXYCAN oxygen backup system for ISS. Though not flown, this system is representative of all operational SCOG hardware. A recent explosion aboard a submarine of the British Royal Navy was traced to a CAN-26 (possibly defective, possible contaminated). WSTF is currently working to understand and reproduce the catastrophic failure.

The WSTF test team continued to support the NESC investigation of potential solutions to reduce the risk posed by ice formation in the Space Shuttle LOX feedline bracket areas. A test fixture, known as the LOX Feedline Articulation Restraint Simulator, was designed and built at WSTF to simulate the geometry and temperatures of the bracket arm area during fill, de-tanking and launch scenarios. The fixture was used to test several versions of the polyimide flexible foam, a solution to mitigating ice formation in the gap between the feedline bracket arm and the feedline itself.

WSTF

WSTF Engineers John Haas and Larry Starritt examine a CAN-26 chemical oxygen generator.

NESC

(From left) Jeffrey Stewart (GSFC); Jeffrey Seebo (LaRC); John Baker (JPL); Ray Rhew (LaRC); Ralph Roe (NESC Director/Presenter); Derrick Cheston (GRC); Delmar Foster (United Space Alliance); Michael Hagopian (GSFC); Christopher Hansen (JSC); David Watson (ATK Space); Ian Fernandez (ARC); Dr. Daniel Polis (GSFC); James Jeans (Genesis Engineering); Paul Guy (GSFC); Dr. Eugene Ungar (JSC); Robert Cherney (GSFC); Dr. Edwin Fasanella (LaRC); Dr. Stephen Scotti (LaRC); Tim Wilson (NESC Deputy Director/Presenter); Kenneth Cameron (NESC Chief Astronaut/Presenter). *Not pictured:* Joel Broome (JSC); Christopher Cerimele (JSC).

The NESC Honors Engineering Excellence in Williamsburg

NESC Honor Awards are part of an incentive and recognition program. They are given each year to NASA Center employees, industry representatives, and other stakeholders for their efforts and achievements in the areas of engineering, leadership, teamwork, and communication.

These honorary awards formally identify individuals and groups who have made outstanding contributions to the NESC's mission and who demonstrate the following characteristics:

- Engineering and technical excellence
- Fostering an open environment

The Four NESC Honor Award Categories

NESC Director's Award

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

NESC Engineering Excellence Award

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

NESC Leadership Award

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

NESC Group Achievement Award

Honors a team of employees comprised of government and non-government personnel. The award is in recognition of outstanding accomplishment through the coordination of individual efforts that have contributed substantially to the success of the NESC's mission.

Honoree's List

NESC Director's Award

Dr. Daniel L. Polis

In recognition of technical excellence to the Composite Crew Module Team through practical methodology and approach for managing structural reliability through material properties, building block testing, and factors of safety for composite spacecraft structures.

NESC Leadership Award

Christopher P. Hansen

In recognition of outstanding leadership providing engineering excellence, solving complex engineering problems, and building team consensus for the Composite Crew Module Project.

Awards continued on next page

Jeffrey W. Stewart

In recognition of outstanding leadership in establishing the organization structure of the composite crew module team, and for designing and implementing the Composite Crew Module Concurrent Design Center at Goddard Space Flight Center.

David B. Watson

In recognition of outstanding leadership coordinating the work of 16 designers and analysts from across the country resulting in a mature Preliminary Design Review for the Composite Crew Module Project.

NESC Engineering Excellence Award

Joel M. Broome

In recognition of exceptional technical support for Crew Exploration Vehicle (CEV) entry, descent, and pad abort trajectory analyses in support of the CEV Water vs. Land Landing Risk Assessment.

Christopher J. Cerimele

In recognition of exceptional technical support for the development of an entry and descent trajectory analysis methodology that enabled identification of potential risks to the Crew Exploration Vehicle (CEV) flight crew.

Dr. Edwin L. Fasanella

In recognition of exceptional technical support for investigations into the Crew Exploration Vehicle (CEV) Crew Module and Apollo Command Module crew injury analysis and survivability during water and land landings.

Ian M. Fernandez

In recognition of engineering excellence in the development of an innovative load sharing floor design on the Composite Crew Module Project.

Delmar C. Foster

In recognition of technical expertise and outstanding proactive support in establishing the processes and techniques for SAS software utilization within the Data Mining and Trending Working Group.

Paul D. Guy

In recognition of outstanding technical leadership of the independent review of the NASA Standard Initiator (NSI) for the Phoenix Project.

James W. Jeans

In recognition of engineering excellence in rapidly and accurately building an engineering analysis model of the Composite Crew Module Project.

Ray D. Rhew

In recognition of innovative incorporation of system calibration methodologies into the quantification of the internal roll torque contributions associated with segmented solid rocket motor firings.

Dr. Stephen J. Scotti

In recognition of engineering excellence in the innovative design of an Alternate Launch Abort System configuration.

Jeffrey P. Seebo

In recognition of outstanding technical support of NESC Nondestructive Evaluation for the External Tank Thermal Protection System Team.

NESC

Derrick Cheston, NESC Chief Engineer at GRC *(center)* receives an NESC Engineering Excellence Award from NESC Deputy Director for Safety and NESC Chief Astronaut, Kenneth Cameron *(left)*, and NESC Director Ralph Roe, Jr. *(right)*.

Dr. Eugene K. Ungar

In recognition of outstanding support to numerous NESC assessments pertaining to the Shuttle External Tank.

NESC Group Achievement Award

Crew Exploration Vehicle Water Versus Land Landing Assessment Team

In recognition of technical excellence in the investigation into the merits of water versus land landings for the Crew Exploration Vehicle (award accepted by John Baker on behalf of the team).

NESC

Michael Hagopian, NESC Chief Engineer at GSFC *(center)* receives an NESC Engineering Excellence Award from NESC Deputy Director for Safety and NESC Chief Astronaut, Kenneth Cameron *(left)*, and NESC Director Ralph Roe, Jr. *(right)*.

Crew Exploration Vehicle Alternate Launch Abort System (ALAS) Team

In recognition of outstanding efforts in developing and evaluating a design solution for an Alternate Launch Abort System (ALAS) for the Crew Exploration Vehicle (award accepted by Dr. Stephen Scotti on behalf of the team).

Shuttle Power Transfer System (SSPTS) Open PRACA Risk Evaluation Team

In recognition of outstanding contributions to the International Space Station to Shuttle Power Transfer System Open PRACA Risk Evaluation (award accepted by Robert Cherney on behalf of the team).

NESC Special Recognition

Derrick J. Cheston

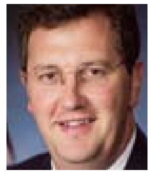
In recognition of outstanding leadership and engineering excellence as the NASA Engineering and Safety Center's Chief Engineer at Glenn Research Center.

Michael Hagopian

In recognition of outstanding leadership and engineering excellence as the NASA Engineering and Safety Center's Chief Engineer at Goddard Space Flight Center.

LEADERSHIP CORE TEAM

Ralph R. Roe, Jr.



NESC Director

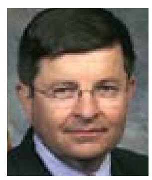
Mr. Ralph R. Roe, Jr. serves as the NESC's Director at Langley Research Center (LaRC). Mr. Roe has over 24 years of experience in human space flight program management, technical management, and test engineering. Mr. Roe previously held several key positions in the Space Shuttle Program, including Vehicle Engineering Manager, Launch Director, and Kennedy Space Center Engineering Director.

Timmy R. Wilson

NESC Deputy Director

Mr. Timmy R. Wilson is the NESC's Deputy Director. Mr. Wilson was formerly the NESC's Chief Engineer at Kennedy Space Center (KSC). Prior to joining the NESC, Mr. Wilson served as Deputy Chief Engineer for Space Shuttle Processing at KSC. Mr. Wilson has over 26 years of engineering and management experience supporting the Space Shuttle Program.

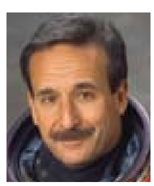
Kenneth D. Cameron



NESC Deputy Director for Safety
and NESC Chief Astronaut

Mr. Kenneth D. Cameron is an Astronaut and serves a dual role in the NESC as the Deputy Director for Safety and the Chief Astronaut and is resident at the Johnson Space Center (JSC). Mr. Cameron was formerly an NESC Principal Engineer serving at Langley Research Center (LaRC). Mr. Cameron joined the NESC after 7 years in private industry and a career in the U.S. Marine Corps. Mr. Cameron has over 27 years of experience in aeronautics and astronautics as a Naval Aviator, Test Pilot, and Astronaut, and is the veteran of three Space Shuttle missions: Pilot of STS-37 and Commander of STS-56 and STS-74.

Dr. Charles J. Camarda



NESC Deputy Director
for Advanced Projects

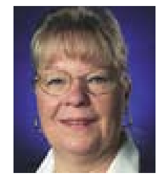
Dr. Charles J. Camarda is the Deputy Director for Advanced Projects and is resident at the Johnson Space Center. Dr. Camarda began his NASA career in 1974 as a thermal structures research scientist at the Langley Research Center. He has over 33 years of technical and management experience in thermal structures and materials research for aircraft, spacecraft, and space launch vehicles. He was selected as an astronaut candidate in 1996, and flew aboard STS-114 as a Mission Specialist.

Dr. Daniel Winterhalter

NESC Chief Scientist

Dr. Winterhalter is the NESC's Chief Scientist and is resident at the Jet Propulsion Laboratory (JPL). Dr. Winterhalter has over 29 years of experience as a research scientist at JPL. His research interests include the spatial evolution of the solar wind into the outer reaches of the heliosphere, as well as its interaction with and influence on planetary environments. In addition, as a member of several flight teams, he has been intimately involved with the planning, launching, and operating of complex spacecraft and space science missions.

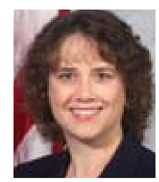
Patricia L. Dunnington



Manager, Management
and Technical Support Office

Ms. Patricia L. Dunnington is the Manager of the Management and Technical Support Office at Langley Research Center (LaRC). Prior to joining the NESC, Ms. Dunnington served as the Agency's Chief Information Officer (CIO) at NASA Headquarters. Ms. Dunnington began her NASA career in 1982 as a Presidential Management Intern. Ms. Dunnington has held several positions in the Agency, including the Agency Deputy CIO and the CIO for the NASA Langley Research Center.

Dawn M. Schaible

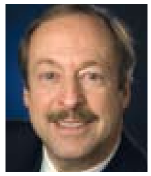


Manager, Systems Engineering Office

Ms. Dawn M. Schaible is Manager of the NESC Systems Engineering Office at Langley Research Center (LaRC). Prior to joining the NESC, Ms. Schaible worked in the International Space Station/Payload Processing Directorate at Kennedy Space Center. Ms. Schaible has over 20 years of experience in systems engineering, integration, and ground processing for the Space Shuttle and International Space Station Programs.

NASA HEADQUARTERS LIAISON

Wayne R. Frazier



NASA Headquarters Senior SMA Integration Manager

Mr. Wayne R. Frazier currently serves as Senior Safety and Mission Assurance Manager in the Office of Safety and Mission Assurance (OSMA), where he is assigned as the Liaison Officer to the NESC, the Office of the Chief Engineer, the Software Independent Verification and Validation Facility in West Virginia, and other remote activities of OSMA. He was formerly Manager of System Safety in the OSMA at NASA Headquarters and has over 32 years of experience in System Safety, Propulsion and Explosive Safety, Mishap Investigation, Range Safety, Pressure Systems, Crane Safety and Orbital Debris Mitigation.

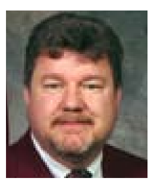
NESC PRINCIPAL ENGINEERS

Clinton H. Cragg

NESC Principal Engineer

Mr. Clinton H. Cragg is a Principal Engineer with the NESC at Langley Research Center (LaRC). Mr. Cragg came to the NESC after retiring from the U.S. Navy. Mr. Cragg served as the Commanding Officer of the U.S.S. Ohio and later as the Chief of Current operations, U.S. European Command. Mr. Cragg has over 29 years of experience in supervision, command, and ship-borne nuclear safety.

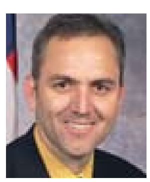
Steven J. Gentz



NESC Principal Engineer

Mr. Steven J. Gentz is a Principal Engineer with the NESC at Langley Research Center (LaRC). Mr. Gentz joined the NESC from the Marshall Space Flight Center with over 24 years of experience involving numerous NASA, Department of Defense, and industry failure analyses and incident investigations, including Challenger, Columbia, Tethered Satellite System, and the TWA 800 Accident Investigations.

Michael T. Kirsch



NESC Principal Engineer

Mr. Michael T. Kirsch is a Principal Engineer with the NESC at Langley Research Center (LaRC). Mr. Kirsch joined the NESC from the NASA's White Sands Test Facility (WSTF) where he served as the Deputy Manager responsible for planning and directing developmental and operational tests of spacecraft propulsion systems and related subsystems. Mr. Kirsch has over 18 years of experience in managing projects and test facilities.

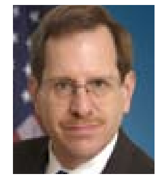
NESC CHIEF ENGINEERS

Derrick J. Cheston

NESC Chief Engineer

Mr. Derrick J. Cheston is the NESC Chief Engineer at Glenn Research Center (GRC). Mr. Cheston joined the NESC from his prior position at GRC as Chief of the Thermal/Fluids Systems Branch. Mr. Cheston has 23 years of experience in aerospace engineering and management, including mechanical design and testing and thermal/fluids analysis.

Dennis B. Dillman



NESC Chief Engineer

Mr. Dennis B. Dillman is the NESC Chief Engineer at NASA Headquarters. Mr. Dillman came to the NESC from the Goddard Space Flight Center (GSFC), where he chaired design reviews for major projects, including the Hubble Space Telescope Servicing Missions, the James Webb Space Telescope, and several Earth Observing System satellites. Prior to his time at GSFC, Mr. Dillman worked at the NASA Johnson Space Center managing Space Shuttle Orbiter sustaining engineering efforts and training Space Shuttle flight crews.

Freddie Douglas, III

NESC Chief Engineer

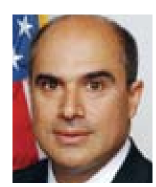
Freddie Douglas, III is the NESC's Chief Engineer at Stennis Space Center (SSC). Mr. Douglas joined the NESC from SSC where he served as the Deputy Manager of the Office of Safety and Mission Assurance. Mr. Douglas has over 24 years of management and technical experience. He has worked on several projects including the International Space Station, Hubble Space Telescope, post-Challenger Accident Return to Flight Effort and served as a neutral buoyancy diver.

Dr. Michael G. Gilbert

NESC Chief Engineer

Dr. Michael G. Gilbert is the NESC Chief Engineer at Langley Research Center (LaRC). Before joining the NESC, he was Head of the LaRC Systems Management Office. Dr. Gilbert has over 30 years of engineering, research, and management experience with aircraft, missile, spacecraft, Space Shuttle, and International Space Station Programs.

Michael Hagopian

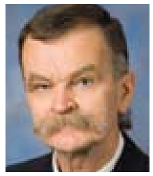


NESC Chief Engineer

Mr. Michael Hagopian is the NESC Chief Engineer at Goddard Space Flight Center (GSFC). Mr. Hagopian came to the NESC from his position as Associate Chief of the Mechanical Systems Division at GSFC. Mr. Hagopian has over 23 years of experience in the development of space and Earth science satellites.

NESC CHIEF ENGINEERS *Con't.*

David A. Hamilton



NESC Chief Engineer

Mr. David A. Hamilton is the NESC Chief Engineer at Johnson Space Center (JSC). Mr. Hamilton came to the NESC from JSC, where he served as Chief of the Shuttle/Station Engineering Office and also as the Chairman of the Shuttle Chief Engineers Council. Mr. Hamilton has over 40 years of combined experience in NASA manned space flight programs, including Apollo, Skylab, Apollo-Soyuz, ISS, Space Shuttle, and Mir.

R. Lloyd Keith

NESC Chief Engineer

Mr. R. Lloyd Keith is the NESC's Chief Engineer, as well as the Deputy Center Chief Engineer at the Jet Propulsion Laboratory (JPL). Mr. Keith has over 31 years of experience working in both technical and managerial positions. Mr. Keith has supported a number of flight projects including the Mars Pathfinder Project, SeaWinds, Stardust, Mars '98, New Millennium Deep Space 1, and the Flight Hardware Logistics Program.

Stephen A. Minute

NESC Chief Engineer

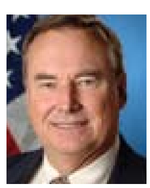
Mr. Stephen A. Minute is the NESC Chief Engineer at Kennedy Space Center (KSC). Mr. Minute came to the NESC from KSC, where he served as the Chief of the Space Shuttle Safety, Quality, and Mission Assurance Division. Mr. Minute has over 24 years of engineering and management experience in the Space Shuttle and International Space Station Programs.

Dr. Charles F. Schafer

NESC Chief Engineer

Dr. Charles F. Schafer is the 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 propellant development.

Dr. James F. Stewart



NESC Chief Engineer

Dr. James F. Stewart is the NESC 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.

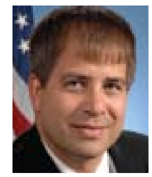
NASA TECHNICAL FELLOWS

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 31 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 25 years of experience in power and avionics.

Cornelius J. Dennehy

NASA Technical Fellow

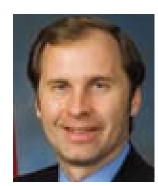
Mr. Cornelius (Neil) J. Dennehy is the NASA Technical Fellow for Guidance, Navigation and Control (GN&C) systems and is resident at Goddard Space Fight Center (GSFC). Mr. Dennehy came to the NESC from the Mission Engineering and Systems Analysis Division at GSFC, where he served as the Division's Assistant Chief for Technology. Mr. Dennehy has over 27 years of experience in the architecture, design, development, integration, and operation of GN&C systems, and space platforms for communications, defense, remote sensing, and scientific mission applications.

George D. Hopson

NASA Technical Fellow

Mr. George D. Hopson is the NASA Technical Fellow for Propulsion and is resident at Marshall Space Flight Center (MSFC). Mr. Hopson came to the NESC from the Space Shuttle Main Engine Project Office, where he served as Director. Mr. Hopson has over 45 years of combined experience in Space Shuttle main engine, space propulsion, space systems dynamics, and project management.

Dr. Curtis E. Larsen

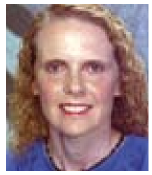


NASA Technical Fellow

Dr. Curtis E. Larsen is the NASA Technical Fellow for Loads and Dynamics and is resident at Johnson Space Center (JSC). Prior to joining the NESC, Dr. Larsen was the Technical Discipline Manager for Cargo Integration Structures in the Space Shuttle Program's Flight Operations and Integration Office. Dr. Larsen has over 27 years of engineering experience with expertise in stochastic structural dynamics, structural safety, and probabilistic engineering applications.

NESC TECHNICAL FELLOWS *Con't*

Dr. Cynthia H. Null



NASA Technical Fellow

Dr. Cynthia H. Null is the NASA Technical Fellow for Human Factors and is resident at Ames Research Center (ARC). Before joining the NESC, Dr. Null was a scientist in the Human Factors Division and Deputy Program Manager of the Space Human Factors Engineering Project. Dr. Null has 21 years of experience lecturing on Human Factors, and another 16 years of experience in Human Factors applied to NASA programs.

Dr. Robert S. Piascik

NASA Technical Fellow

Dr. Robert S. Piascik is the NASA Technical Fellow for Materials and is resident at Langley Research Center (LaRC). Dr. Piascik joined the NESC from the LaRC Mechanics of Materials Branch and the Metals and Thermal Structures Branch, where he served as a Senior Materials Scientist. Dr. Piascik has over 23 years of experience in the commercial nuclear power industry and over 15 years of experience in basic and applied materials research for several NASA programs.

Dr. William H. Prosser

NASA Technical Fellow

Dr. William 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 20 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 32 years of experience in structures, structural mechanics, and structural integrity.

Henry A. Rotter

NASA Technical Fellow

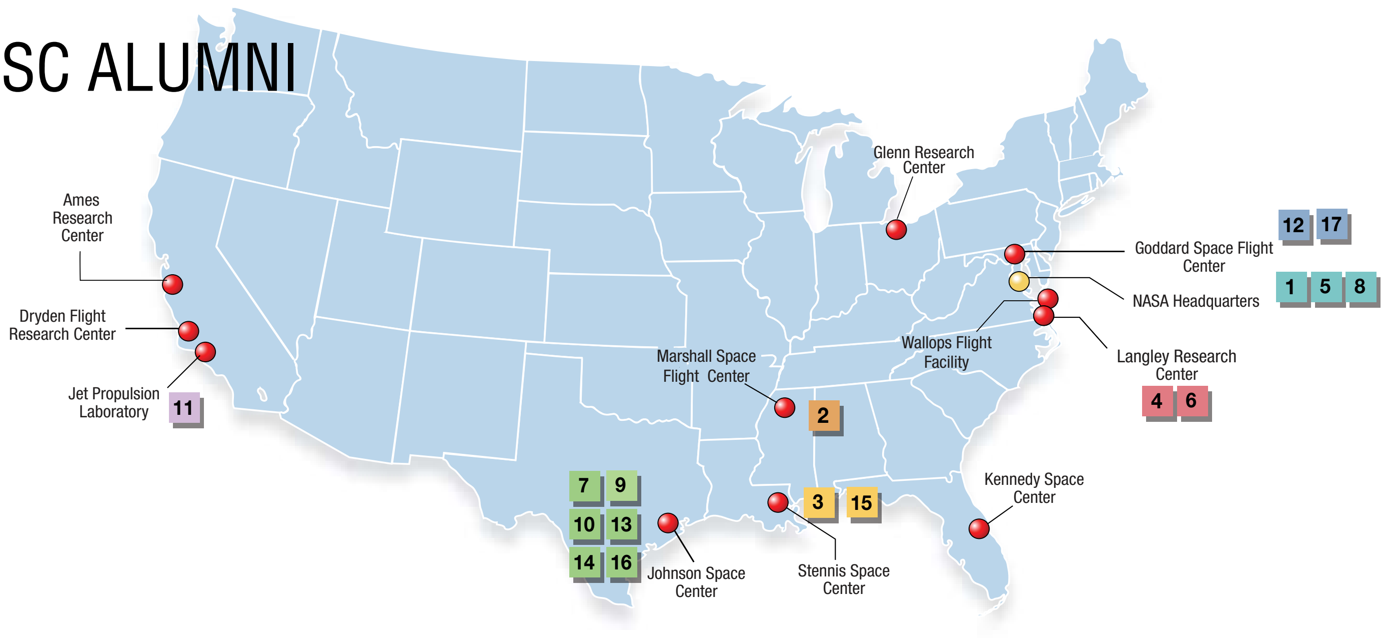
Mr. Henry (Hank) A. Rotter is the NASA Technical Fellow for Life Support/Active Thermal, and is resident at Johnson Space Center (JSC). Mr. Rotter joined the NESC from the JSC Crew and Thermal Systems Division and the Space Launch Initiative Program, where he was Engineering Manager and the Orbital Space Plane Team Leader for life support and active thermal control teams. Mr. Rotter has over 40 years of life support and active thermal control systems experience during the Apollo, Space Shuttle, and Orbital Space Plane Programs.

Dr. David M. Schuster

NASA Technical Fellow

Dr. David M. Schuster is the NASA Technical Fellow for Aerosciences and is resident at Langley Research Center (LaRC). Prior to joining the NESC, Dr. Schuster was the Branch Head for the Structural and Thermal Systems Branch in the Systems Engineering Directorate. Dr. Schuster has over 29 years experience in the aerospace industry with expertise in aeroelasticity and integrated aerodynamic analysis

NESC ALUMNI



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 MSFC (2005) Currently the Deputy Manager, Shuttle Propulsion Office at MSFC

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

T. Randy Galloway 3
NESC Chief Engineer at Stennis Space Center (SSC) (2003-04) Currently the Director of the Engineering and Science Directorate at SSC

Dr. Edward R. Generazio 4
NESC Discipline Expert for Nondestructive Evaluation (2003-05) Currently a Senior Research Engineer, Research & Technology Directorate, LaRC

Dr. Richard J. Gilbrech 5
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

Dr. Charles E. Harris 6
NESC Principal Engineer (2003-06) Currently the Director, Research & Technology Directorate at LaRC

Dr. Steven A. Hawley 7
NESC Chief Astronaut (2003-04) Currently the Director of Astromaterials Research and Exploration Science at Johnson Space Center (JSC)

Marc S. Hollander
Manager, Management and Technical Support Office (2005-06) Currently Associate Director for Management, National Institutes of Health

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 8
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

Julie A. Kramer White 9
NESC Discipline Expert for Mechanical Analysis (2003-06) Currently the Chief Engineer, Crew Exploration Vehicle Office at JSC

Steven G. Labbe 10
NESC Discipline Expert for Flight Sciences (2003-06) Currently the Chief Engineer, Constellation Program Office at JSC

Matthew R. Landano 11
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 12
NESC Chief Scientist (2003-06) Currently the Senior Project Scientist for the Hubble Space Telescope at GSFC

John P. McManamen 13
NASA Technical Fellow for Mechanical Systems (2003-07) Currently the Chief Engineer, Shuttle Program Office at JSC

Brian K. Muirhead 14
NESC Chief Engineer at NASA's Jet Propulsion Laboratory (JPL) (2005-07) Currently the Program Systems Engineer in the Constellation Program's Program 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

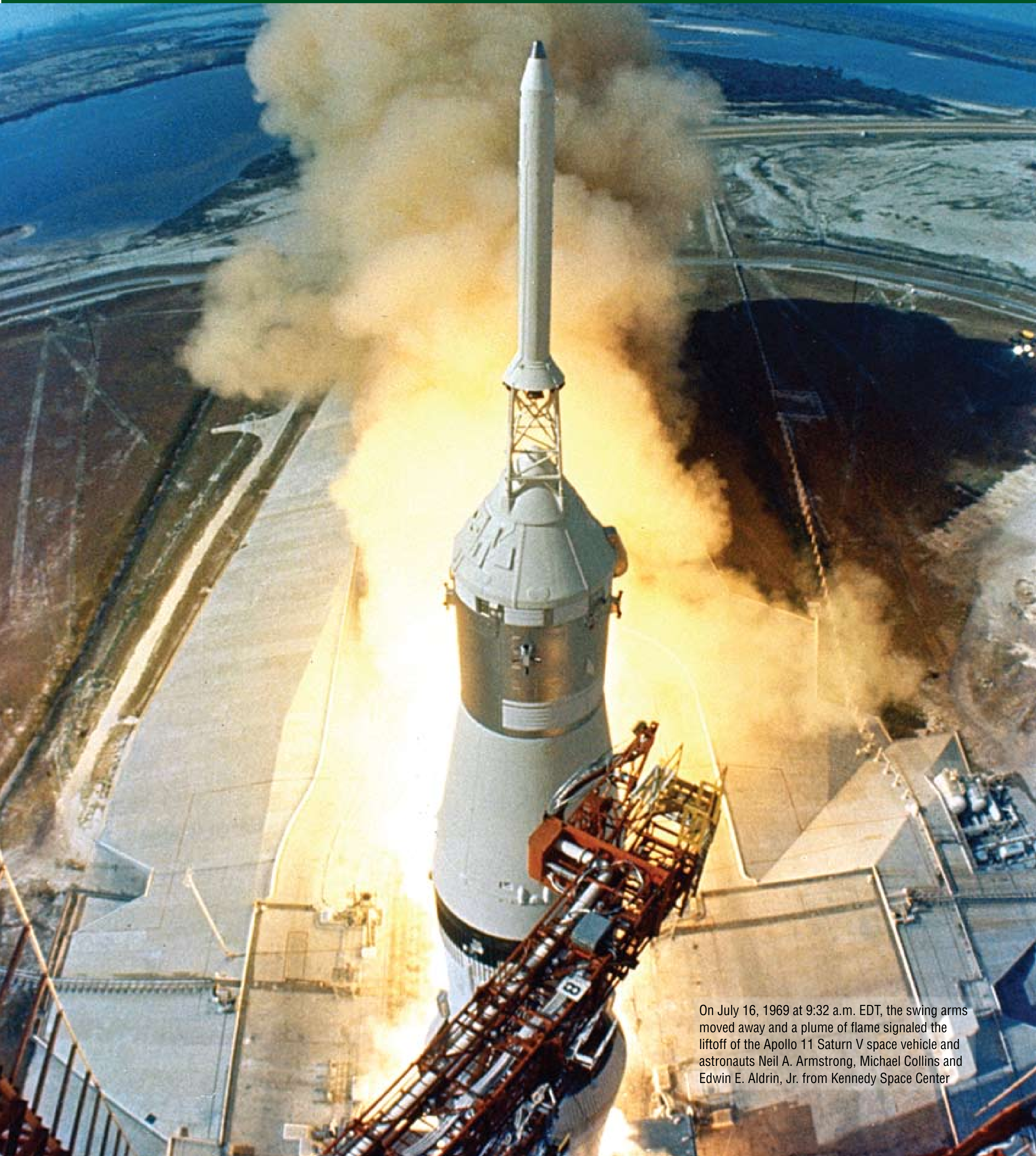
Stan C. Newberry
Manager of NESC's Management and Technical Support Office (2003-04) Left NESC to become the Deputy Center Director at Ames Research Center (ARC) and has since left NASA to accept a position at DoD

Dr. Shamim A. Rahman 15
NESC Chief Engineer at Stennis Space Center (2005-06) Currently the Propulsion Test Program Manager at SSC

Jerry L. Ross 16
NESC Chief Astronaut (2004-06)
Currently the Chief of the Vehicle Integration Test Office at JSC

Steven S. Scott 17
NESC Discipline Expert for Software (2003-05) Currently the Chief Engineer at GSFC

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



On July 16, 1969 at 9:32 a.m. EDT, the swing arms moved away and a plume of flame signaled the liftoff of the Apollo 11 Saturn V space vehicle and astronauts Neil A. Armstrong, Michael Collins and Edwin E. Aldrin, Jr. from Kennedy Space Center

Best Practices for Reliable and Robust Spacecraft Structures

I. S. Raju[1], P. L. N. Murthy[2], N. R. Patel[3], P. J. Bonacuse[4], K. B. Elliott[5], S. A. Gordon[6], J. P. Gyekenyesi[7], E. O. Daso[8], P. Aggarwal[8], and R. F. Tillman[9]
NASA Engineering and Safety Center
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Abstract

A study was undertaken to capture the best practices for the development of reliable and robust spacecraft structures for NASA's next generation cargo and crewed launch vehicles. In this study, the NASA heritage programs such as Mercury, Gemini, Apollo, and the Space Shuttle program were examined. A series of lessons learned during the NASA and DoD heritage programs are captured. The processes that "make the right structural system" are examined along with the processes to "make the structural system right". The impact of technology advancements in materials and analysis and testing methods on reliability and robustness of spacecraft structures is studied. The best practices and lessons learned are extracted from these studies. Since the first human space flight, the best practices for reliable and robust spacecraft structures appear to be well established, understood, and articulated by each generation of designers and engineers. However, these best practices apparently have not always been followed. When the best practices are ignored or short cuts are taken, risks accumulate, and reliability suffers. Thus program managers need to be vigilant of circumstances and situations that tend to violate best practices. Adherence to the best practices may help develop spacecraft systems with high reliability and robustness against certain anomalies and unforeseen events.

Introduction

NASA is currently in the process of developing the next generation crewed and cargo launch vehicles and spacecraft to return to the moon and beyond. With the experience and knowledge base available from past similar programs, a document that captures salient aspects of successful programs is being developed. This document serves as an important guide in evaluating next generation and future spacecraft concepts and proposals. As a part of this guide, guides for individual technical disciplines are being developed. Reliable and robust structural systems design is one of these technical disciplines. The structures document describes pertinent issues, best practices, errors, miss-steps, lessons learned, and summarizes the previously used design processes (tools and standards) for the structures discipline.

---

[1] Langley Research Center, Hampton, Virginia, Fellow AIAA
[2] Glenn Research Center, Cleveland, Ohio, Associate Fellow AIAA
[3] The Aerospace Corporation, El Segundo, California, Senior Member AIAA
[4] Army Research Laboratory at NASA Glenn Research Center, Cleveland, Ohio
[5] Langley Research Center, Hampton, Virginia
[6] Goddard Space Flight Center, Greenbelt, Maryland
[7] Glenn Research Center, Cleveland, Ohio, Member AIAA
[8] Marshall Space Fight Center, Huntsville, Alabama
[9] Jet Propulsion Laboratory, Pasadena, California

Structural systems provide the basic framework to distribute external and internal loads resulting from all flight loads, ground loads, and associated operational and environmental loads. The primary objective of a structural system is to remain intact and experience minimal deformation when exposed to various environments, including ground processing, testing, launch, on-orbit, and re-entry operations. Structural systems also provide containment for pressures as in pressure vessels, pressure components, and pressurized structures. Structures tend to be a dependent subsystem in the sense that many requirements flow to structures from other subsystems. Space systems are very complex products of multiple disciplines and therefore are multidisciplinary, and therefore require a multidisciplinary analysis and optimization approach to capture various system interactions and sensitivities in order to obtain optimum system solutions, develop flight constraints, and validate and verify the system architecture. As a result, as illustrated in Figure 1, the development of the structural system is a complex iterative design process.

This paper outlines the best practices that are essential to the design and production of reliable and robust spacecraft structural systems. First, the NASA heritage programs are examined. Lessons learned from these heritage programs are captured. Next the processes that need to be used to "make the right structural system" are examined. Third, the processes that need to be followed to "make the structural system right" are addressed. In addition, a brief review of methods for assessing reliability and risk for structural systems is provided. Finally, the lessons learned and the best practices are presented.

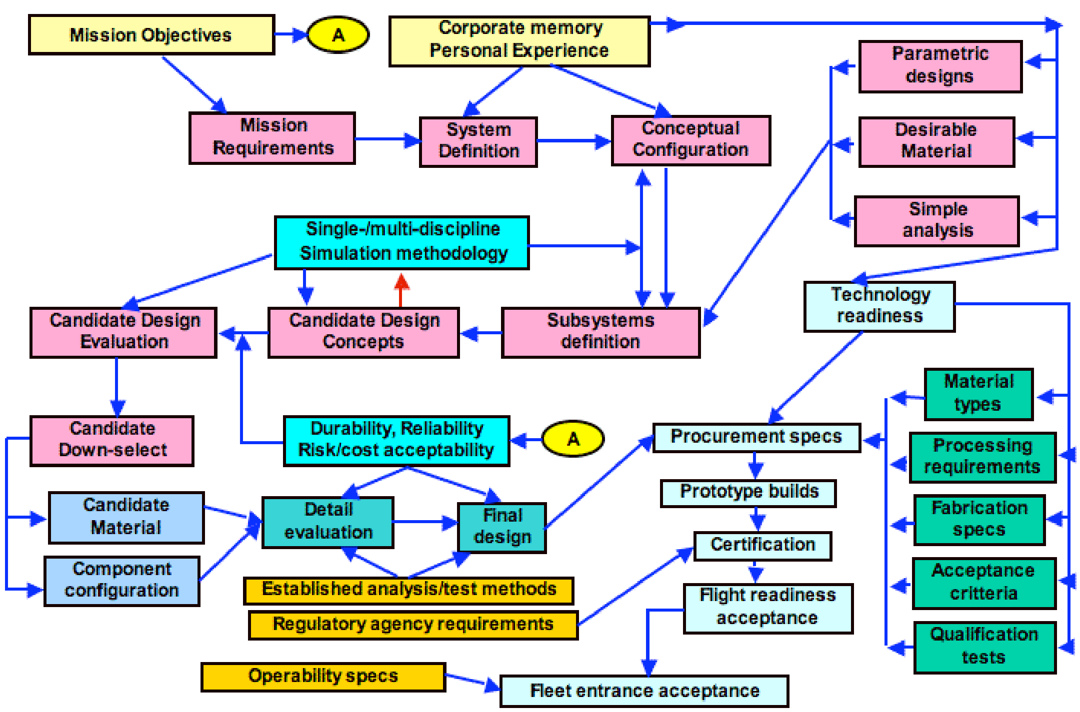

Figure 1. Complex interactions involved in structural system design.

Heritage Programs

Heritage programs such as Mercury, Gemini, Apollo, and the Space Shuttle program (see Figure 2) are first examined [1-8]. A study of these programs resulted in several lessons learned. They can be briefly summarized as follows:

- Design deficiencies result from the inability to predict load paths and load distributions accurately. All load paths in a complex structure may be difficult to discern. Thus careful analysis followed by a rigorous test program should be conducted to uncover any design deficiencies.
- Testing of components requires care. Whenever possible, test hardware should be structurally similar to flight hardware. Special attention needs to be given to interfaces and boundaries to ensure that proper boundary conditions are imposed on the system or component.
- Despite advances in analysis techniques, modeling and simulation verification and validation is a vital part of insuring the reliability of structural systems.
- A building block approach is required to design and build reliable complex structures. Key steps that need be followed are:
    - Fully characterize special materials used in the structures and structural components.
    - Develop and validate, to the extent possible, accurate environmental predictions and verify the techniques used in the predictions.
    - Develop accurate structural dynamic and stress models and validate their predictions. Avoid extrapolations of models and results.
    - Develop a fracture control/nondestructive evaluation program.
    - Develop extensive verification and validation procedures for:
        - Modeling and analysis
        - Coupon tests, subcomponent tests, component tests, full scale tests, and flight tests
        - Analysis and test correlation
    - Develop rigorous manufacturing and quality control procedures.

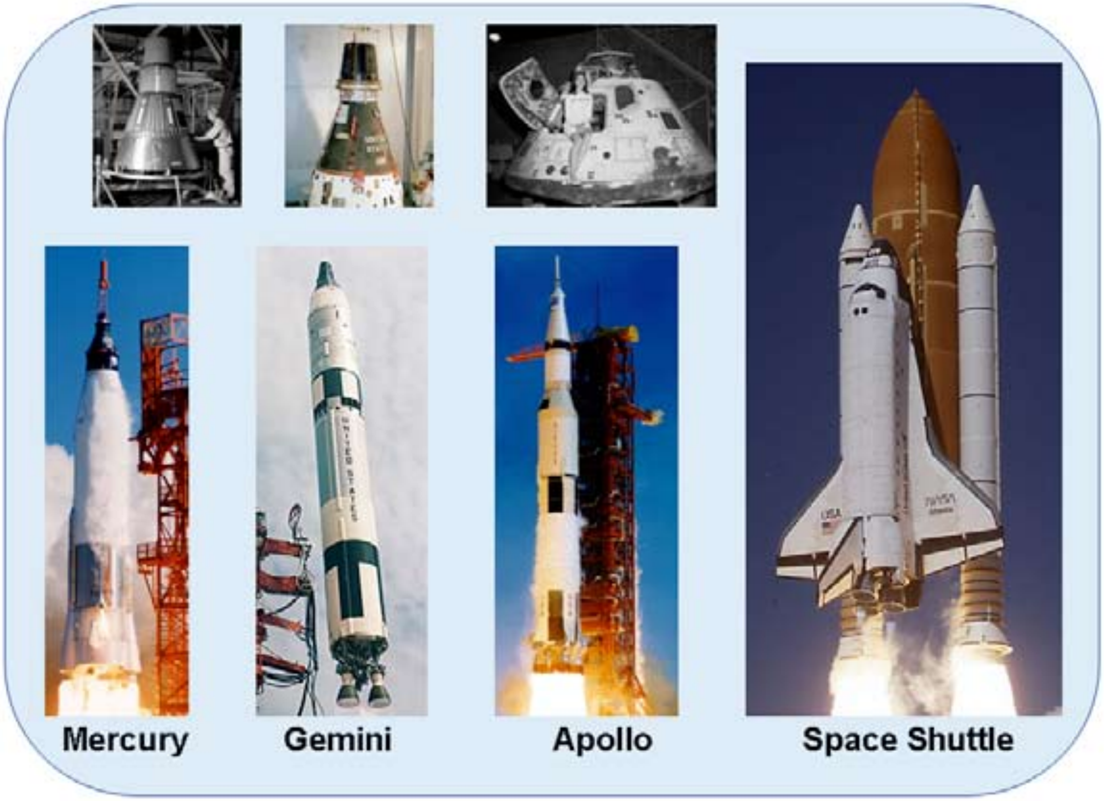

Figure 2. NASA Heritage Space Programs

Making the Right Structural System

Structural components (other than consumable or life limited items) are intended to have sufficient durability to perform adequately over the expected service life of the system. Structural systems deteriorate and/or develop damage due to a single cause or a combination of causes such as: (a) the design is inadequate for the applied loading and environment (conceptual design or calculation error), (b) the loading (amplitude, frequency, and/or interactions) is not well understood or underestimated, (c) the effects of environment are underestimated (requirements specification error), (d) a flaw in the materials or manufacturing is undetected (quality control and/or inspection error), and (e) unexpected damage occurrs through unforeseen means (e.g. handling damage). Thus to make the right structural system, several best practices, such as the establishment and understanding of the proper design and mission requirements, the implementation of trade studies, and the creation of sufficient verification and validation studies, need to be instituted.

Design Requirements:

The primary purpose of a structure is to protect spacecraft systems and to ensure that the system remains intact by maintaining the relative position of components under service-life loads and environments. Thus the fundamental requirement of any space structure is to maintain structural integrity throughout the life of the structure. The process of defining structural requirements for new spacecraft typically begins with a review of previous development efforts and applicable technical standards. Both of these sources should be mined for appropriate design constraints, testing requirements, methodologies, and procedures. Care should be taken in selecting the requirements that will appear in the final system specification. All requirements should add value, be clear in their intention, and should not overly constrain the design and development. The list of requirements should be determined through an active negotiation process between the project management and the appropriate technical community. As a minimum, all NASA programs should evaluate NASA and other government standards for applicability. In general, these standards capture best practices, and they represent the starting point for the design, analysis, and verification of structural systems within NASA and other Government Agencies. If a program intends to deviate from the approach outlined in the NASA standards, then it will most likely require that documentation of the technical rationale or waiver be provided to the organizations performing technical oversight of the program during the formal review process.

Mission Requirements:

Performance: Structural design, including the implementation of new technologies, is driven by the system performance requirement goals. These performance requirements are driven by the mission requirements. Demanding performance requirements combined with volume and weight constraints often lead to greater sensitivities to design uncertainties. Design uncertainties exist in material properties, environments, loads, analyses, testing, and manufacturing. It is preferred to have a linear sensitivity of performance to these parameters. On the other hand, a high performance design may require nonlinear dependence on these parameters. In that case, great care must be taken to characterize material properties, define environments, and validate analyses. Manufacturing, quality control and assurance, and acceptance criteria must be enhanced to account for additional uncertainty. On the other hand, robust or conservative designs can be used at a price of higher weight and possibly lower performance. The optimum design choice probably lies between the two extremes. Trade and sensitivity studies must be performed to determine the trade offs and select the optimum design.

Environments: The structural system is designed and tested to withstand all pertinent environmental conditions, naturally occurring and induced, to which the system will be subjected during its life-cycle. These life-cycle environments should be identified as early as possible in the structural design process, and appropriate loading conditions should be defined as requirements for design and testing. Typical environments include production, testing, integration, storage, transportation, launch, ascent, thermal, radiation, meteoroid impact, vacuum, dust or contamination, re-entry, and landing. Care should be taken to consider load uncertainties, combine environmental effects, and contingency load cases. The structural system should also be designed to withstand the cumulative effects of the environments without loss of mission performance.

Trade Studies:
The preliminary requirements for the design of a structural system typically involve the definition of mass allowables, volume constraints, and the specification of both static and dynamic design loads. These requirements stipulate the trade space for evaluating different structural concepts. In addition, manufacturability, inspectability, and cost (both initial and lifetime) may be additional constraints on the trade space. In most cases, the structural design trades are aimed at minimizing vehicle weight while showing positive margins under the specified design loads and providing sufficient stiffness to meet mission goals. One of the first trades in developing a preliminary structural design is to define the load paths and the type of structure that will sustain the design loads. Trade studies can also be performed to evaluate different material types (for example, composite vs. metal), the implementation of new technologies, and different construction methods.

Verification and Validation (V/V): Verification and validation are terms often used in relation to the qualification of reliable structures. The terms verification and validation are often misused or used interchangeably. NASA system engineers define verification as "proof of compliance with specification as determined through a combination of test, analysis, and demonstration" [9]. Validation is defined as "proof that a product accomplishes the intended purpose as determined through a combination of test, analysis, and demonstration" [9]. In other words; verification is demonstrating that the product meets the design requirements, and validation is demonstrating that the product meets the goals of the intended application. These definitions originate at the system level and primarily apply to hardware products. A second set of definitions are commonly used in reference to computational models. Model verification, as defined by AIAA, ASME, and DoD [10-12], is "the process of determining that a computational model accurately represents the underlying mathematical model and its solution." Model validation is "the process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model." In this case, verification is ensuring the computational model is correct in terms of the governing equations (stress, strain, motion); validation is ensuring the modeling effort captures the physics of the intended application. Producing reliable structures requires meeting both sets of definitions. For example, computational models need to endure sufficient V/V to define or reduce uncertainty and demonstrate sufficient accuracy to support program decisions. This is particularly important when computational models are to be used for product V/V. Best practice dictates that all structural systems should undergo a rigorous V/V process.

The following are examples of lessons learned taken from various past aerospace programs that relate to "making the right structural system":

- Document engineering requirements as clearly as possible. All requirements, including seemingly minor changes, should be clearly documented and tracked in order to avoid misinterpretation.
- In a totally new system, requirements may have to be continually reviewed for applicability. Requirements may change as a result of trade studies or design maturity.

- Each requirement should be traceable to a compliance matrix. All test data should be inspected for trends and "out of family" values, even when all values are within the expected range. Anomalous data should be thoroughly investigated.
- Impact of requirements changes for a subsystem should be properly evaluated on the system and interfacing subsystems.
- Review out-of-flow processes to ensure no steps are bypassed.
- Spacecraft must be designed to withstand worst-case life-cycle environments. All possible load combinations should be considered. Credible mission failure scenarios should be considered in evaluating the failure modes of the structure.

Making the Structural System Right

The key aspects for reliable and robust structures are design, analysis, manufacturing and process control, testing, and quality assurance. Each topic must be properly addressed to "make the structural system right".

Design:
Primary and secondary structures of space systems are designed to provide sufficient strength, rigidity, and other characteristics required to sustain the critical loading conditions without damage or degradation of performance throughout their service life. Several key design aspects necessary to ensure a reliable structure are structural integrity requirements, fatigue and fracture control, factors of safety, material properties, and tolerance requirements.

Analysis:
Structural analyses are performed to predict structural response to the critical loads and environments anticipated during the service life of the structure. Typical analyses include investigations of fatigue, safe-life, and fail-safe considerations. These analyses are important to establish the service life, tolerance of the structure to defects, design margins, and residual strength. To ensure a reliable structure, it is important to verify the analysis models and validate the analysis predictions over the range of use.

Manufacturing and Process Control:
The design of reliable and robust structures requires well-characterized fabrication processes and procedures. The fabrication process for each structural item is a controlled, documented process. Proven processes and procedures for fabrication and repair are needed to preclude damage or material degradation during material processing and manufacturing operations. An inspection plan is required to identify all key process parameters essential for design verification. In-process inspection or process monitoring are needed to verify setup and acceptability of critical parameters during the manufacturing process.

Testing:
Demonstrations are required to ensure that a structural system meet both mission and regulatory requirements. These demonstrations can be performed in four ways: 1) by heritage/similarity, 2) by analysis, 3) by qualification testing, and 4) by a combination of 1, 2, and 3. Qualification through heritage/similarity is not a reliable process without adequate analyses and tests to conclusively demonstrate similarity in materials, loads, environments, and responses. Qualification through analysis may be used when testing cannot demonstrate a target environment, such as zero-g or combined load effects, or the tests required are hazardous or unrealistic in terms of cost and schedule. By far the best approach to qualification is through testing. The mantra for a qualification-testing program should be "Test what you fly, and fly what you test."

Quality Assurance:
A quality assurance program based on a comprehensive study of the product and engineering requirements is established to ensure that necessary nondestructive inspection and acceptance proof tests are performed effectively. The program ensures that no damage or degradation occurred during material processing, fabrication, inspection, acceptance tests, shipping, storage, assembly, and operational use and refurbishment, and that defects that could cause failure are detected or evaluated and corrected. Acceptance proof tests are conducted on pressure vessels, pressurized structures, and composite structures for verification of workmanship.

Reliability Assessment Methods

Risk and reliability are complementary terms. Reliability is a quantified probabilistic assurance that a system or a product/device (or structure) will perform satisfactorily (i.e. will not fail, and will satisfy performance requirements) during its intended lifetime under specified operating conditions. Probability of failure refers to likelihood that the system will fail to satisfy the designated performance requirement. Risk, on the other hand, combines the probability of failure and the consequence of failure. Risk is generally defined as a product of the probability of failure and the cost (consequence) of failure.

A distinction also needs to be made between probability and statistics. Statistics is the mathematical quantification of uncertainty (mean, standard deviation, and other higher moments) mainly through the analysis of measured data. Probability theory uses statistical data to quantify the likelihood of occurrence of specific events.

Many structural systems (particularly space propulsion structures) are one-of-a-kind and hence have little or no learning curve. Generally, space propulsion systems are relatively large and expensive; and often they are not fully tested prior to their use nor are they tested repeatedly to create a statistical database. These propulsion systems may also have relatively long exposure periods and are designed for low risk. Often there is little or no redundancy is in these systems because of cost and weight considerations. These factors make the reliability analysis of these systems extremely challenging.

Margins and Factors of Safety:
Engineers have always recognized the existence and presence of uncertainty in the analysis and design of structural systems. These uncertainties can arise due to human factors (error in analysis and/or fabrication), limitations in technology, inherent randomness in the material properties, the environment in which the system operates, and the specific utilization of the structural system. Traditionally, uncertainty has been accounted for by using safety factors and/or knock-down factors. Structural reliability and robustness is improved by increasing the safety margins for critical structures (with a cost and weight penalty) and by practicing rigorous quality assurance (QA) and quality control (QC) techniques.

Depending upon the nature of their criticality, space system structures and structural components are designed using either a fail-safe or a safe-life design philosophy. Fail-safe systems, sometimes referred to as fool-proof systems, are designed such that their failure does not affect other components and systems. In the safe-life design philosophy, systems are designed to survive a specific design life with a chosen reserve.

Historically, the use of empirical safety factors has been the prevalent method of making designs more reliable. However, deterministic safety factors do not provide a quantitative measure of risk. In contrast, probabilistic analysis methods can provide this information.

Traditionally, safety factors are estimated based on rules-of-thumb and experience and are intended to be conservative. Selection of safety factors is insensitive to required reliability. It is possible to establish relationships between the traditional safety factors and the more rigorous probabilistic methods provided the underlining distributions and the statistical parameters for various design factors are known. Lately, there has been a push to relate safety factors to probabilistic or statistical methods. Safety factors that are based on standard probabilistic analyses provide a transparent approach to the end user recognizing the statistical nature of material properties and stress, the applicability of the failure theory, fidelity of the analysis techniques, and the required reliability. In applying this methodology, all design parameters of interest are typically assumed to have normal distributions [13]. This is an approximation, but in the absence of adequate data, the normal distribution assumption is advantageous in that it can be fully characterized by just two parameters: the mean and the variance. Since the applied stress and allowable strength are statistical in nature and assumed to be normal (with known parameters), the safety factor can be shown to be a function of probability of failure, mean and standard deviation of strength, and mean value and standard deviation of applied stress.

Probabilistic Approaches:
Usually, in risk-based design methodologies, a traditional load and resistance model is used. In its most fundamental form, design safety is ensured by requiring that the resistance is greater than the load. The safety factor is defined as the resistance divided by load. The determination of resistance and load distributions depend on the specific application. In aerospace applications, another measure of safety, margin of safety

(MOS), is often used. Positive values of MOS indicate safe designs, and negative values indicate unsafe designs.

In a probabilistic analysis, the design safety is ensured by requiring that the overlap between the load and resistance (strength) probability distribution curves be minimized within the constraints of economy. Figure 3 illustrates and compares the traditional and probabilistic design methodologies. The probability of failure is defined as the total area of the overlap [14]. The shapes of the curves are represented by probability density functions. In certain situations, the resistance distribution curve needs to account for more than the traditional strengths. For example, when the structural components are subjected to variable amplitude, high frequency loading where fatigue is the primary failure mechanism, the resistance needs to properly account for history dependent fatigue damage accumulation.

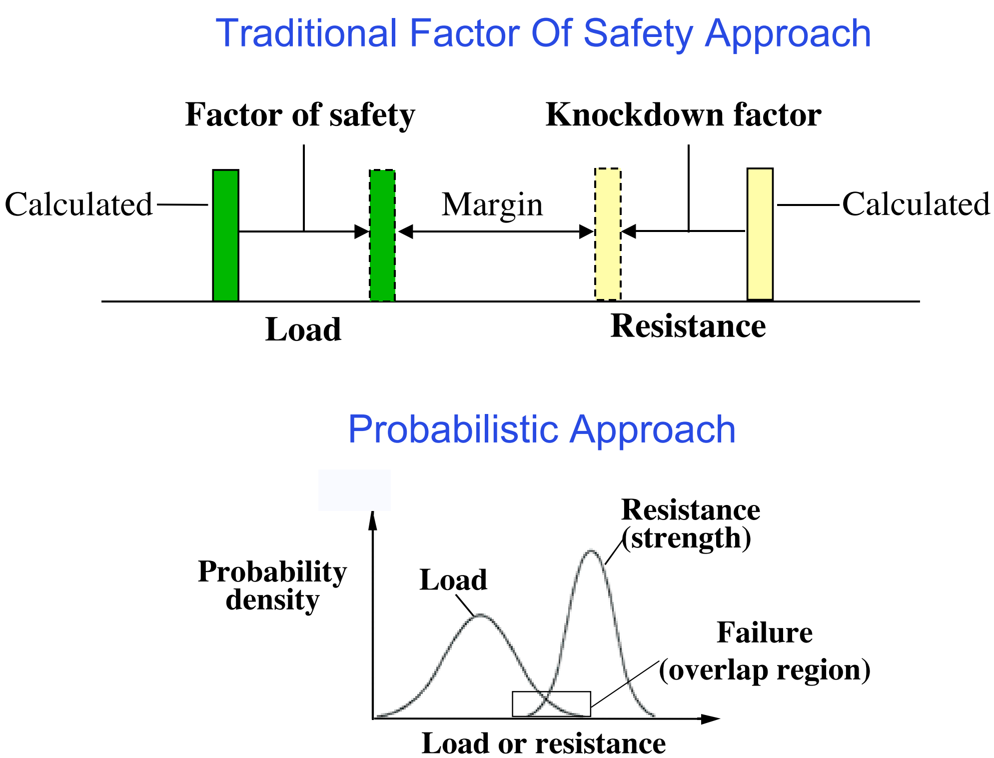

Figure 3. A comparison of traditional vs. probabilistic design methodologies

Generally, the methods to quantify the element level reliability (component reliability) can be broadly grouped into four categories as, (1) first-order reliability methods (FORM) and second-order reliability methods (SORM), (2) Monte Carlo simulation and its derivatives like efficient sampling methods etc., (3) response surface approaches, and (4) sensitivity-based probabilistic finite element analysis. References 14-17 provide details on these methods.

The state-of-the-art in the area of structural reliability assessment has improved significantly in the past two decades both in component and system level reliability estimation. Many commercial finite element codes have adopted probabilistic analyses methods [18,19]. These methods have been applied successfully in the areas of material uncertainty characterization, probabilistic fracture mechanics, probabilistic fatigue analysis, and probabilistic analysis of structural systems. However, these methods are computationally intensive. The challenge that remains is to synthesize, adapt, and simplify research efforts into practical and efficient methods that can be used for a variety of engineering applications.

Best Practices Based on Lessons Learned

The following are examples of the best practices developed based on the lessons learned taken from various past aerospace programs. Adherence to these practices will help ensure the development of reliable and robust structural systems.

Qualification

- Thoroughly evaluate heritage systems and data (test and analysis) as well as the applicability of using “existing” or “flight proven” equipment.
- Unexpected hardware behavior in test and/or flight is often a sign of impending failure and must be thoroughly investigated. Perform thorough post-flight analyses.
- Replacement materials should be sufficiently tested under conditions that realistically simulate flight conditions, and the results should be correlated with those exhibited by the original material systems.
- Study past anomalies that involved similar designs or technologies and implement appropriate corrective actions.
- Safeguard flight hardware against inadvertent damage due to handling and over-testing.
- Do not succumb to launch schedule pressure and compromise engineering recommendations.

Analysis and Testing

- All design changes must be thoroughly analyzed and tested.
- Analysis should properly account for all flight environments.
- Inaccuracies in material properties, structural loads, and environments continue to threaten mission success. Validation of material properties, structural loads, and environments through rigorous test campaigns is the best method of insuring reliable structures.
- Test failures must be thoroughly investigated and the root causes of the test anomalies ascertained and understood.
- Verify field installation of all single point failure items.

Design, Manufacturing, and Assembly

- Thoroughly verify the interfaces of all subcontracted items.
- Honeycomb structures should be vented wherever possible. If un-vented design cannot be avoided, sufficient testing including development, qualification, and proof tests should be conducted under applicable temperature and vacuum conditions.
- Changes and some non-conformances typically do not go through material review board processes. *All* changes and discrepancies should be properly evaluated.
- 11^{th}-hour modifications at the launch site require thorough evaluations.
- Protect the flight hardware from handling and transportation damage. Provide ample checks for damage detection.
- Design hardware to minimize the areas that cannot be inspected, and avoid the use of potential contaminants whenever possible. Account for all loose materials used during assembly.

Concluding Remarks

Spacecraft structural systems are complex and have multiple interacting components. As such these structural systems can only be developed through complex iterative design process. Various best practices that lead to the development of reliable and robust spacecraft structures are reviewed.

NASA heritage programs such as Gemini, Mercury, Apollo, and the Space Shuttle are examined. Lessons learned from these programs are captured. To be able to build an appropriate structural system for a mission, design and mission requirements and the environment must be adequately defined. Then, trade studies and verification and validation need be performed. To build the structural system that performs as intended needs design, analysis, manufacturing and process control, testing, and quality assurance.

Since the first human space flight, the best practices for reliable and robust spacecraft structures appear to be well established, understood, and articulated by each generation of designers and engineers. However, the implementation of these best practices appears to be a problem. When the best practices are ignored or short cuts are taken, reliability suffers and risks accumulate. Program managers deviate from best practices due to the programmatic and resource (cost and schedule) issues brought on by anomalies and unpredicted problems, and unforeseen events. Thus for a reliable structural system, program managers need to be vigilant when anomalies and unforeseen problems arise that tend to violate best practices.

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