National Aeronautics and Space Administration

NASA ENGINEERING & SAFETY CENTER

NESC

10

TEN YEARS AND COUNTING

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NASA ENGINEERING & SAFETY CENTER

ENGINEERING EXCELLENCE

Remembering Columbia

"After the tragedy of Columbia, we not only returned to flight, we established policies and procedures to make our human spaceflight program safer than ever. Exploration will never be without risk, but we continue to work to ensure that when humans travel to space, nothing has been left undone to make them as safe as possible."

An excerpt from a message from NASA Administrator Charles F. Bolden, Jr., Feb.1, 2013

Rick Husband
Commander

William McCool
Pilot

Laurel Clark
Mission Specialist

Kalpana Chawla
Mission Specialist

Ilan Ramon
Payload Specialist

Michael Anderson
Payload Commander

David Brown
Mission Specialist

"From our orbital vantage point, we observe an Earth without borders, full of peace, beauty, and magnificence, and we pray that humanity as a whole can imagine a borderless world as we see it and strive to live as one in peace."

—William (Willie) Cameron McCool

"The NESC has been both the mover and the forum for bringing alternate points of view to a problem. A central tenet of the NESC is to engage in open, passionate discussions, attacking ideas, attacking assumptions, and bringing alternate points of view ... "

— Dr. Michael Ryschkewitsch, NASA Chief Engineer

Sometimes looking back can be as important as looking forward. And on its 10th anniversary, the NASA Engineering and Safety Center (NESC) has the rare opportunity to do both. A decade ago, the NESC was being organized in the wake of the Shuttle Columbia accident. Though tremendous strides have been made to learn and grow from that tragedy, paying tribute and taking time to remember the Columbia crew is what instills humility and at the same time, inspires vigilance and a continued dedication to minimizing the risks inherent to space flight.

"I think that having friends and colleagues who were on the crews of both Challenger and Columbia certainly focuses you — that you need to do everything you can do to make sure spaceflight is as safe as it can be," says NESC Director Ralph Roe, Jr. "It's always going to be high risk, but we want to ensure we're doing everything we can to make it as safe as possible and not falling back into bad habits or cultures. Everyone who went through those experiences is changed in some way, and our whole organization was created to help prevent these things from ever happening again."

As the NESC recounts its 2013 technical activities and looks to its future role at NASA, those who have worked with the organization also recall the story of why and how the NESC came to be, and the reason why they never quit striving for excellence in engineering and safety.

Our Story

Why an NESC? In the summer of 2003, a vision of what the new NASA Engineering and Safety Center might look like was coming into focus. The Columbia Shuttle accident, which had occurred just a few months earlier, was still under investigation, but development of the NESC, designed to help keep such an accident from happening again, was already underway.

In 2003 NASA Administrator Sean O'Keefe announces plans to form the NESC at Langley Research Center.

"The Columbia Accident Investigation Board (CAIB) hadn't finished its final report, but we were already getting some hints as to some of the things they were worried about," remembers Bryan O'Connor, NASA's retired Chief of Safety and Mission Assurance and former Shuttle astronaut. Concerns were being brought to light that the resources, skills, and capabilities to offer the Shuttle Program a second perspective on difficult technical problems, like those experienced by Columbia, wasn't available. "That's when we started thinking about the NESC, where it should be appropriately organized, and what it should do," he says.

Tasked by then NASA Administrator Sean O'Keefe, O'Connor and a small team explored ways the NESC could bring to bear that much-needed second perspective. They studied safety and engineering processes already in place at NASA Centers and looked outside the Agency to other organizations with strong safety and engineering programs, such as the U.S. Navy. As ideas were distilled, the concept of an organization with an independent technical capability started to emerge. "We needed independent testing and analysis work to solve tough engineering problems," says O'Connor.

With that basic concept, the NESC was formed. There were still obstacles to overcome, such as funding and assuring NASA Centers that a separate organization focused on independent test and analysis wouldn't result in fewer resources for them. As those larger issues were resolved, O'Connor and the team narrowed in on the finer details and pulled together the engineering team that would bring the NESC concept to life.

NESC Founding Principles

Over the last 10 years, the NESC has grown in the scope, diversity, and reach of its assessments. What has remained constant, however, is a continued focus on the fundamental principles that form the foundation of the NESC:

Perform Independent Test and Analysis
Provide independent test and analysis to offer a second, broader-focused perspective to some of NASA's most challenging issues.

Leverage Expertise from Across the Agency, Industry, and Academia
Pursue engineering excellence through technically diverse expertise from across the Agency, industry, and academia.

Share Knowledge
Share the vast engineering knowledge gained in its assessments with all who might benefit.

Recognize those who Demonstrate a Commitment to a Strong Safety Culture
Recognize those who actively and unfailingly pursue and demonstrate a strong safety culture.

Learn and Lead
Serve in the NESC or on assessment teams for a period of time and then rotate back to the Centers.

Developing the NESC model

The team needed a model for how the new organization would operate, and ultimately chose an already proven method for tackling tough challenges – the tiger team. "It's a very simple model," says NESC Director Ralph Roe, Jr., who in 2003 was the Manager of the Space Shuttle Vehicle Engineering Office. Typically a tiger team is put into motion after a catastrophic event to figure out what went wrong and find resolutions. "During those times we bring the best and brightest together and go solve that particular problem," says Roe. "But instead of waiting for that catastrophic event to occur, we wanted to institutionalize that tiger team model and have the best and brightest ready to support a program, before a problem became catastrophic."

To build that model, the NESC had to convince NASA's top engineers to come onboard. "We knew we had to focus on having the best available engineering skills from across the Agency," says Roe. Offering senior grade positions was a start, as well as letting engineers reside at their respective Centers without having to move to NASA Langley.

Another feature of the NESC model would be a 2- to 5-year rotation for engineers, rather than a permanent position in the NESC. "It's been beneficial for both sides. We've been able to get some of the best engineers in their disciplines, and when the Centers get them back, they've got a broader perspective they wouldn't have had otherwise," says Roe.

To prevent the new organization from becoming insular, as the CAIB noted with the Shuttle Program, the NESC would include members from industry, academia, and other government agencies, so as to avoid NASA-only perspectives. "Roughly 30% of our matrixed teams are from outside the Agency," Roe says. "That was important."

Once established, the NESC could start pulling together assessment teams with the perfect mix of technical expertise to tackle any problem. But ensuring those individuals came together as a cohesive team was yet another challenge. "This model works because we spend a good deal of time working on personal relationships," Roe says. "We work hard to build trust and an open environment so that when we work a difficult problem, we can debate and argue and discuss things openly. When you bring together folks with different backgrounds, it takes a while to develop a common language, but once you do, you ultimately end up with better solutions because you leverage those different backgrounds and experiences. That's the real benefit of bringing together this technically diverse group. It's a challenge, but the benefit is so great, it's worth the effort that goes into it."

Much of the NESC's early assessment work was concentrated on the Shuttle Program. "It was right after the accident investigation, so our focus was certainly on helping shuttle return to flight," says Roe. But as the Shuttle Program began to wind down, and confidence in the NESC model grew, a more diverse workload from across

Continued next page

The NESC logo

The NESC's unique insignia has its roots in the early Mercury Program. " … I named my spacecraft Sigma Seven. Sigma, a Greek symbol for the sum of the elements of an equation, stands for engineering excellence. That was my goal — engineering excellence. I would not settle for less … "

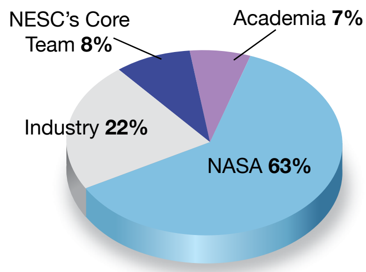
— Wally Schirra

For the NESC, the Sigma also represents engineering excellence. While Wally Schirra's spacecraft represented the 7 Mercury astronauts, the 10 in the NESC insignia represents the 10 NASA Centers. The NESC draws upon the resources of the entire Agency to ensure engineering excellence.

Centers and across programs started coming in. "Now there's a relatively good distribution across all of NASA's mission directorates," Roe says.

As the number of NESC technical activities grew, so did the engineering knowledge being generated from those assessments. Because capturing and sharing that knowledge would be key to preventing future problems, the NESC developed knowledge-share tactics, such as generating technical reports and bulletins, implementing an NESC Academy Website, and holding workshops and forums. The NESC also began adding early career engineers to its assessment teams. Paired with seasoned NASA experts, the next generation could get a jump start on climbing the learning curve, recognize more quickly the benefits of collaboration, and take away knowledge that would serve them throughout their profession.

The NESC extended team



Today the NESC continues to accept about 50-60 requests annually. "Even with shuttle retirement, the workload has remained very consistent from year to year," says Roe. Though its core team remains small, the NESC draws from a large pool of talent inside and outside the Agency every time it forms an assessment team. "That matrixed workforce has grown to about 700 engineers strong, 500 within the Agency and 200 outside the Agency. And the support we've been given by the Centers has been outstanding and instrumental to the success of the NESC." The NESC also takes time to acknowledge those within that workforce who exhibit the strong safety culture that the NESC is trying to promote with awards that celebrate engineering excellence.

The future of the NESC at NASA

As NASA looks to the future, Associate Administrator Robert Lightfoot sees the NESC's role becoming even more crucial to mission success. "The NESC was established because of lessons we learned — very painful lessons learned as an Agency. We don't want to lose that lesson. It's part of our DNA now. If anything, we need to figure out how to make sure it is maintained," says Lightfoot. "The NESC can bring to bear national expertise to any issue that we have. They're not constrained by Center boundaries and Center walls. They just look for the best person in the Agency. And because they are more discipline rather than program related, they can come in with an independent view. The NESC provided us a structure and an avenue to open a dialogue."

NASA Chief Engineer Dr. Michael Ryschkewitsch agrees. "The NESC has been both the mover and the forum for bringing alternate points of view to a problem. A central tenet of the NESC is to engage in open, passionate discussions, attacking ideas, attacking assumptions, and bringing alternate points of view with the goal of having all programs flying known, reliable systems — and that everybody does so in an environment of mutual respect," he says. "It really strengthens what we do."

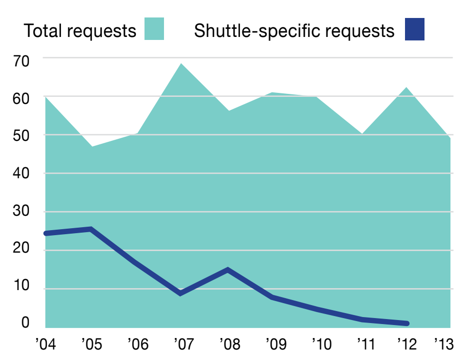
As a result, collaboration across Centers has increased. As more assessment teams come together to solve problems, relationships are fostered. It may be an unintended consequence of the NESC, but a welcome one, says Ryschkewitsch. "People get to know people across Centers. They can pick up a phone and talk with someone they worked with on a previous problem that brought good expertise to bear. NESC alumni have gone on to a lot of responsible positions, so they bring with them knowledge of having worked in cross-Agency teams and relationships. Having those relationships is absolutely essential."

That atmosphere of collaboration wasn't as common 10 years ago as it is today, notes Terrence Wilcutt, NASA's Chief of Safety and Mission Assurance. "Sometimes, in NASA's past, Centers would try to handle problems within their own boundaries. People would hesitate, maybe feeling that their Center should already have this expertise and should help themselves," he says. "Going to an outside entity has bridged that gap — opened that door — and seeking outside help has encouraged collaboration. The NESC led the way on that."

"Now that we've done more than 500 technical assessments, the Centers can see the benefit of bringing experts from other Centers together to help solve problems," adds Roe. "I think the CAIB was certainly right when they said the Shuttle Program was insular, but I think we've been instrumental in setting the example of Center collaboration and that has spread across the Agency."

"Now everyone knows to call the NESC," Wilcutt says. "They'll look at things in a cross-discipline manner. They'll ask questions you never even thought of. To me, the NESC is a known place to go to get technical help on our toughest problems. That did not exist before."

NESC technical activities

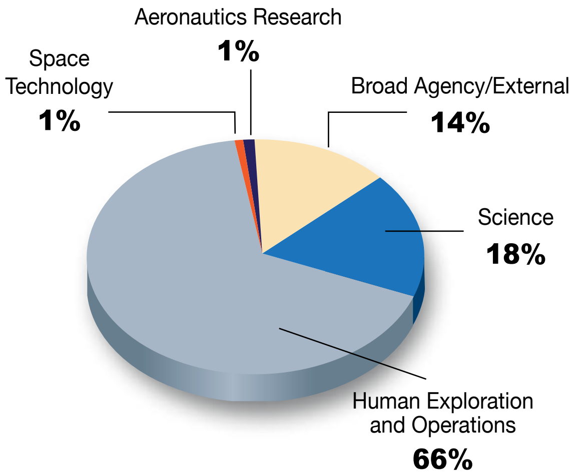


"With deep space exploration and partnerships with commercial spacecraft programs in its future, NASA will continue to rely on the NESC to help minimize risk," says Ryschkewitsch. "As we get to the later stages of commercial crew, Space Launch System, and Orion, I see some very hard discussions about the details of design and whether this hardware is safe enough to fly. We're also going to be in a very tight fiscal environment, which puts immense pressures on programs and projects. It's essential for technical groups to have the NESC as a backstop."

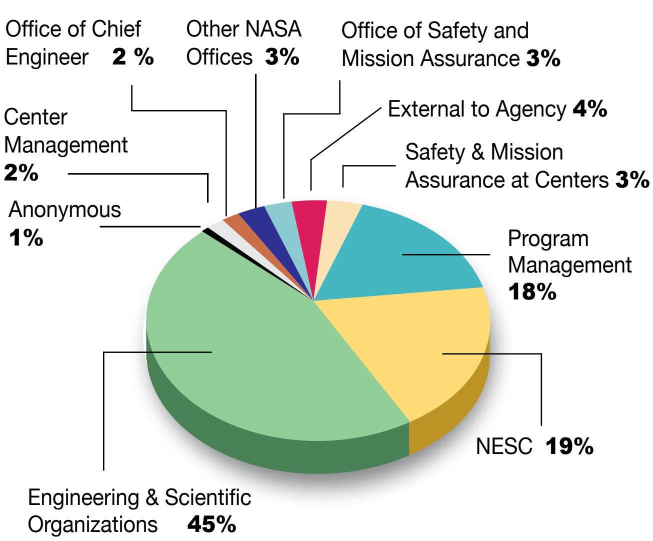
Lightfoot also depends on the NESC. "They are one of my go-to resources as soon as I see a crosscutting issue, a bigger issue than we can handle on our own," he notes. "Knowing the NESC is there is so valuable."

Wilcutt concurs. "After the Columbia accident, technical issues were coming up during return to flight, and on every issue the NESC weighed in, giving everyone a level of comfort that we understood the risks involved. The NESC will continue to be involved. We insist on it. We depend on it. The tougher the problem, the more we depend on the NESC to come in and take a look at it. I love having experts to call on," says Wilcutt. "That's quite a gift."

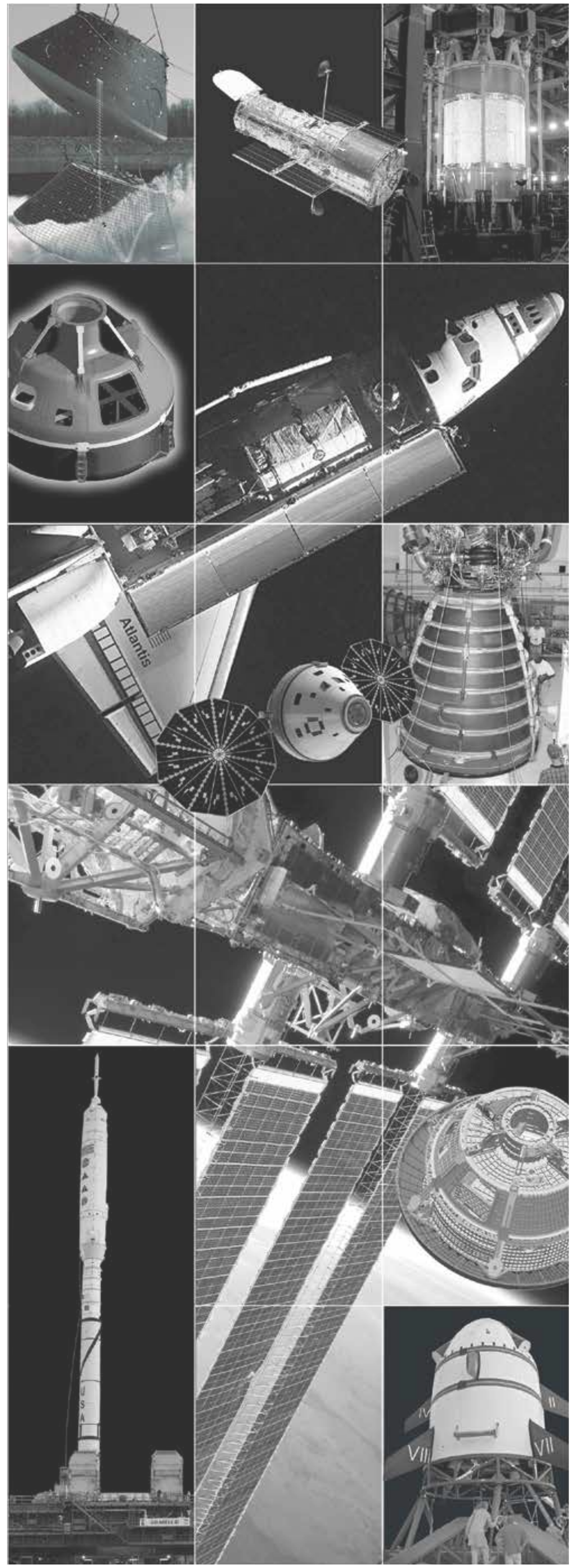
Accepted Requests: 541 Total

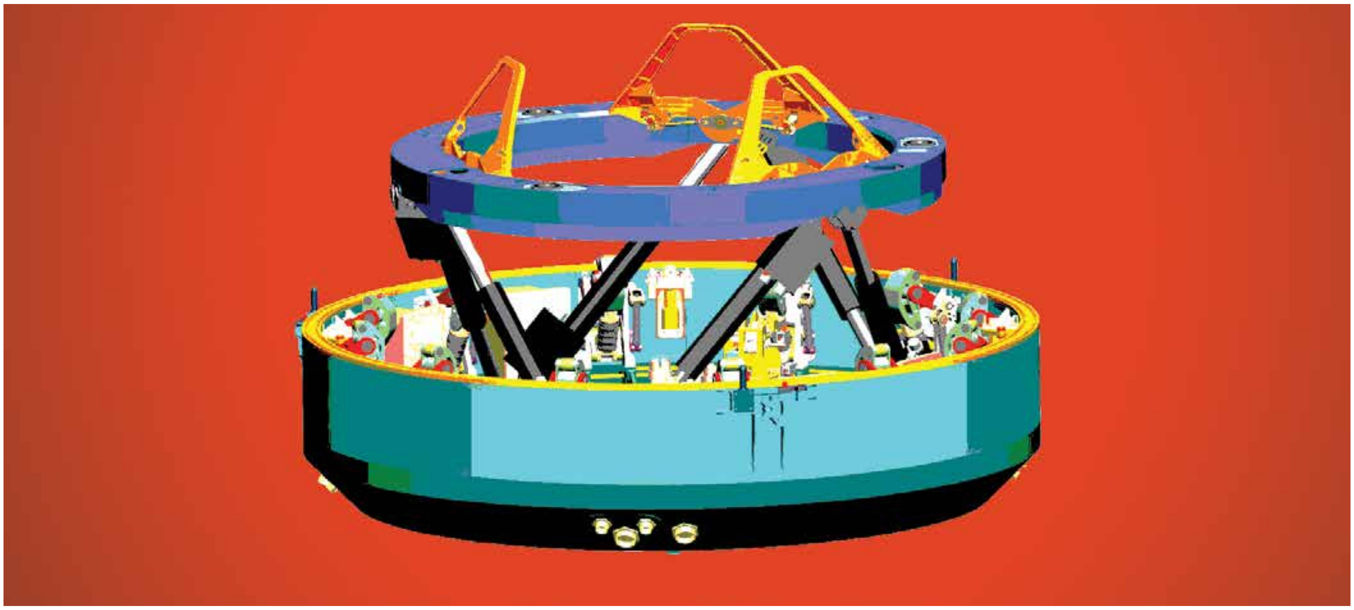


Sources of Accepted Requests: 541 Total



All statistics as of October 31, 2013





Performing Independent Test and Analysis

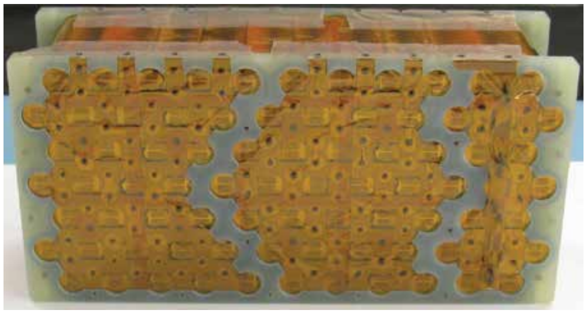
Our core mission is to provide value-added independent technical assessments, testing, and analyses in support of the Agency's high-risk programs and projects. Our goal is to provide the engineering data and recommendations needed for NASA Centers and Mission Directorates to make more informed decisions.

Our Extended NESC Team

Dr. Serena Auñón, JSC

Leveraging Agency Expertise

Our Agency-wide, diverse, multi-generation teams enable robust, timely, and innovative solutions to NASA's tough technical problems. It is our team members, especially the hundreds of matrixed personnel from within NASA, academia, and industry, who are the true strength of the NESC.



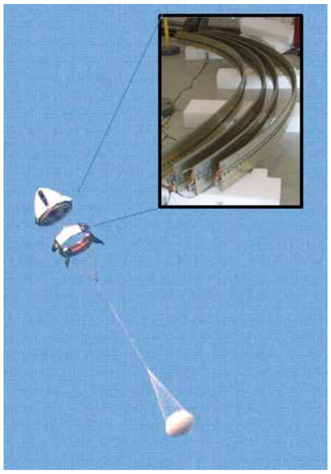
An EMU battery bank with numerous individual cells shown in holding fixture with Kapton insulation.

EMU Lithium Ion Battery Assessment

The recent Boeing Dreamliner lithium ion battery fires have prompted the Agency to take a closer look at NASA's own risk of a similar incident. In one such example, the International Space Station (ISS) Program requested that the NESC engage its Dreamliner Root Cause Investigation Support Team in an assessment of the ISS extravehicular mobility unit (EMU) batteries and charger system. This assessment focused on comparing the EMU and its charger to the list of potential contributing factors developed as a result of the Dreamliner investigation earlier this year.

Assessing Risks of Frangible Joint Designs

The Commercial Crew Program requested the NESC's assistance in the evaluation of commercial partners' frangible joints to provide confidence for their use in human spaceflight. Prior crewed spacecraft used other separation mechanisms including frangible nuts and bolts for stage separations. The NESC reviewed historical frangible joint designs, provided an estimate of the resources required to develop a frangible joint model, and planned an empirical test program for single mild detonating fuse highload frangible joint systems.



Example of frangible joint used for Max Launch Abort System.

Selecting Instrumentation for ISS On-orbit NDE

Micrometeoroid and orbital debris (MMOD) impact damage is a significant threat to the International Space Station (ISS). Nondestructive evaluation (NDE) instruments capable of assessing structural damage from MMOD impacts are currently not onboard the ISS. At the request of the ISS Program, the NESC evaluated a variety of NDE systems and recommended a phased array ultrasonic system for potential deployment aboard ISS. Evaluation criteria included the capability to assess hidden structural damage, ability of astronauts to use the system without prior NDE training, and engineering modifications that would be required to certify the instrument for spaceflight.

Veteran astronaut Shannon Walker evaluates an NDE system for potential use on ISS.

Jared Dervan, MSFC

Bill Benson, KSC

Mark Davis, DFRC

Dr. Roamer Predmore, AMA

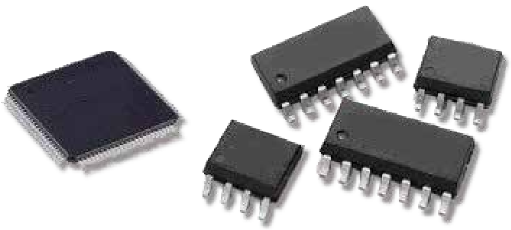
Jeremy Shidner, AMA, is a member of the NESC EDL Team.

Independent Modeling and Simulation for CCP EDL

Three Commercial Crew Program (CCP) companies are developing either capsule or lifting body crew transport vehicles. The NESC is developing a sustainable independent modeling and simulation capability to investigate entry, descent, and landing (EDL) issues on the three vehicles. The team created an integrated framework of models including atmospheric entry; thermal heating; aerodynamic uncertainties; vehicle stability and control; and capsule parachute inflation. The team first built generic capsule and lifting body models and conducted multiple degrees of freedom Monte Carlo flight simulations from entry to landing and is now developing models specific to each of the three vehicles. By developing relationships with company personnel and by proactively developing independent models, the team will be positioned to conduct independent analyses throughout the vehicles' life cycles.

Use of Commercial Electronic Parts in Safety-Critical Systems

The NESC assessed the use of commercial off-the-shelf (COTS) electrical, electronic, and electromechanical (EEE) components in safety-critical crewed spacecraft avionics systems. The reliability of COTS EEE parts, as compared to parts meeting the U.S. Military Standard, is controversial, as is the efficacy of box-level stress screening and qualification compared to part-level testing. Qualitative analysis by the NESC team indicated significant differences in reliability and safety assurance when comparing screened military grade and unscreened COTS EEE parts. To reduce mission risk, the NESC recommended the Commercial Crew Program require vehicle providers to develop and implement a top-down mission assurance program to address EEE parts derating, qualification, traceability, and counterfeit control; demonstrate how it mitigates the risks associated with EEE parts applications; and provide data supporting the effectiveness of the proposed screening approach ensuring part failure rates are adequately bounded and margins are clearly identified.



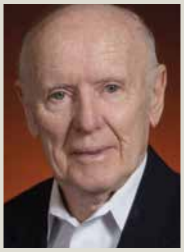
Commercial electronic parts in plastic packaging.

Sensitivity of Mission Success to Electronic Part Quality

The NESC performed a case study to assess the sensitivity of mission success to electronic part grade variation and redundancy as a function of mission duration. Mission durations assessed ranged from tens of minutes, i.e. duration of a launch to low Earth orbit, to a 6-month stay at the International Space Station. The results helped to identify and characterize benefits and risks of traditional and nontraditional approaches to screening, qualification, and architectural mitigation.

Our Extended NESC Team

R. James "Jim" Lanzi, WFF



Ed Devine, ATK

Tim Jett (left) and Chip Moore, MSFC

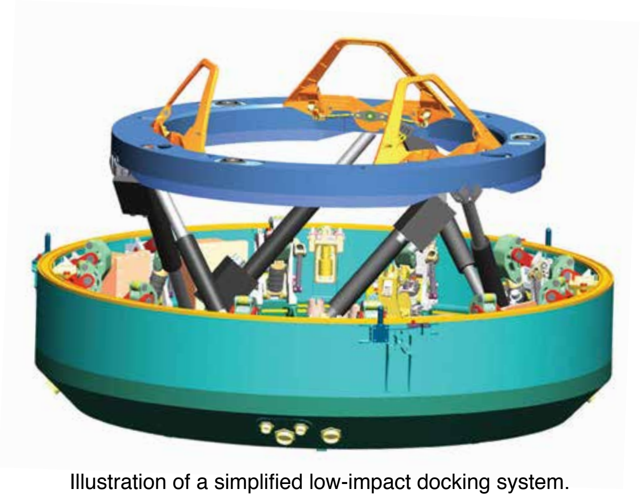


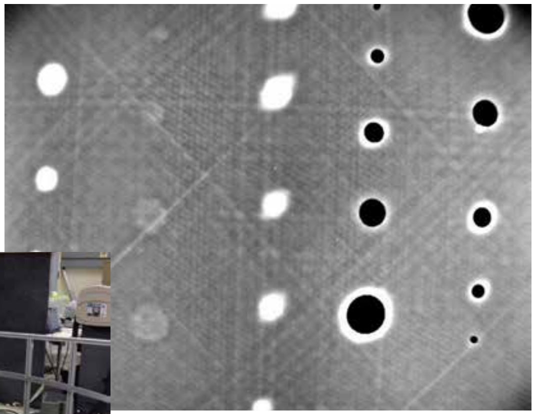
Illustration of a simplified low-impact docking system.

ISS Simplified Docking System

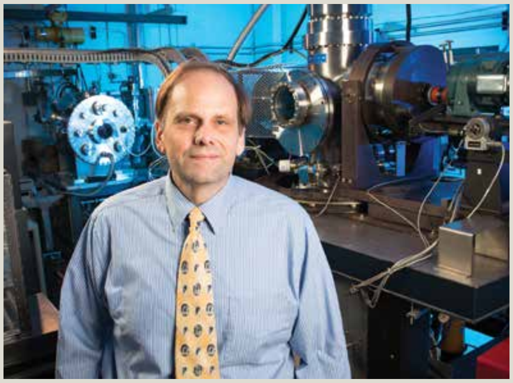
The International Space Station (ISS) Program Manager requested that the NESC participate on an independent reliability assessment of the low impact docking system (LIDS) that will be integrated onto ISS and to review other proposed simplified docking systems. The team conducted several technical interchange meetings with the LIDS engineers as well as with the contractors proposing simplified docking system alternatives. Reviews of analyses, trade studies, and hardware test data provided the support for a team recommendation that resulted in a change in direction to a lower cost and complexity system without compromising performance.

Collaboration on NDE of Impacted Composite Structures

A commercial partner requested the NESC's assistance in evaluating alternate nondestructive evaluation (NDE) techniques for inspection of composite structures that may be used in reusable space vehicles. Ultrasonic techniques are currently baselined by the partner for detecting and quantifying impact damage to assess the health of the space vehicle for subsequent flights. The NESC is investigating the capability of additional NDE techniques including flash thermography and computed tomography to determine damage levels in several impacted carbon composite samples provided by the partner.



Thermal image of a defect calibration standard illustrating impact, delamination, and core separation damage types (above); LaRC Automated Thermography Scanner (left).



Dr. Timothy Krantz, GRC

Tom Irvine, Dynamic Concepts Inc.

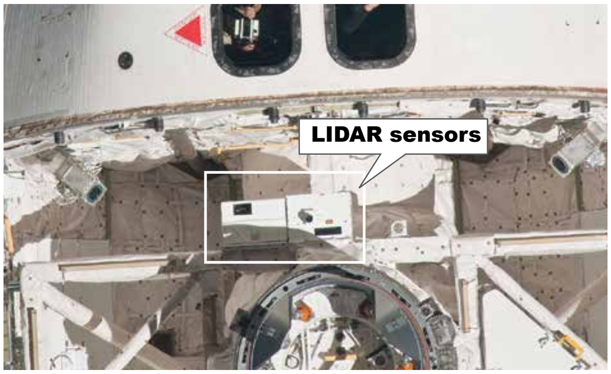
Dr. Phillip Tang, KSC

Dr. Tannen VanZwieten, MSFC

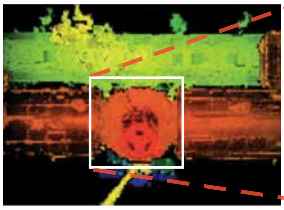
Launch Vehicle Explosion Model Evaluation

The blast overpressure, heat, and fragmentation environment produced by a launch vehicle catastrophic failure is an important safety consideration in spacecraft design. Knowledge gained about these accident environments can be factored into crew capsule integrity and strength requirements and help to determine the reaction time and separation distance the escape system must provide to keep the crew safe. The NESC has combined existing accident and test program databases into a single, comprehensive environments database that includes several new sets of relevant launch vehicle accident environment data. This database, with over 5,800 records, has been developed to facilitate the application of statistical analysis tools to better understand the most likely environments produced by catastrophic launch vehicle failures for human-rated systems.

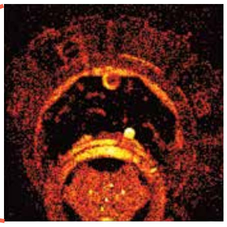
Illustration of KSC's Pad 39A reconfigured to support a number of heavy-lift launch vehicles.



LIDAR sensor location in orbiter payload bay.



LIDAR-sensed intensity image of ISS docking adaptor.



LIDAR-sensed closeup of ISS adaptor.

Relative Navigation Rendezvous Sensor DTO Performance Evaluation

Light detection and ranging (LIDAR) sensors perform critical rendezvous relative navigation (RelNav) sensing for spacecraft proximity operations and are baselined for use on several upcoming missions. The NESC performed an assessment to quantitatively evaluate the performance of three LIDAR rendezvous sensors: the Sensor Test for Orion RelNav Risk Mitigation Vision Navigation Sensor, DragonEye, and Triangulation and LIDAR. These sensors were flown as space shuttle development test objectives (DTOs) from 2009-2011. An independent, statistically based analysis of the DTO data was performed, and each sensor's performance was summarized relative to its individual DTO performance specifications. As a result, NASA improved its posture as a smart buyer for future LIDAR RelNav sensors by understanding each sensor's hardware and software functionality and by gaining an improved definition of LIDAR sensor performance/functional requirements.

Our Extended NESC Team

Dr. John Thesken *(left)* and Eric Baker, GRC

Mike Mendenhall, Nielsen Engineering and Research

Doug Wells, MSFC

Lawrence Green, LaRC

Illustration of the Orion MPCV crew module during reentry.

Phase II MPCV Thermal Protection System Margin Study

After completing an initial Orion Multi-Purpose Crew Vehicle (MPCV) heat shield reliability analysis, a partnered NESC-MPCV Phase II Study was initiated to update the reliability model using new arc jet and material property test data and an updated ablation analysis model. An analytical tool using Bayesian probability techniques was developed to assist in prioritizing testing, analyses, and model refinement for efficient resource utilization. Design of experiments techniques were employed to assist in the development of an efficient arc jet test matrix. Elements of the reliability process were utilized to formulate a design for heat shield sizing based on probabilistic modeling of the predicted reliability of several options.

Dr. Daniel Dvorak, JPL

Elmain Martinez, JPL

Ratnakumar Bugga, JPL

Joe Gasbarre, LaRC

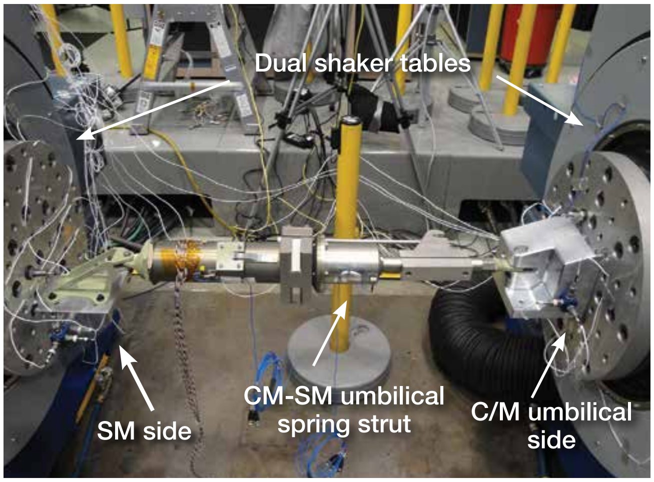
CAD Tools to Support Human Factors Design Teams

The NESC is developing computer-aided design (CAD) tools to support human factors analyses. Working in the Virtual Environments Lab at MSFC, the assessment team is in the early stages of developing a database of human model primitives to be used in creating virtual simulations for human factors analyses of launch vehicle ground processing. Primitives are basic postures and motions that humans use to perform common ground processing tasks. Assessment objectives include improving model reliability and enhancing the appearance of human models in virtual environments. Motion capture technology is used to record human movements for integration into the virtual environment. The database also will include images, anthropometric data, and statistical analyses of lower back strain and lifting limits.

The Virtual Environments Lab Team prepares for a motion capture session. From left: Mark Blasingame, Jason Quick (seated), Caitlyn Durham, Clay Robertson, Victoria Garcia, Trey Perry (kneeling), and Dr. Mariea Dunn Jackson, assessment lead.

MPCV CM/SM Spring Strut Vibration Testing

Fluids, data signals, and electrical power are transferred between the Multi-Purpose Crew Vehicle (MPCV) crew module (CM) and service module (SM) via an external umbilical driven from the CM by dual-spring struts. To reduce program risk, the NESC, working with Lockheed Martin, performed qualification-level vibration and performance tests on a spring strut development unit and ultimately uncovered issues that would not have been identified until strut qualification. Based on the test results and a follow-on failure investigation, corrective actions were identified and implemented by the MPCV Program for the upcoming Exploration Flight Test-1, and additional recommendations and best practices in areas of design, analysis, test, and workmanship were provided to the MPCV Program for future design iterations.



CM-SM umbilical spring strut installed in dual shaker test configuration.

Our Extended NESC Team

Dr. Kenny Elliott, LaRC

Samantha Fore, KSC

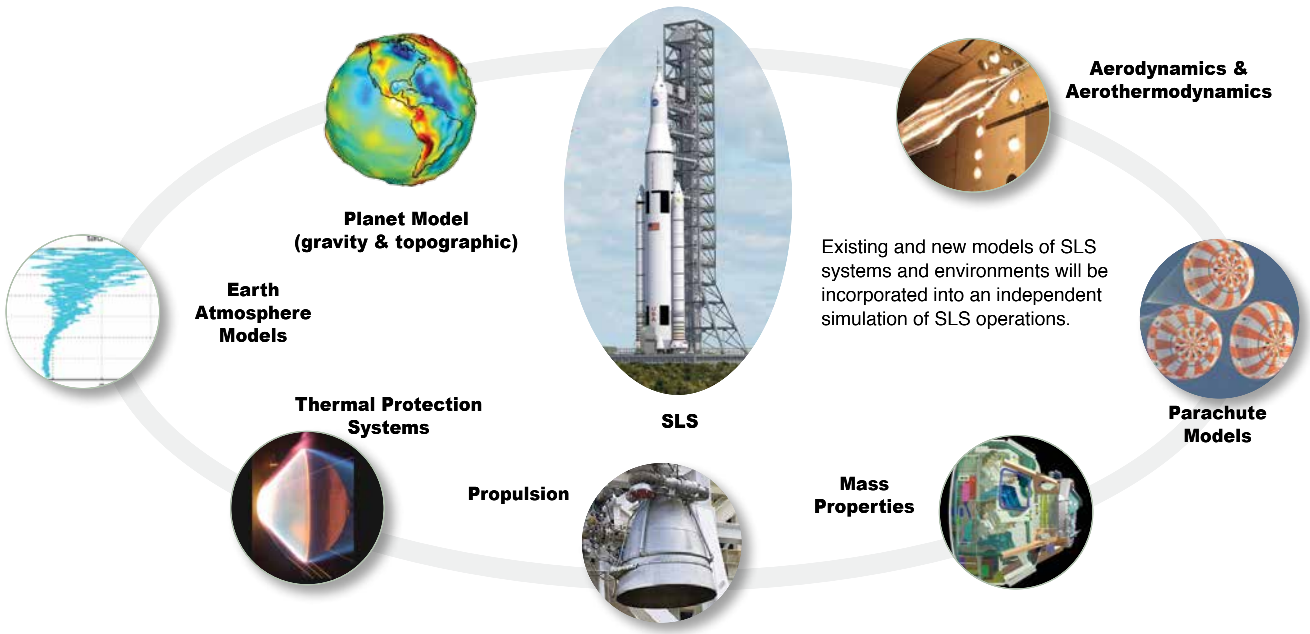
Michael Bay,
Bay Engineering

Dr. Kenneth Lebsock, Orbital Sciences Corp.

Flight Testing of the SLS Launch Vehicle Adaptive Control Algorithm

Augmenting Adaptive Control (AAC) is intended to improve robustness and performance for the Space Launch System (SLS) by adapting the flight control system to unexpected environments or variations in launch vehicle dynamics. Test experience with this new AAC algorithm reduces the risk of its inclusion in the SLS vehicle's flight control system and demonstrates performance of the algorithm in a relevant environment. The F/A-18 Full-Scale Advanced Systems Testbed aircraft at DFRC provided a suitable flight environment and the opportunity for multiple test runs. Flight tests will provide findings in time to be incorporated into the third SLS Design and Analysis Cycle.

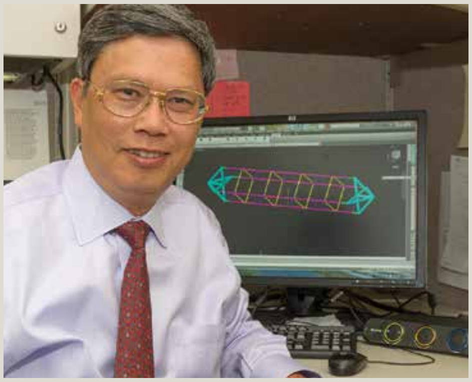
The DFRC F/A-18 is a test bed used to mature and refine the SLS adaptive control algorithm.



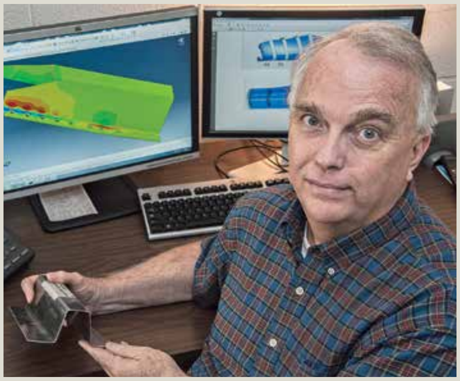
Independent Modeling and Simulation for Exploration Systems

The NESC has assembled a multi-Center team to develop independent models for Human Exploration Office Programs: the Space Launch System (SLS), Orion Multi-Purpose Crew Vehicle, and Ground Systems Development and Operations Programs. The purpose of this effort is to independently identify or corroborate technical issues that occur within the highly integrated nature of these new systems and enable the NESC to be ready to provide independent assessments and technical analyses as issues arise. The NESC completed 3 degree of freedom (3-DOF) and 6-DOF simulations of the SLS Design Analysis Cycle 2 configuration with guidance for the nominal trajectory, and the team is currently working to add slosh and flex modeling and dispersions for Monte Carlo analyses.

Jody Woods, SSC



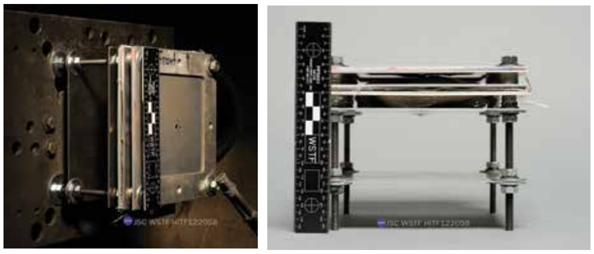
Hung Pham, JPL



Dr. Norm Knight, General Dynamics

MMOD Design and Analysis Improvements

The NESC partnered with the JSC Human Exploration Science Office to improve micrometeoroid and orbital debris (MMOD) damage predictions and risk assessments for the International Space Station, Orion Multi-Purpose Crew Vehicle, and other spacecraft. The team used finite element model simulations and hypervelocity impact testing to produce updated ballistic limit equations (used to define MMOD shield effectiveness) that incorporated the effects of higher density MMOD particles than previously assessed. The team also tested new shield configurations that combined MMOD and radiation protection and tested shields with a thermoplastic film layer that have the ability to self-heal MMOD penetrations.



Two views are shown of a multilayered shield test target after impact from a 2.80 mm diameter aluminum particle traveling 7.38 km/s. The innermost layer of the shield was not penetrated, indicating a pass for this test.

Pyroshock Characterization of Composite Materials

The NESC initiated a developmental study seeking to quantify the impact various material parameters have on the structural response of a composite structure in a pyroshock environment. Data generated from a test series using design of experiments methods are evaluated using statistical analysis to identify to what extent various composite material parameters influence a flat composite panel's structural response to shock-induced loading. The results from these tests will aid in future large-scale testing by eliminating insignificant parameters and contributing to the development of empirical scaling methods for composite structures' response to shock-induced loading.

(From left) Brian Collins, James Newton, and Phillip Thompson complete fabrication of a composite panel at MSFC for pyroshock testing.

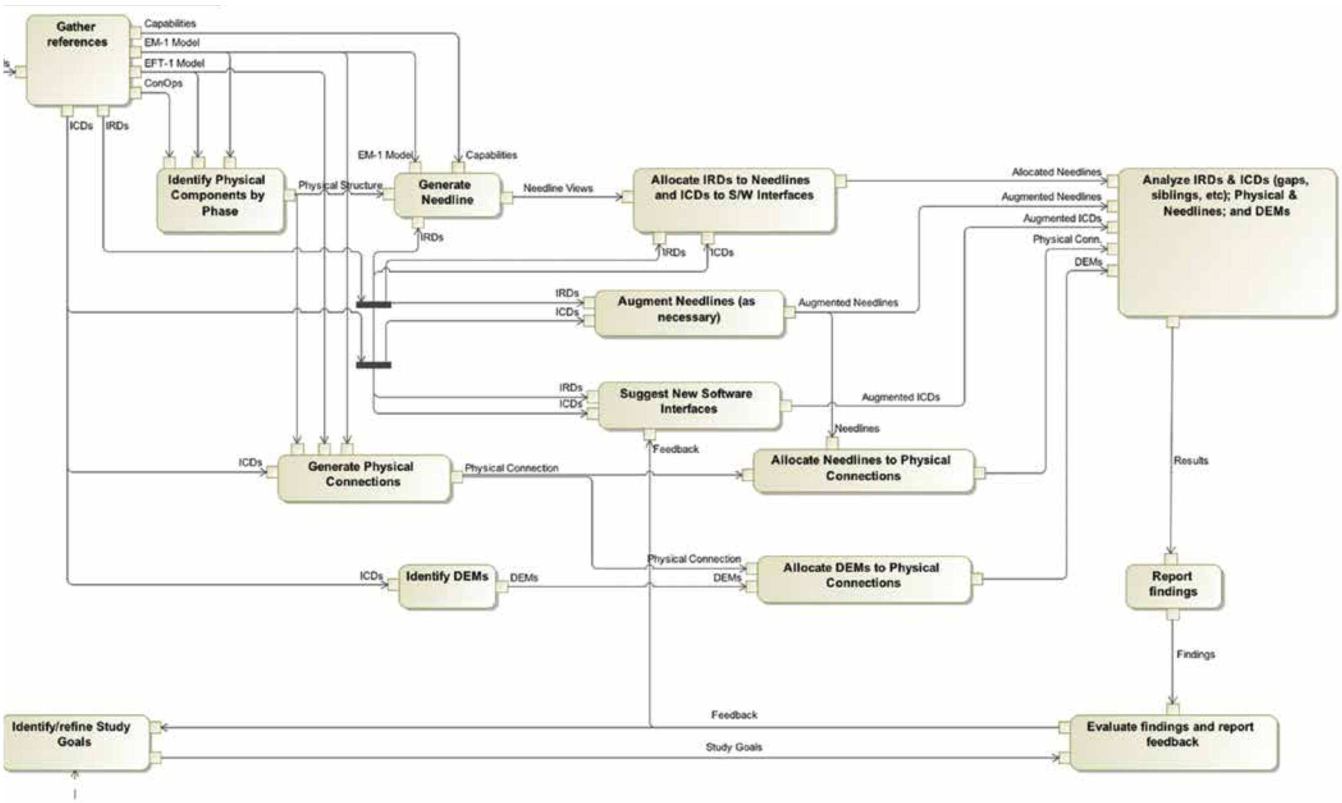
Our Extended NESC Team

Peter Berg, SGT Inc.

Julie Foster, JPL

Dan Rascoe, JPL

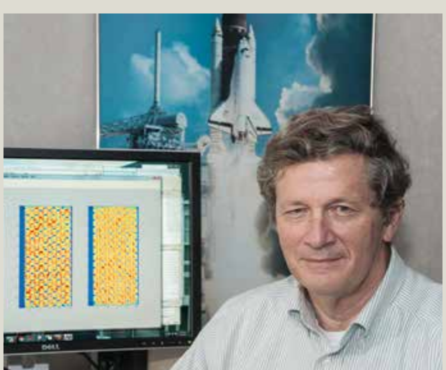
Dr. Danny Allgood, SSC



Activity and process diagram for the SLS-MPCV SysML model design.

Model-Based Systems Engineering of the Exploration Systems Interfaces

Lessons learned in model preparation, build processes, and tool usage, which were gained during previous NESC software studies, have been applied to the Exploration Systems Development (ESD) interfaces. Space Launch System (SLS) and Orion Multi-Purpose Crew Vehicle (MPCV) teams have been modeling internal interfaces, and the NESC is assessing the modeling of the interfaces between SLS, MPCV, and Ground Systems Development and Operations (GSDO) components using model-based systems engineering techniques. Guided by requirements and interface documents, the NESC team is modeling the distribution of flight, health, and safety information between GSDO, MPCV, and SLS and how SLS internally processes the data. Also modeled are the commands from GSDO/MPCV to SLS, including distribution of command responses. Using modeling tools, discrepancies and gaps in and between the document sets have been identified. This work will help determine what interfaces and expected behaviors will be needed by ESD.



Dr. Bill Winfree, LaRC

Dr. Christopher DellaCorte, GRC

Robert Powers, JPL

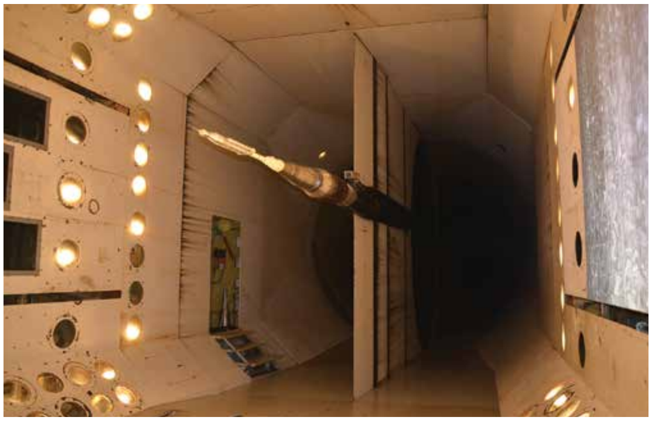
Qualification of Parachutes for High Altitude Deployments

The Orion Multi-Purpose Crew Vehicle Program initially planned to qualify the capsule parachute assembly system (CPAS) drogue parachutes for high altitude contingency deployment by analysis using models validated with low altitude data, based on an early crew module (CM) stability estimate. The NESC team evaluated the simulation models and found issues that gave conservative estimates of CM stability above the nominal deployment altitude. The program updated the model and is reevaluating the need for testing above nominal parachute deployment altitudes. Like all working parachute models in use, many parameters are empirical and so predictions beyond their validated range would have uncharacterized uncertainty. The NESC team's principal recommendation was to conduct high altitude aircraft air drops to qualify CPAS to as high an altitude as practicable.

Parachute test vehicle with reefed dual drogues.

Transonic Shock Reflections in SLS Wind Tunnel Testing

To predict the performance of NASA's Space Launch System (SLS) during ascent, engineers measure the aerodynamic forces on the vehicle using wind tunnel testing. At transonic and supersonic speeds, the vehicle generates shock waves that can reflect off wind tunnel walls. If these waves reflect back and impact the model, they can cause inaccuracies in the prediction of aerodynamic forces on the vehicle. SLS engineers encountered these reflections in their original testing of the vehicle. The NESC supported installation and testing of the SLS model in a much larger wind tunnel to reduce the effect of these reflections and better deduce the impact of these reflections on the original aerodynamic data.



Wind tunnel shock reflection testing in LaRC's Transonic Dynamics Tunnel helped engineers evaluate the effect of shock reflections on SLS ascent performance predictions.

Our Extended NESC Team

Dr. Henning Leidecker, GSFC

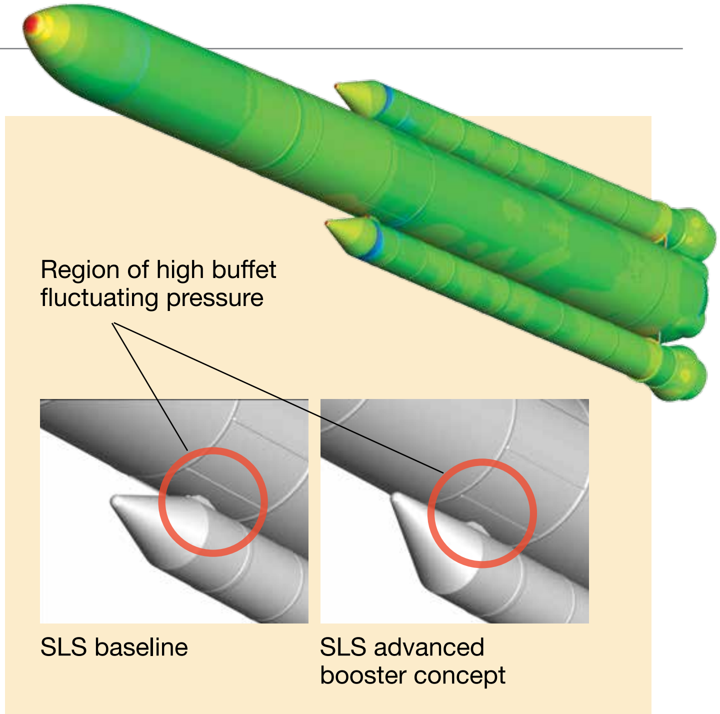
Timothy Risch, DFRC

Courtney Flugstad, KSC

Alden Mackey, AMA

Space Launch System Booster Interface Loads Analysis

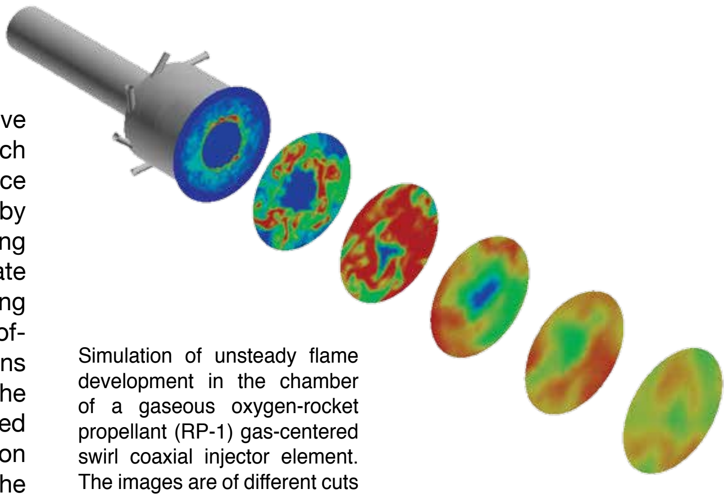
NASA's Space Launch System (SLS) uses solid rocket boosters to overcome high aerodynamic and inertial forces during launch. The interaction of these boosters with the SLS main engine core can produce highly unsteady buffet loads on both the core and booster stages, resulting in design decisions that can increase the weight of the vehicle. Previously, these buffet loads could only be evaluated using costly wind tunnel and flight tests. The NESC is employing state-of-the-art computational aerodynamics design tools to evaluate and reduce these interface loads. Wind tunnel tests of candidate shapes showing the greatest potential for load reduction will be conducted to verify the computational designs.



Design techniques employing computational aerodynamics indicate that a canted booster nose cone geometry reduces aerodynamic buffet loads on the SLS.

Liquid Engine Combustion Stability Analysis

The NESC has undertaken a task to advance the predictive capability of tools being used to assess Space Launch System (SLS) liquid engine stability. State-of-the-practice engineering combustion stability tools are limited by empirically based embedded models and inputs resulting in mostly postdictive results. These limitations create significant uncertainties in stability assessments leading to increased engine development time and cost. State-of-the-art computational fluid dynamics injector simulations are being executed to upgrade key aspects of the engineering stability assessment tools. These improved tools and methodology will enable confident identification of combustion instabilities leading to timely mitigation. The ultimate result will be reduced SLS engine development costs and time.



Simulation of unsteady flame development in the chamber of a gaseous oxygen-rocket propellant (RP-1) gas-centered swirl coaxial injector element. The images are of different cuts through the domain at the same instant in time.

Dr. Louise Struzenberg, MSFC

Nicolas Rouquette, JPL

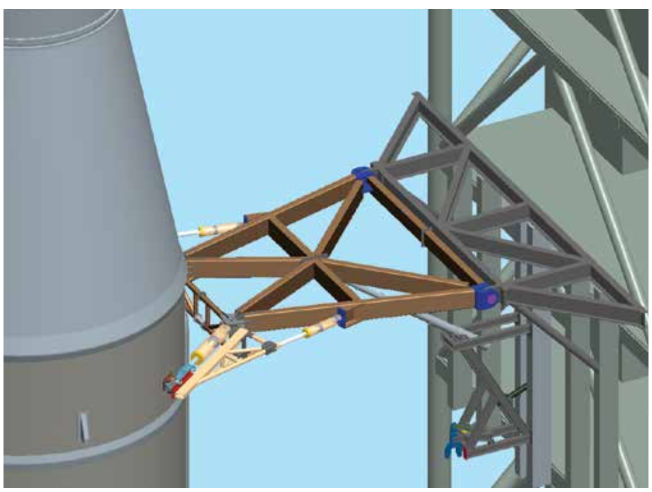
Rick Russell, KSC

David Ordway, MSFC

SLS Main Engine Startup Acoustics

NASA's Space Launch System (SLS) will use the Space Shuttle Main Engine (SSME) to power its core stage, but the number, orientation, and relative location of the engines are different from those used on the Space Shuttle Program. The acoustics generated in the SSME nozzles at startup are significant and can damage nearby vehicle components and launch pad hardware. The NESC is employing a new subscale ground testing approach to investigate the acoustic environments generated by the SSMEs in their SLS configuration. This testing will refine the early estimates of the SLS launch acoustic environment and may reduce the number of large-scale tests needed to qualify various SLS components for the vehicle's launch acoustic environment.

Subscale SSME testing at the University of Texas at Austin will provide data to help engineers evaluate engine startup acoustics for the SLS.

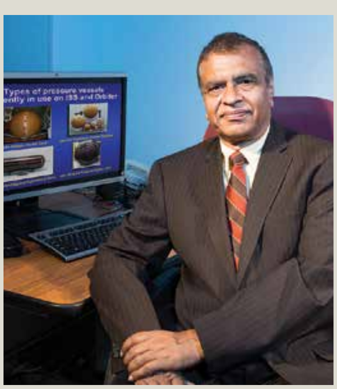


Conceptual T-0 stabilizer for SLS Block 1.

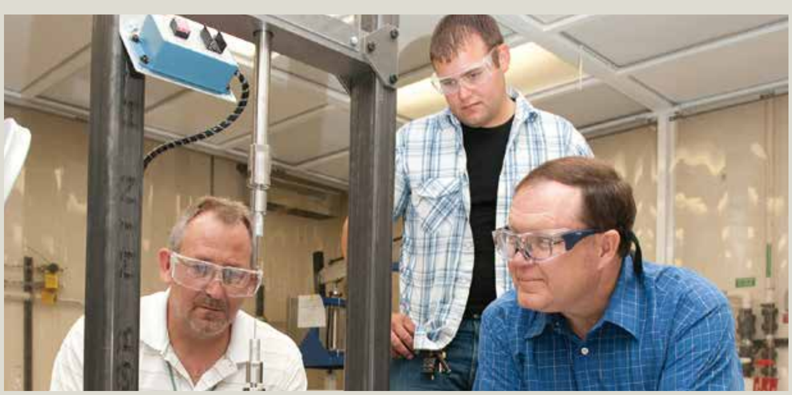
SLS T-0 Vehicle Stabilization Loads Evaluation

The NESC performed an independent evaluation of the Space Launch System (SLS) T-0 vehicle stabilization loads at the request of the SLS Program. During SLS liftoff loads analysis, gapping (uplift) was noted at the joints between the vehicle support system (VSS) posts and the solid rocket booster aft skirts. This nonlinear behavior invalidated the respective load cases. The NESC team reviewed gapping and structural margin mitigation options and SLS loads models and analyses. The team concluded that a T-0 stabilizer between the mobile launcher tower and the SLS core stage provides the best option to mitigate VSS joint gapping and structural margin issues.

Our Extended NESC Team



Dr. Pappu Murthy, GRC

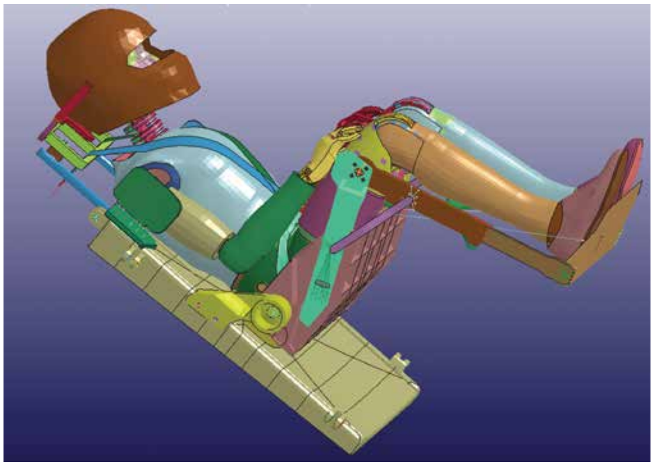


(Left to right) Anthony Carden, ERC Inc.; Darin Franzoni, Jacobs Technology; and Harold Beeson, WSTF

Amri Hernandez-Pellerano, GSFC

Orion Crew Module Impact Attenuation System Assessment

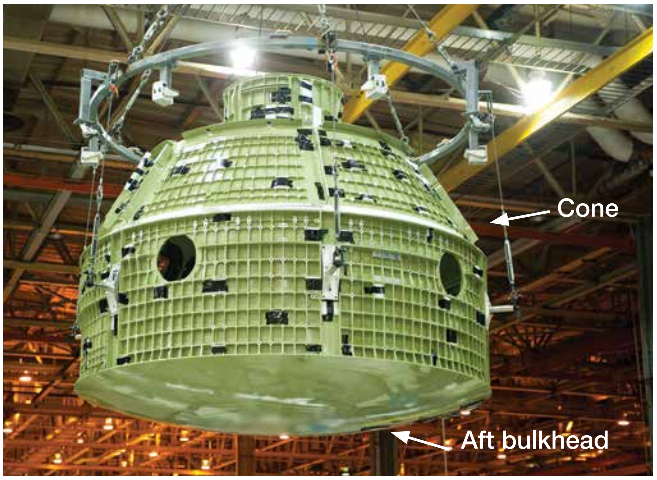
The NESC is assessing the impact of a proposed change to the Multi-Purpose Crew Vehicle (MPCV) Crew Impact Attenuation System (CIAS). Currently, crew seats are mounted to an energy-attenuating pallet that is designed to stroke and limit the loads that are transferred to the crew members. As part of the MPCV mass-reduction effort, a proposal was made to delete the CIAS pallet and substitute it with individual seat attenuation. The primary contractor has computed the Brinkley Dynamic Response criteria for a set of nominal and off-nominal landing conditions and has determined that the proposed design complies with NASA Human System Integration Requirements. The NESC will model and analyze the response of a 50th-percentile anthropomorphic test dummy (ATD) to nominal and off-nominal landing accelerations, including potential flail and body movements. These results will provide valuable criteria for evaluating MPCV occupant safety.



The Hybrid III ATD is shown in a proposed MPCV seat. Seat accelerations from the LS-DYNA landing model are used to drive the seat motions to compute the ATD responses.

Spin Forming Crew Module Metallic Aft Bulkhead and Cone

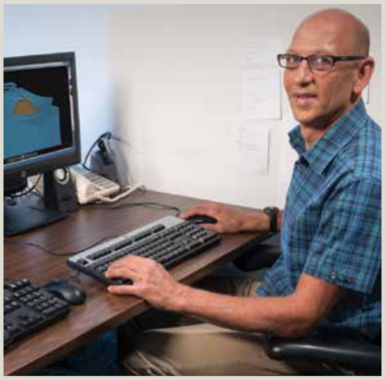
The NESC will evaluate spin forming as a technique that may reduce Multi-Purpose Crew Vehicle risk by simplifying the fabrication of the Orion crew module (CM) aft pressure vessel bulkhead and cone. The spin forming process can produce a single-piece aluminum alloy aft bulkhead and a single-piece cone resulting in the elimination of the nine major welds from the cone required for the current multiple-piece construction. Objectives of the two-part study will be to spin form an aft bulkhead pathfinder and develop a first-of-a-kind thick-component (6 inches) spin forming process for the manufacture of a CM cone.



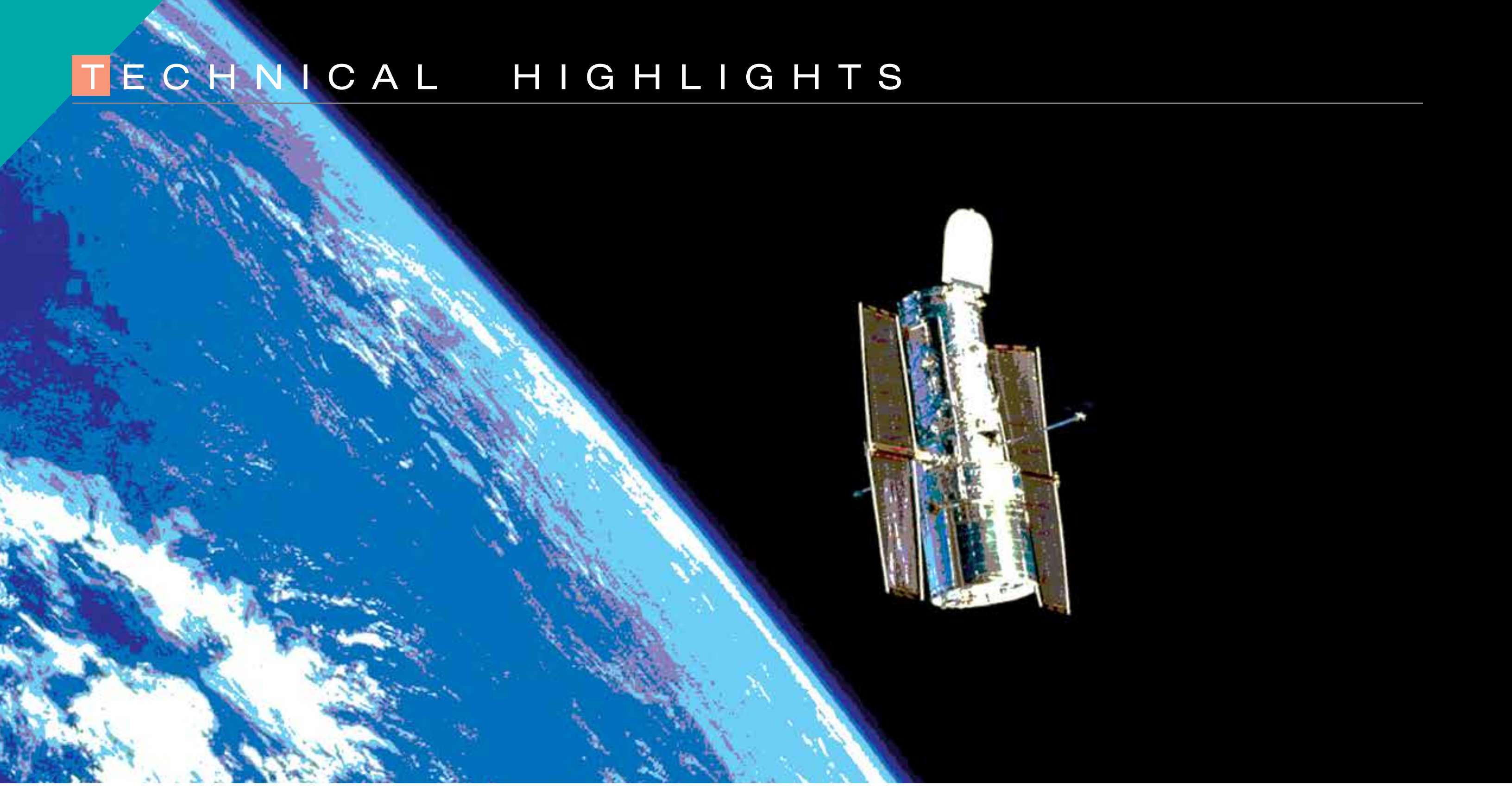
Pressure vessel component of CM.

Dr. Mary Kaiser, ARC

Chad Hastings (left) and Phillip Thompson, MSFC

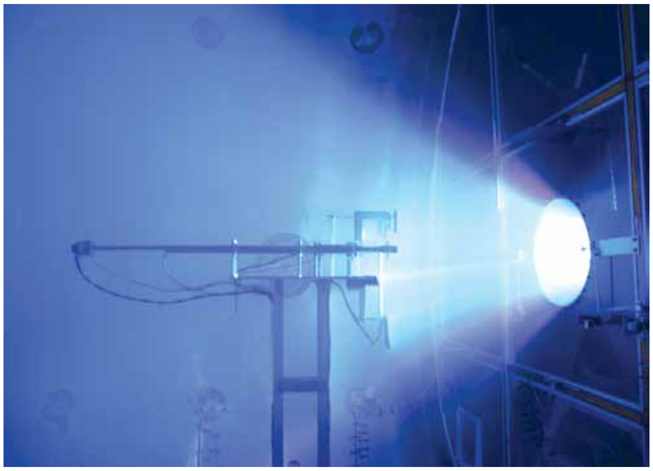


Dr. Charles Lawrence, GRC



Evaluation of Solar Electric Propulsion Alternatives

Future deep space NASA missions, such as the Asteroid Retrieval Mission (ARM), will require the use of advanced solar electric propulsion (SEP) technologies to allow for larger payloads. The NESC conducted an independent study of the SEP component of the ARM. The NESC reviewed the underlying assumptions used in the baseline ARM SEP concept study and examined alternative propulsion approaches for achieving the mission.



Ad Astra

Vacuum chamber ground testing of Ad Astra's VX-200 Electric Propulsion Thruster with argon propellant.

Our Extended NESC Team

Richard Wear, SSC

Dr. Russell "Buzz" Wincheski, LaRC

Richard Larson, DFRC

Tom Modlin, Modlin Aerospace

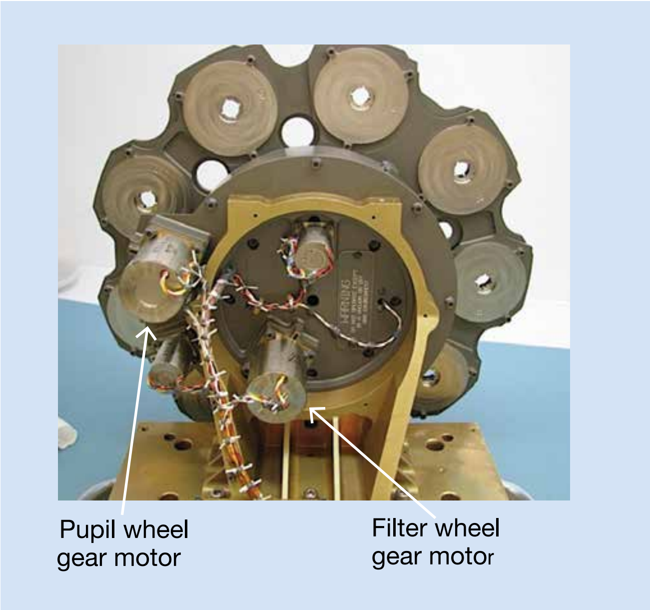
HST gyroscope.

Hubble Space Telescope Attitude Observer Anomaly

Hubble Space Telescope (HST) operations have been impacted by an anomaly called the Attitude Observer Anomaly (AOA). During guide star acquisitions, the fine guidance sensor has occasionally lost lock on the guide star, threatening a potential loss of science. The NESC Guidance, Navigation, and Control Technical Discipline Team has been supporting the HST Project in understanding and mitigating the AOA, believed to be linked to gyroscope flex lead corrosion. The NESC performed independent flex lead corrosion experiments, updated gyroscope life predictions accounting for variable gyroscope thermal conditions, and is pursuing development of a new multidisciplinary model of the gyroscope flex lead corrosion. The NESC also provided gyroscope engineering subject matter experts from outside NASA to support the resolution of this anomaly.

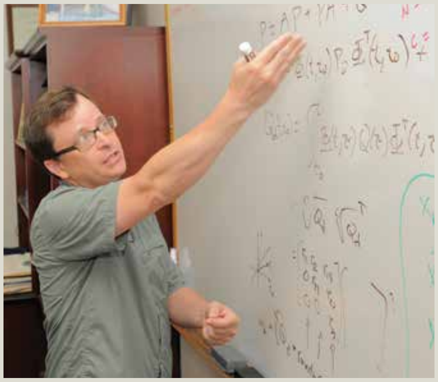
JWST Fine Guidance Sensor Gear Motor Anomaly Investigation

After a dual-wheel filter wheel mechanism in the fine guidance sensor on the James Webb Space Telescope (JWST) failed its life test, the NESC was requested to provide mechanical systems support for the Failure Review Board. Review of the drawings, assembly procedures, and life test hardware revealed root causes, which were improperly applied dry film lubricant on gears, gearheads not properly designed for dry lubrication, no gearhead run-in and clean-out steps, and improper gear motor installation in the dual wheel. New gear motors and adapters designed to correct these issues are currently being manufactured for a life test.



JWST dual-wheel filter wheel mechanism.

Tom Horvath, LaRC



Dr. J. Russell Carpenter, GSFC

Terry Bradford, MSFC

Combustion Instability in Black Brant Motors

The Black Brant motor has a history of combustion instability during flight. This assessment used combustion-response data generated by the Naval Air Warfare Center to update the combustion-response characteristics of two flown Black Brant motor propellant formulations: Mk1 (Chinese ammonium perchlorate (AP)) and Mk2 (United States-manufactured AP). The test data indicate that both formulations have high response characteristics, with the Mk1 propellant being more responsive. Observations from Black Brant flights indicate instability initiation is related to slag expulsion from the motor.

The Black Brant sounding rocket motor, operational since the 1960s, is the workhorse of NASA's Sounding Rocket Program.

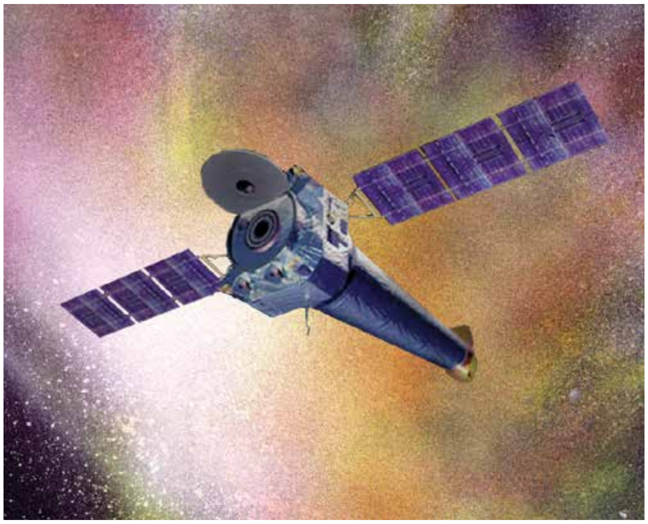


Illustration of Chandra X-Ray Observatory.

Chandra X-Ray Observatory COPV Risk Assessment

The Chandra X-Ray Observatory Project requested an evaluation of an increased thermal environment on a composite overwrapped pressure vessel (COPV) propellant tank due to degraded multilayer insulation and a change in spacecraft attitude. The review focused on COPV stress rupture and aluminum liner corrosion and crack growth failure modes. The carbon fiber/epoxy COPV was assessed to have a low stress rupture risk. However, hydrazine compatibility data were insufficient to identify issues with the liner surface corrosion, stress corrosion cracking, and environmentally assisted crack growth. The NESC recommended a test plan be developed to characterize the liner when exposed to hydrazine in the expected pressure, temperature, and exposure duration.

Our Extended NESC Team

Kim Simpson, JPL

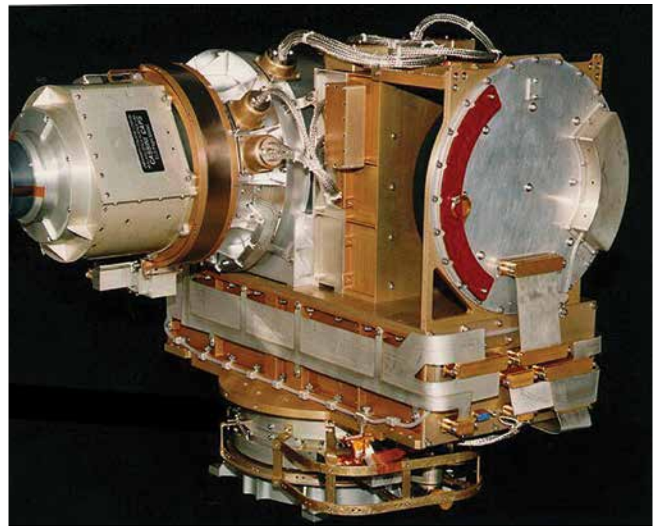
Dr. Floyd Spencer, Sfhire

Everett Miller-Smith, MSFC

Bernard "Dov" Adelstein, ARC

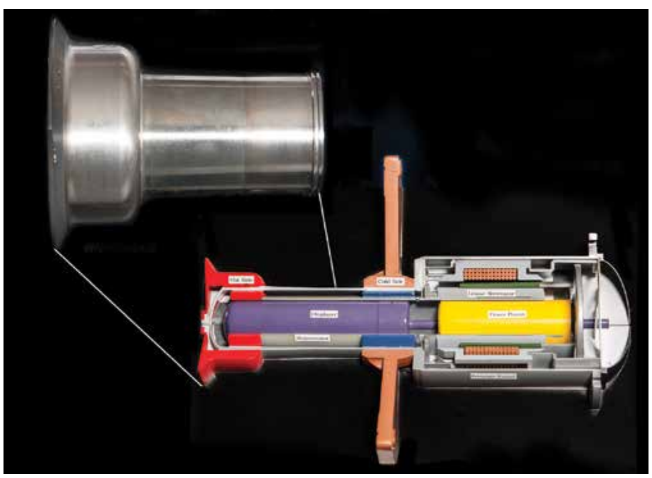
Cassini Plasma Spectrometer Short Circuit Anomaly Investigation

The solid-state overcurrent protection device located on the Cassini Plasma Spectrometer (CAPS) tripped, resulting in the loss of the instrument. The dynamic event signature leading up to the trip prompted the Cassini Project to request an NESC investigation. The NESC explored shorting scenarios and verified them via telemetry sequence re-creation using circuit models. The team developed possible root causes, evaluated drawings, and conducted lab testing to further develop an understanding of the failure modes. These activities allowed the team to characterize the risk of reactivating CAPS for the project and presented operational risk mitigation measures should the project consider reactivation.



Pat Mokashi/Southwest Research Institute

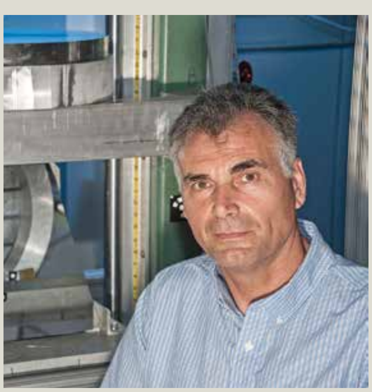
Cassini Plasma Spectrometer Instrument flight hardware.



The Advanced Stirling Converter within the ASRG.

ASRG Heater Head Critical Flaw Analysis

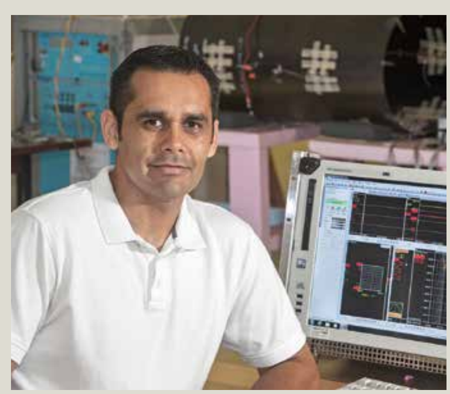
The NESC provided technical expertise to the Advanced Stirling Radioisotope Generator (ASRG) Project to establish flight hardware acceptance criteria for the heater head component. Metallic oxides that form in the heater head material during the casting process create embedded flaws that present a risk of fatigue failure during dynamic stress environments like transportation, launch, landing, and nominal long-term operation. The NESC determined that the traditional analytical methods to predict maximum allowable flaw size were not appropriate due to the thin heater head wall thickness. The NESC provided technical assistance to develop an empirical method to predict component life and performed independent testing to characterize material properties. The test program culminated in new acceptance criteria to screen out discrepant hardware.



Dr. Sotiris Kellas, LaRC

David Coote, SSC

Dr. Yuan Chen, LaRC



Omar Torres, LaRC

The NESC Looks Back on a De

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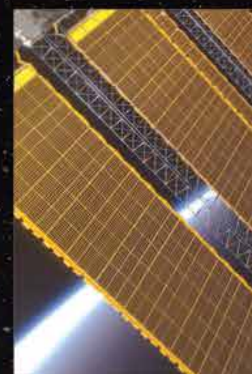




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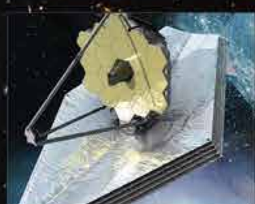





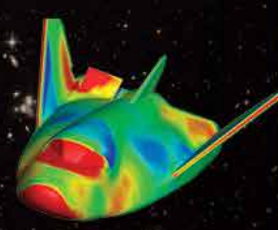

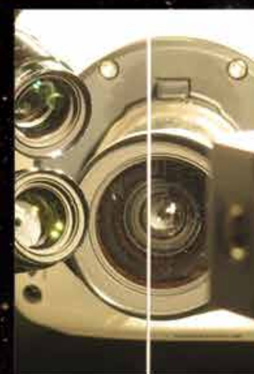
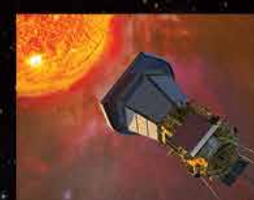


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Solar Probe Plus Upper Stage Performance Assessment

The Solar Probe Plus mission, being performed by the Johns Hopkins University Applied Physics Laboratory (APL), is scheduled for launch in 2018 and will conduct key scientific research of the sun. This mission is highly mass-constrained, and a new upper stage, the STAR 48GXV, is under development to provide the high-energy trajectory required for the desired solar orbit. The NESC conducted an independent assessment of the STAR 48GXV performance including flight stability, control authority, and trajectory insertion accuracy. The results are being used by APL to refine the design to provide the required performance while minimizing mass and cost.

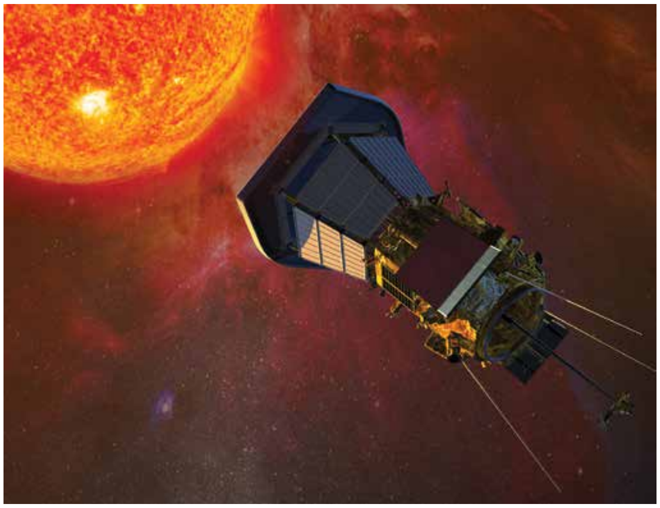
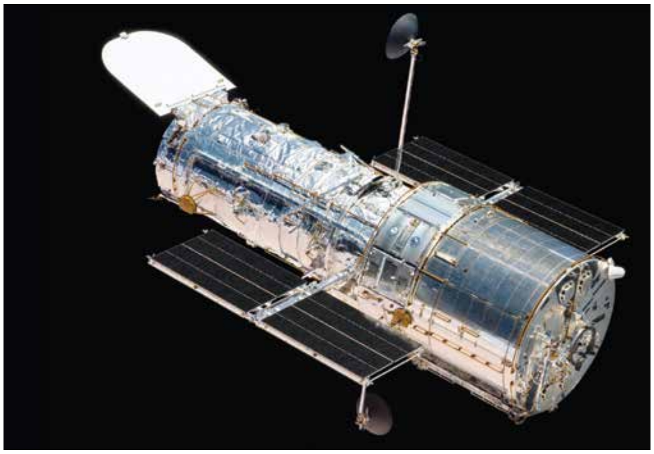


Illustration of the Solar Probe Plus.

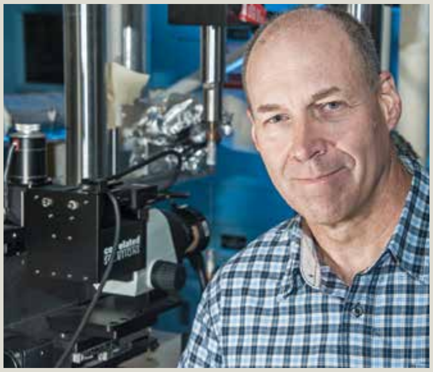


The Hubble Space Telescope after the final servicing mission in 2009.

Hubble Space Telescope Observatory System Reliability

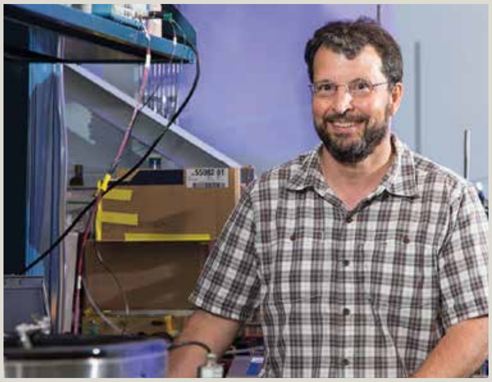
The Hubble Space Telescope (HST) Program requested an evaluation of the current reliability model used to determine critical system component reliability as a function of time. Their current reliability model predicts a chance of one or more major component failures from present time through the telescope's predicted end-of-life. The program believes the current model does not represent the observatory configuration and/or contains overly conservative assumptions. The reliabilities of key subsystems are not adequately modeled due to repairs or improved knowledge, and some subsystems have outperformed expectations. The NESC assembled independent subject matter experts knowledgeable in reliability modeling and HST subsystems to perform an independent evaluation.

Our Extended NESC Team



Dave Dawicke, AS&M Inc.

Dr. Jim Ross, ARC



Dr. John Graf, PE, JSC

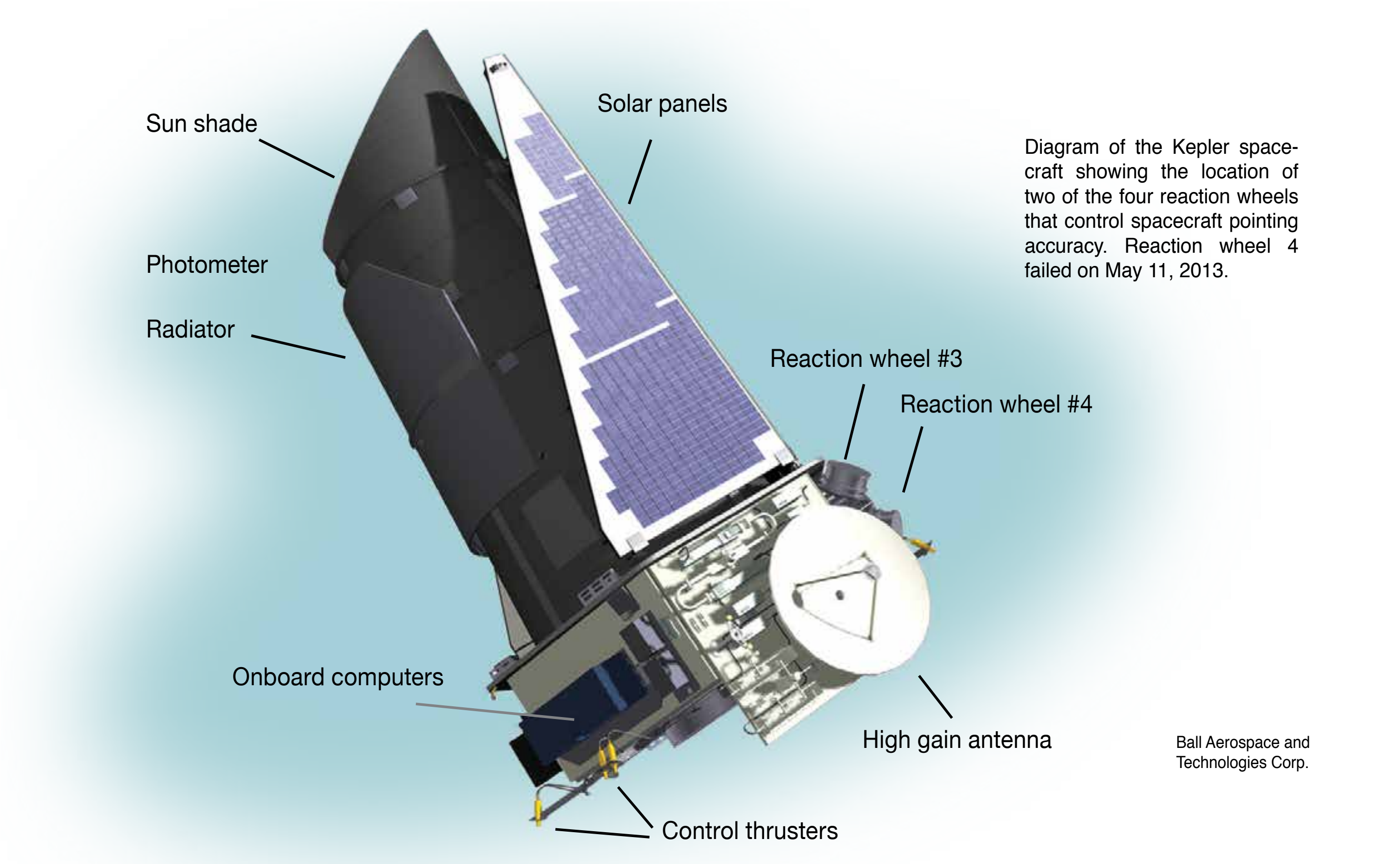


Diagram of the Kepler spacecraft showing the location of two of the four reaction wheels that control spacecraft pointing accuracy. Reaction wheel 4 failed on May 11, 2013.

Ball Aerospace and Technologies Corp.

Assessment of Reaction Wheel Performance on NASA Missions

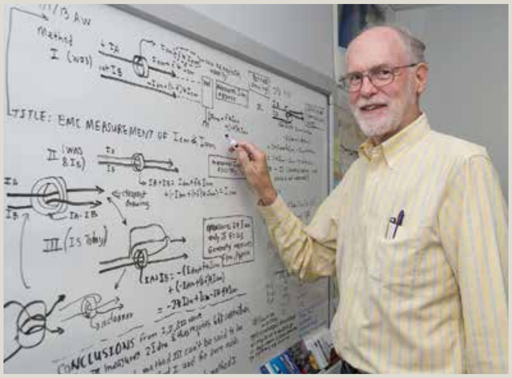
Reaction wheel assemblies (RWAs) are used to orient and stabilize spacecraft and point scientific instruments. The Kepler spacecraft recently suffered the loss of two of its four RWAs, which is now preventing it from performing its primary mission to identify Earth-like planets. As a result of these failures and those on other spacecraft, the NESC formed a team of mechanical systems and guidance, navigation, and control experts from across NASA and industry with the goals of identifying operational best practices promoting long RWA life and identifying actions that might be employed to recover RWAs in distress. Hybrid operations, where fewer than the nominal number of RWAs are available, will be considered to extend mission life. A review of various commercially available RWA designs will also be performed.

Kepler Spacecraft Hybrid Attitude Control Concepts Evaluation

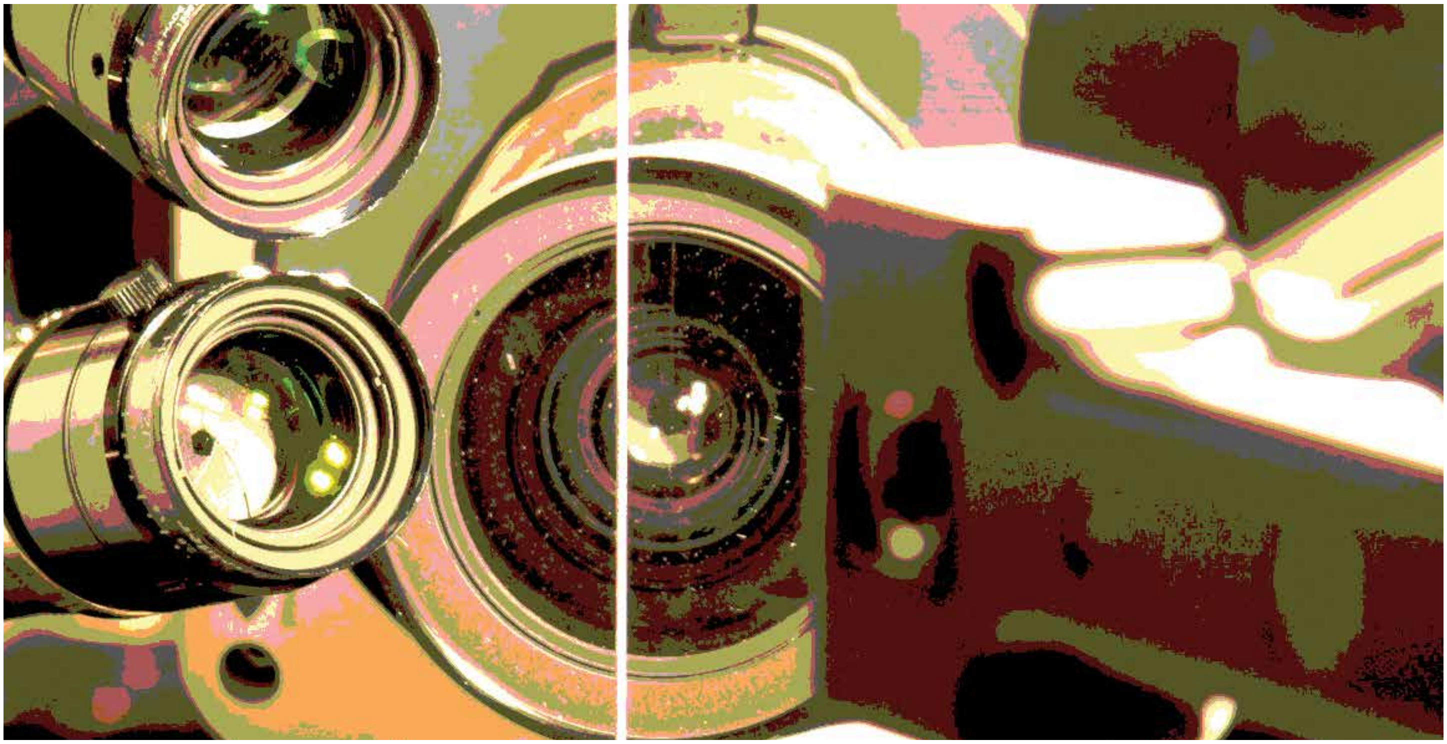
At the request of the Science Mission Directorate, the NESC led the NASA Spacecraft Hybrid Control Workshop with participants from NASA, JPL, industry, and nonprofit laboratories. Shortly after the workshop, the second of four reaction wheels aboard the Kepler spacecraft failed, causing the loss of its primary mission to search for Earth-like planets. The NESC was requested to support the Kepler Project with the identification, development, and technical evaluation of hybrid attitude control concepts, where attitude control is provided using thrusters in concert with the remaining operational reaction wheels. This could potentially lead to a repurposed Kepler science mission using the two remaining nominally functioning reaction wheels.

Dick Powell, AMA

Dr. Judith Jeevarajan, JSC



Albert Whittlesey, JPL



ELV Payload Pyrovalve Reliability

The NESC assessed parent-metal pyrotechnic-operated valves (pyrovalves) used on Expendable Launch Vehicle (ELV)-launched spacecraft such as the Mars Science Laboratory (MSL). The team concentrated on risk uncertainties and whether NASA Payload and Air Force Range Safety Command requirements for ELVs were satisfied when flying these valves. The team evaluated pyrovalve reliability in controlling hazardous gases and fluids and found that if the assessment design guidelines were followed, the pyrovalves would meet or exceed all applicable requirements. Based on these findings, the Air Force Space Range Safety Command approved the use of the MSL pyrovalve configuration on Mars 2020 and future spacecraft launched by the ELV Program.

Launch of the MSL rover from Cape Canaveral Air Force Station on an Atlas V ELV.

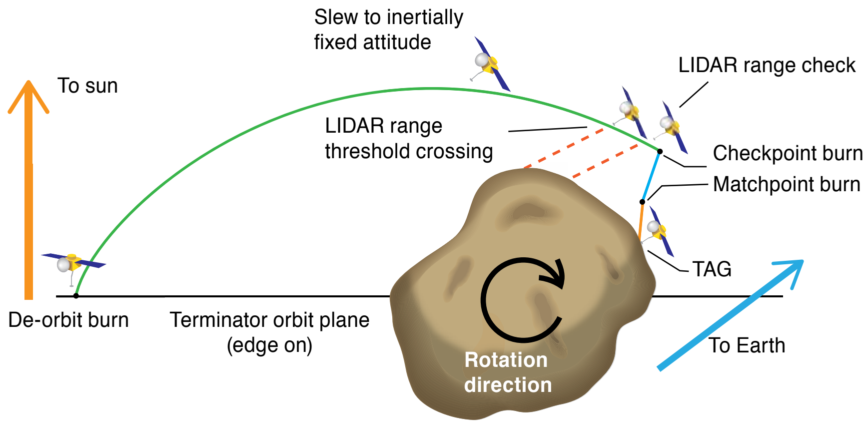
John Anderson (left) and Steve Woods (right) of WSTF discuss a pyrovalve stress analysis, performed to evaluate safety margins.

Our Extended NESC Team

(Left to right) Steve Harvison, Andrew Prince, and Ben Davis, MSFC

Bharat Chudasama, JPL

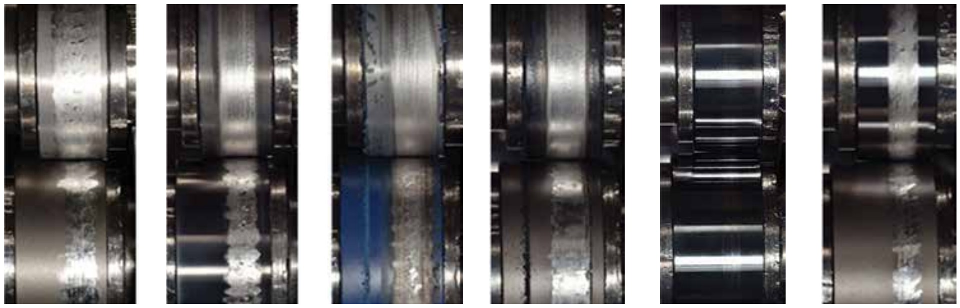
Dr. Rebecca "Becky" MacKay, GRC



TAG trajectory sequence following the de-orbit maneuver with LIDAR measurements.

Asteroid Touch-and-Go Onboard Navigation Capability Assessment

The Origins Spectral Interpretation Resource Identification Security – Regolith Explorer (OSIRIS-REx) mission is planned for 2016 to study an asteroid and return a sample to Earth. The OSIRIS-REx spacecraft will be required to perform a guided touch-and-go (TAG) approach to and engagement with the asteroid using a light detection and ranging (LIDAR) sensor as the primary navigational aid for the two critical checkpoint and matchpoint delta-V maneuvers. The spacecraft will use an optical navigation natural feature tracking (NFT) backup to the baseline LIDAR guided TAG. This system employs an NFT scheme that uses imagery data of the asteroid surface to map specific natural features and identify optimal sampling sites. Members of the NESC's Autonomous Rendezvous and Docking Community of Practice will perform an independent assessment of the maturity of the NFT optical navigation capabilities and identify any technical gaps or weaknesses.



Roller surface wear results from life-cycle testing.

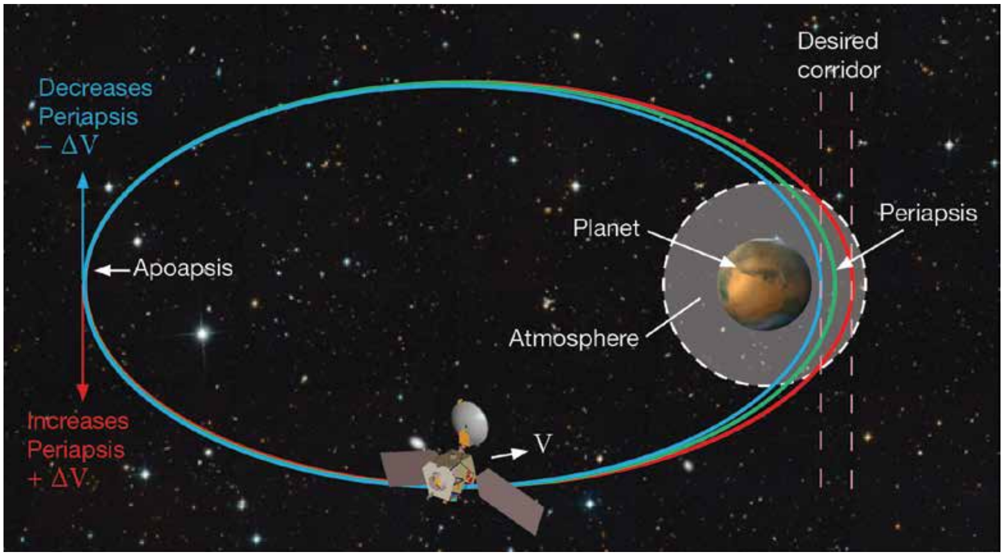
James Webb Space Telescope NIRSpec Microshutter Alternate Materials and Coatings

The NESC provided an independent assessment of the James Webb Space Telescope (JWST) Near Infrared Spectography (NIRSpec) microshutter subsystem life test results. The mechanism met the life requirement, but debris was observed during post-test inspection. The NESC team evaluated the effect of contamination on the instrument's performance and conducted a series of life-cycle tests to determine when debris generation begins during the life of the unit. The test results led to a second phase assessment where the NESC performed a series of tests to evaluate alternate materials and coatings for the mechanism. Recommendations were provided to the JWST Project and implementation for the flight design is underway.

Dr. Eugene Ungar, JSC

Davin Swanson, The Aerospace Corporation

(Left to right) Steve Hornung, MEI Technologies; Regor Saulsberry, WSTF; Steve McDougle, MEI Technologies; and Tony Carden, ERC, Inc.



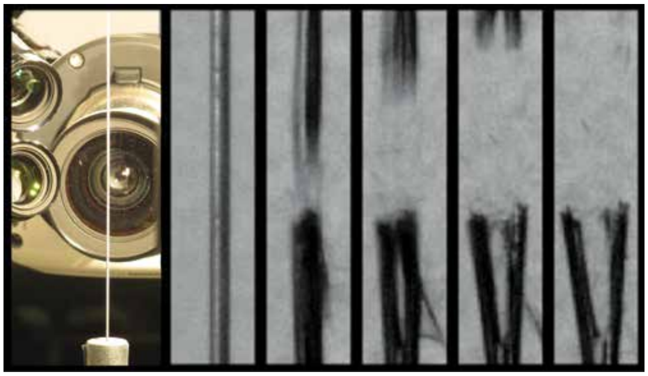
Autonomous ΔV changes at apoapsis enable aerobraking.

Development of an Autonomous Aerobraking Capability for NASA Missions

NASA uses aerobraking to reduce the fuel required to deliver a spacecraft into orbit around a planet or moon with an atmosphere. An NESC team has been developing the capability to allow the spacecraft to aerobrake autonomously, thus reducing risk and costs during aerobraking. Recent efforts focused on improving the Autonomous Aerobraking Development Software (AADS), conducting trade studies, and evaluating AADS performance. Results show that AADS is able to reproduce the safe aerobraking phases used for Mars Odyssey and Mars Reconnaissance Orbiter and that the AADS algorithms are ready to be considered for application to future missions that use aerobraking.

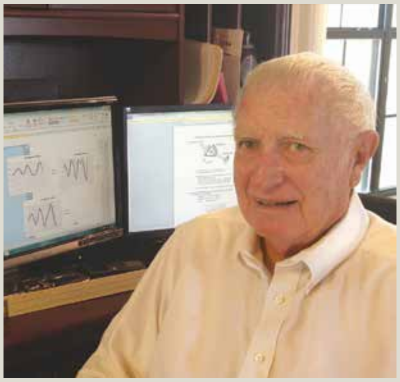
Carbon Fiber Strand Failure Characterization

Carbon fibers are used to provide tensile strength and structural integrity when used in an overwrap for a composite overwrapped pressure vessel. Failure mechanisms of graphite composite strands are not well understood because failures progress rapidly and individual carbon fibers are only 0.03 inches in diameter. Tension failures are highly dynamic and occur without significant warning of impending failure. Plus, the test specimen is often destroyed in the failure process, leaving few clues. The NESC is using high-speed cameras and photogrammetry to locate failure initiation points along the strands. This technique successfully identified a localized high-strain region that developed shortly before failure. By reliably pinpointing failure initiation, damage areas, and failure progression can be better characterized.



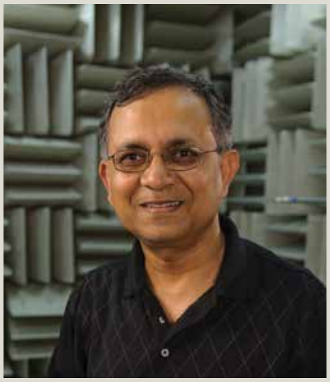
Breaking graphite strand captured at 64,000 frames per second.

Our Extended NESC Team



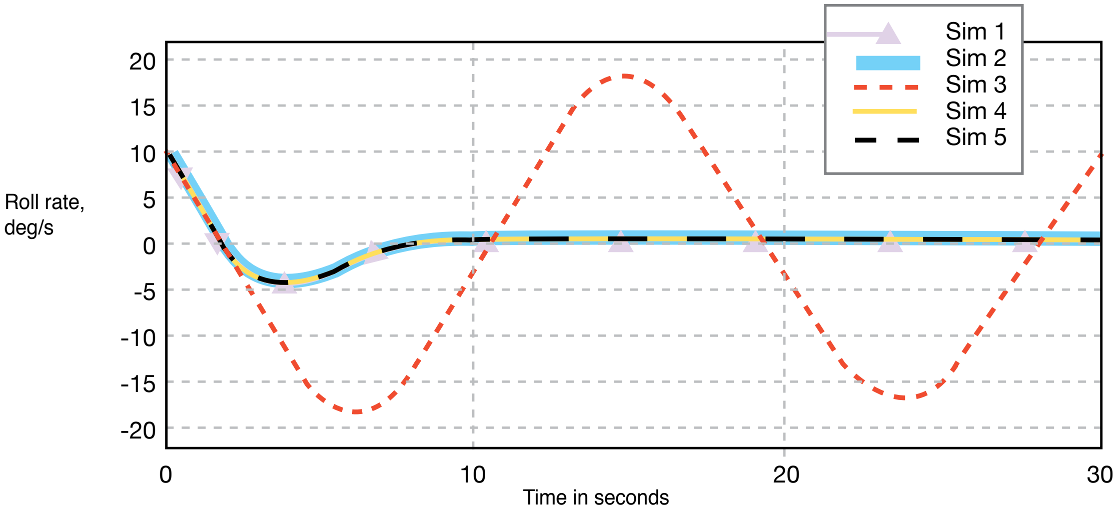
Bass Redd, Nielsen Engineering and Research

Roy Hampton, Owl Analytics, LLC



Jayanta Panda, ARC

Dr. Immanuel Barshi, ARC



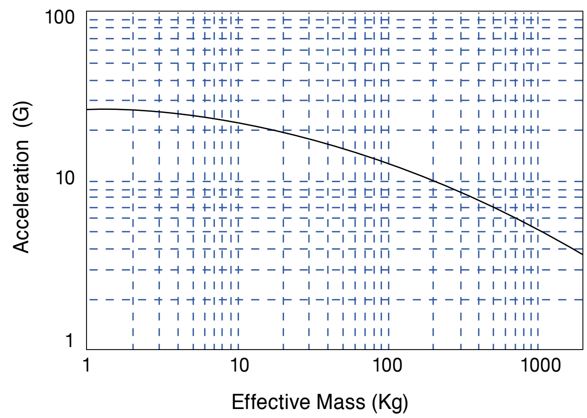
Comparisons between five NASA simulations. The outlier simulation (Sim 3) was subsequently corrected and matched the others.

Development of Verification Data for Flight Simulations

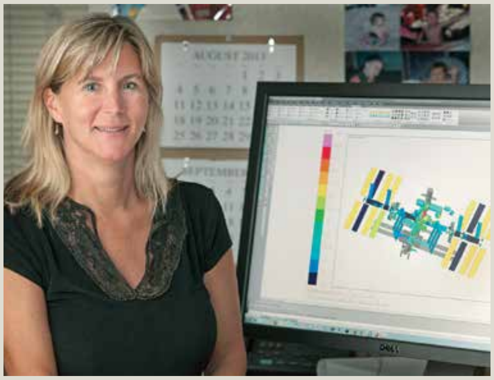
Flight simulations are increasingly used to aid in design and flight prediction of aerospace vehicles. Independently developed tools are typically used to perform these simulations, and this independence provides valuable cross-checking between project partners. Sometimes the fundamental aspects of the simulation frameworks are implemented differently, which can lead to disagreement in predictions. This assessment will provide flight trajectories for simple aircraft and spacecraft models using several NASA simulation tools. These trajectories will serve as test cases for other simulation frameworks used by NASA and others and are expected to result in higher confidence in flight simulation predictions.

Modal Mass Acceleration Curve Loads Analysis Methodology

The NESC initiated a knowledge capture task to document the Modal Mass Acceleration Curve (MMAC) loads methodology so that it could be available across NASA and industry. The MMAC was developed and in use at JPL for more than 25 years. It provides a bound for the acceleration a spacecraft mode may expect to see during launch. The maximum acceleration is a function of the mode's effective mass and decreases with increasing mass. The MMAC can be developed from previous coupled loads analyses and is unique for each launch vehicle. In the MMAC loads analysis, the MMAC is used to provide a bound for each modal response. The physical loads are then obtained by the root-sum-square of response bounds for all modes of interest.



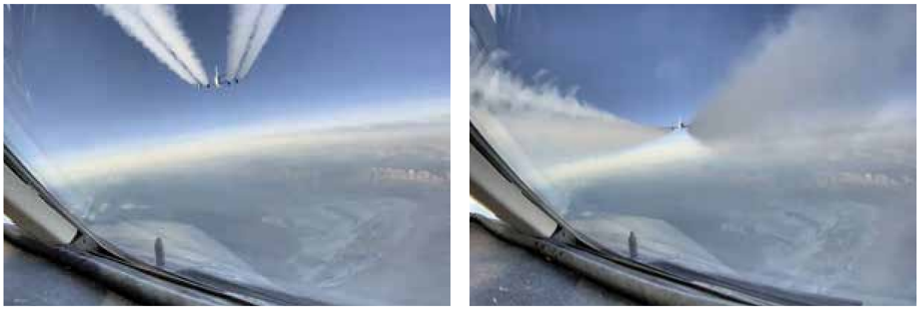
Representative Modal Mass Acceleration Curve.



Ruth Amundsen, LaRC

Tim Crumbley, MSFC

(Left to right) Curt Hanson, James Lee, and Chris Miller, DFRC



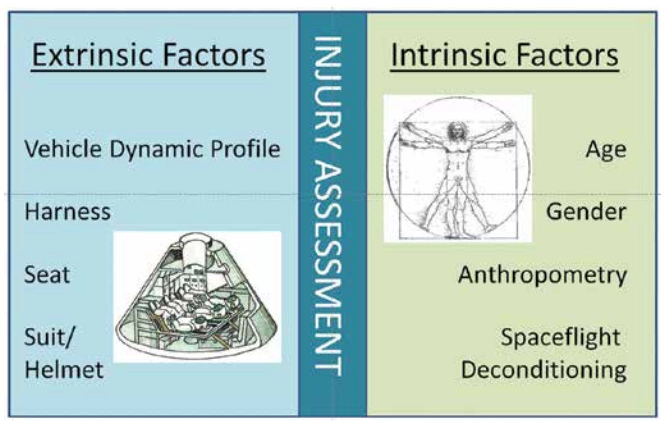
View from Falcon 20 approaching (left) and entering (right) DC-8 exhaust contrail.

ACCESS Flight Test Hazard Mitigation Assessment

The Alternative Fuel Effects on Contrails and Cruise Emissions (ACCESS) research team conducted tests on an instrumented Falcon 20 aircraft flying close behind a DC-8 aircraft at cruise altitude to evaluate airborne biofuels exhaust emission data. Knowing Falcon interaction with the DC-8 trailing vortices could have resulted in structural failure from wake vortex encounter or from loss of control, an NESC team assessed the Falcon structural failure risk. The team reviewed literature on exhaust and wake vortex evolution and lessons learned by other research teams, and also conducted high fidelity loads analyses and 6 degree of freedom trajectory simulations. Specific flight test hazard mitigation actions were identified, and the team made a primary recommendation to conduct pre-experiment flight tests dedicated to developing pilot proficiency in avoiding wake vortices.

Reducing Risk of Injury from Dynamic Loads

The design of future crew transportation systems introduces new challenges to protect crewmembers from injury due to dynamic loads. NASA's Human Research Program requested an independent assessment of the research plan associated with spacecraft occupant protection. Assessment team members included experts in the fields of biodynamics and injury biomechanics from NASA, the National Highway Transportation Administration, the Federal Aviation Administration, and academia. Six main areas were reviewed: occupant protection, definition of acceptable risk, quantification of injury assessment reference values, identification and quantification of deconditioning factors, development of methodologies to allow vehicle design assessment, and identification of countermeasures.



Risk-of-injury factors.

Our Extended NESC Team

Bruce Jackson, LaRC

Dr. Walter Reuter, Idaho National Lab.

Susan Baggerman, JSC

Jeremy Jacobs, JSC

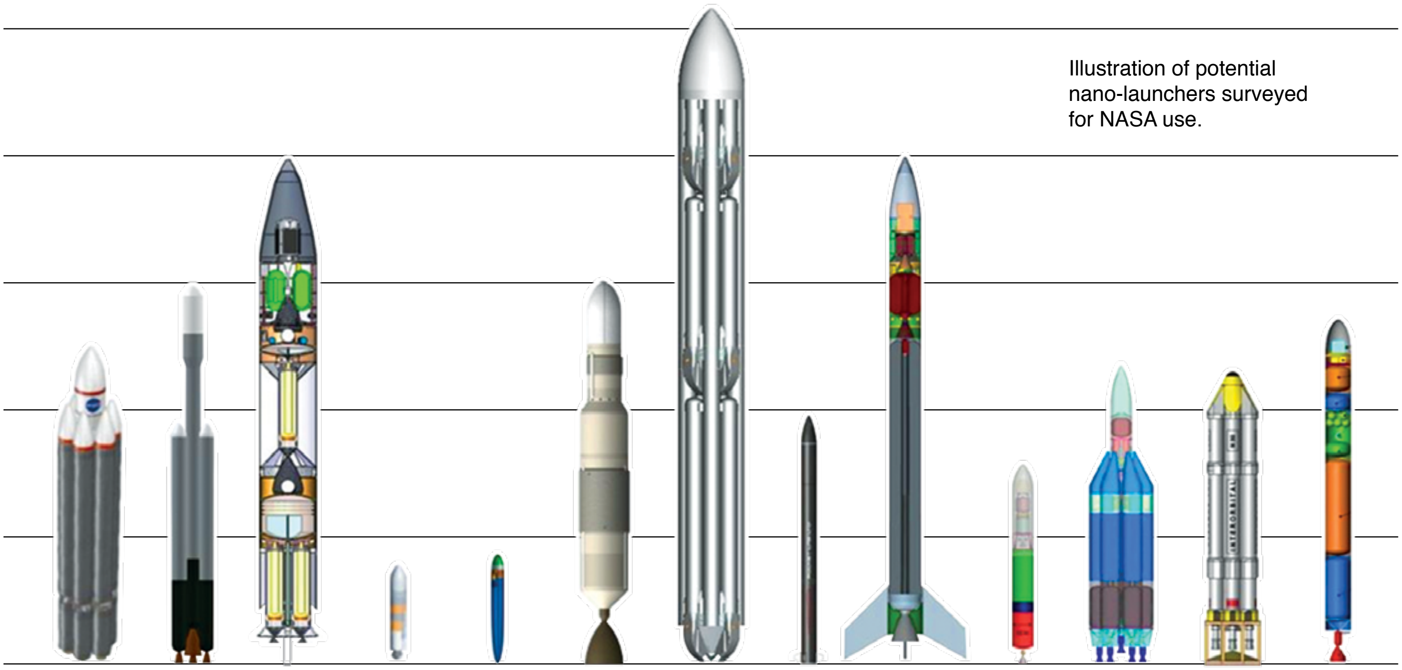


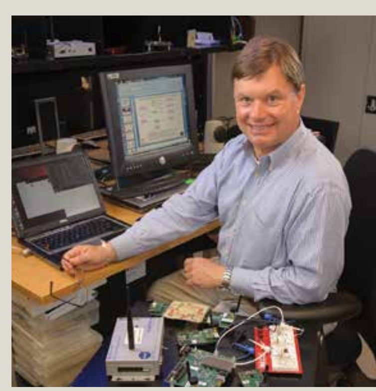
Illustration of potential nano-launchers surveyed for NASA use.

Feasibility Study to Investigate Dedicated Nano-Launcher for NASA Use

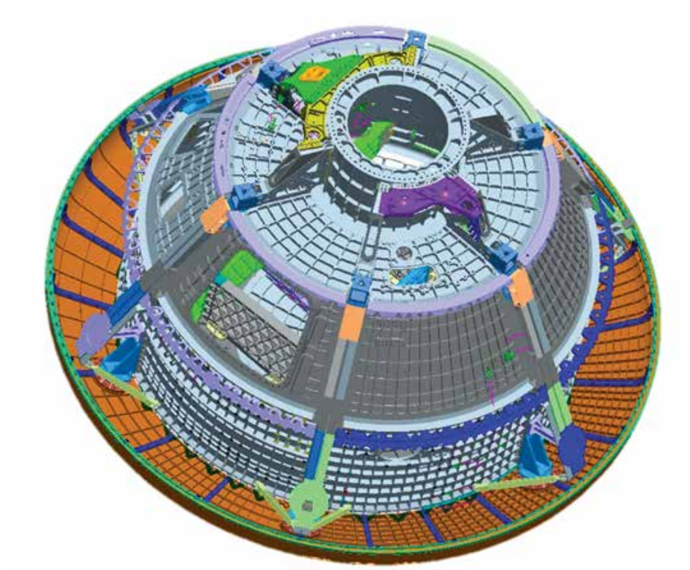
The NESC participated in a study that surveyed 13 developmental nano-launcher systems to identify each system's technical challenges. The study developed options for enabling one or more systems to successfully demonstrate the needed capabilities. The major observation was that while some companies have a reasonable prospect of meeting NASA's cost and initial availability goals, these companies generally are unable to self-finance. However, a NASA-led open-architecture approach could provide a near-term, low-cost operational capability, maintain competition, and provide opportunities for NASA to assist small business entrants into this launcher segment.

David Gilmore, The Aerospace Corp.

(Left to right) Dr. Hon "Patrick" Chan, Allen Parker, Dr. Lance Richards, and Anthony Piazza, DFRC.



Rick Alena, ARC



Conceptual titanium orthogrid heat shield carrier mounted to pressure vessel.

LMCO

Orion crew module for Exploration Flight Test-1.

The NESC Proposes an Alternate Orion Heat Shield Carrier Structural Design

With the aim of carrying astronauts well beyond near Earth orbit to rendezvous with asteroids, the Moon, or Mars, the Orion Multi-Purpose Crew Vehicle (MPCV) spacecraft has no room for extra weight. That is why the engineers and designers of NASA's next-generation spacecraft are finding ways to optimize every single pound that is added to the vehicle and looking at every system for opportunities to shave unnecessary mass. "Mass affects your ability to execute the mission, how far you can go, how long you can stay, and how many people you can take," says Ms. Julie Kramer White, Orion MPCV Chief Engineer.

One area the Orion MPCV Program felt could offer significant weight savings was the heat shield carrier structure. The carrier structure must hold the 16.4-ft diameter heat shield securely to the Orion spacecraft when faced with launch, reentry, and splashdown loads, and temperatures greater than 4,800° F. "The heat shield became the number one item slated for mass reduction activities," says Kramer White. "Nearly 50 percent of mass reductions we achieve will come out of the heat shield. It's very significant."

"The heat shield became the number one item slated for mass reduction activities."

— Julie Kramer White, Orion MPCV Chief Engineer

In late August 2012, Kramer White requested the NESC develop some alternate designs to the structure, with the goal of reducing its overall mass by 25 percent or about 800 pounds.

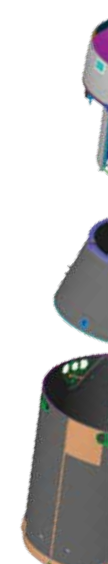
"Because of how much weight was at stake, I thought the NESC was the ideal candidate for an independent look at how to get that mass out," says Kramer White. "They have design, development, and build experience, and we needed to know that a design on paper would make it through to build and not gain a lot of weight. They were ideally situated to help us."

At that time, the baseline design, made of titanium with a composite carbon graphite skin, weighed in at over 3,000 pounds. "It was a very agile design and could be easily manipulated and changed, but the Orion MPCV Program needed to know if it was the most mass-optimum design," says Mr. Michael Kirsch, who led an NESC assessment team to work on alternative designs. The assessment team included members from industry, contractor partners, and NASA Centers including JSC, GSFC, LaRC, and MSFC.

After studying Orion's composite design, the NESC assessment team began developing several alternative concepts including designs that incorporated load sharing with the crew module backbone, replaced the existing wagon wheel stringer design with an H beam configuration, and switched the composite carbon graphite skin to a titanium orthogrid skin.

After discussions with the Orion MPCV Program, the NESC team carried two designs forward for further refinement, and in early February 2013, down-selected to the titanium orthogrid option. "This design was already saving a little over 1,100 pounds," says Kirsch, about 300 pounds beyond the original 800 pound goal. The NESC team began talking with vendors to determine the best manufacturing approach for the titanium orthogrid.

Encouraged by weight savings realized by the NESC team's



Building an assessment team

For several years engineer Jim Jeans, owner of Structural Design and Analysis, Inc., has worked as a NASA subcontractor supporting GSFC on composite design work. With more than 30 years of experience, Jeans was asked by NESC Principal Engineer Mr. Michael Kirsch to join the NESC Orion Heat Shield Carrier Structure Assessment Team.

To build an assessment team, the NESC pulls in discipline experts from across NASA Centers, NASA contractors, industry, and other government agencies, leveraging a broad range of experiences and backgrounds to bring the best possible solutions to problems.

> *"It was all one big team ... Everybody is trying to push the product to the finish line."*
>
> — Jim Jeans, Owner, Structural Design and Analysis, Inc.

"We pull people from across the entire Agency — across the entire country," says Mr. Paul Roberts, an NESC Associate Principal Engineer and heat shield assessment team member. "We go wherever we need to find that knowledge. Once the teams are formed, you can't tell the difference between contractors and civil service or between NASA Centers. We're all just a team focused on a technical issue. It also brings a definite NASA-wide perspective and country-wide perspective to the team."

For Kirsch's team, the diversity and knowledge base was "phenomenal," he says. "The team was very agile and could exploit the opportunities that were revealed during design phase and recover quickly from challenges and setbacks and changes to assumptions that occurred during the design phase."

Putting aside "badges" and "titles," NESC teams focus on the task at hand. "It was all one big team," says Jeans. "Everybody is trying to push the product to the finish line."

This was the third time Jeans had worked with a nation-wide NESC team. "And it worked well," he says. Meeting each morning via web conferencing and chatting anytime via instant messenger meant everyone was always in the loop. And a few times the group got together for a face-to-face meeting.

"It was very productive," adds Mr. James Ainsworth of Collier Research Company. Collier's HyperSizer software helped the team compare structural efficiency of numerous concepts and material systems, and continues to help with sizing optimization. "We all worked remotely from our offices all over the United States. Kirsch was diligent about having team meetings every day and that we all stayed in communication. We were all treated as part of the team — all privy to same information. It was a good team dynamic," Ainsworth says.

Roberts says there are other advantages to NESC's approach to developing assessment teams. "Programs come to us with problems that are very difficult, so the work we get is challenging. You personally learn a lot, and you work with all these different people, ladies and gentlemen who have tremendous knowledge and ability. You have this network to find whatever you need, whatever it is. That network is what gives an NESC team its real strength."

alternate design, the Orion baseline design was undergoing revisions as well and had significantly reduced its mass. So, in March 2013, the Orion MPCV Program asked for an apples-to-apples comparison between the revised baseline design and the NESC titanium orthogrid design. "For 10 weeks, the two designs were compared side by side, assumptions aligned, and adjustments made so that the two could be compared with a similar set of rules," says Kirsch.

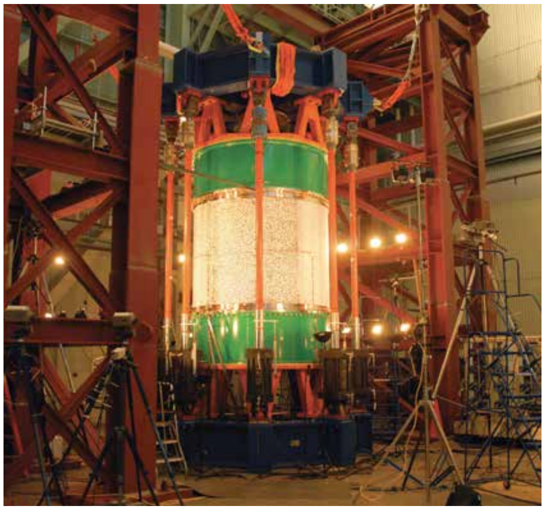
By the end of May, the NESC design had reached a 1,300 pound weight reduction and the baseline design had undergone a significant weight loss as well — about 1,100 pounds. Weight savings, however, were not the only factors being considered. To be ready in time for Orion's first operational mission expected in 2017, the NESC design required additional financial commitments for material procurement and manufacturing and had a tight schedule for construction. The baseline design, which was already built and tested, offered fewer manufacturing risks, little financial commitment, plus a shorter timeline to delivery. "That became a significant discriminator in the decision of which heat shield to select for the program," says Kirsch.

Illustration of Orion MPCV major components.

"In the end we wound up staying with the composite derivative, versus the titanium option that the NESC was proposing," says Kramer White. "But through the NESC pushing and questioning assumptions, it really drove the process of competition between the two designs. It was that interaction with the NESC that allowed the fabulous results we got, and need as a program, to close our mission capture."

"The NESC's alternative design promoted the aggressive redesign on the current baseline and the net result was a pretty significant reduction of overall heat shield mass," agrees Kirsch. The baseline design will also feature NESC risk reduction solutions and test approaches developed during the assessment.

"Whether I need a big trade study or I'm just calling and asking for their experience or guidance, or using them as a sounding board, the NESC is a good place to go to get objective advice," adds Kramer White. "We'll be talking about similar activities with the NESC into the next year."

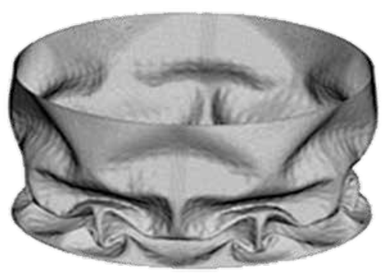


Ares V-style shell undergoing testing at MSFC in 2009.

Buckling of spare shuttle external tank during 2011 test.

NESC Shell Buckling Investigation Continues to Make Gains

Sitting on Dr. Mark Hilburger's desk are several empty aluminum drink cans. These thin-walled cylinders, once filled with soda, have become valuable props in his many discussions on NASA's shell buckling knockdown factors (SBKF). Holding a partially collapsed can, Hilburger can point to its buckled shell and explain how knockdown factors account for the unknown variability in the buckling loads of cylinders, from soda cans to rocket boosters.



Finite element model of a buckled shell.

"It looks like a simple cylinder," says Hilburger. "But structurally speaking, its buckling behavior is very complex." It took decades, from the 1930s to the 1960s, to figure out this unique buckling behavior, and the knockdown factors for shell buckling established by Apollo-era engineers are still in use today by NASA and by industry worldwide.

"We're fostering a concept that is long overdue."

Clint Cragg
— NESC Principal Engineer

Those 40-year-old knockdown factors, however, were developed with conservatisms warranted by the technology of the time and are likely adding unnecessary weight to today's modern aerospace structures. "Today the emphasis is to minimize mass to maximize payload," says Hilburger. He adds that finding ways to reduce the weight of launch vehicles is critical for current and future space missions headed to Mars, near-Earth asteroids, and beyond.

That was the catalyst behind Hilburger's proposal to develop and implement new shell buckling knockdown factors. Since the spring of 2007, he has led an NESC assessment team set on leveraging advanced computer modeling, testing, and analysis capabilities to update those knockdown factors so that new launch vehicles, such as NASA's Space Launch System (SLS), might reap the benefits of significant weight savings and reduced risk.

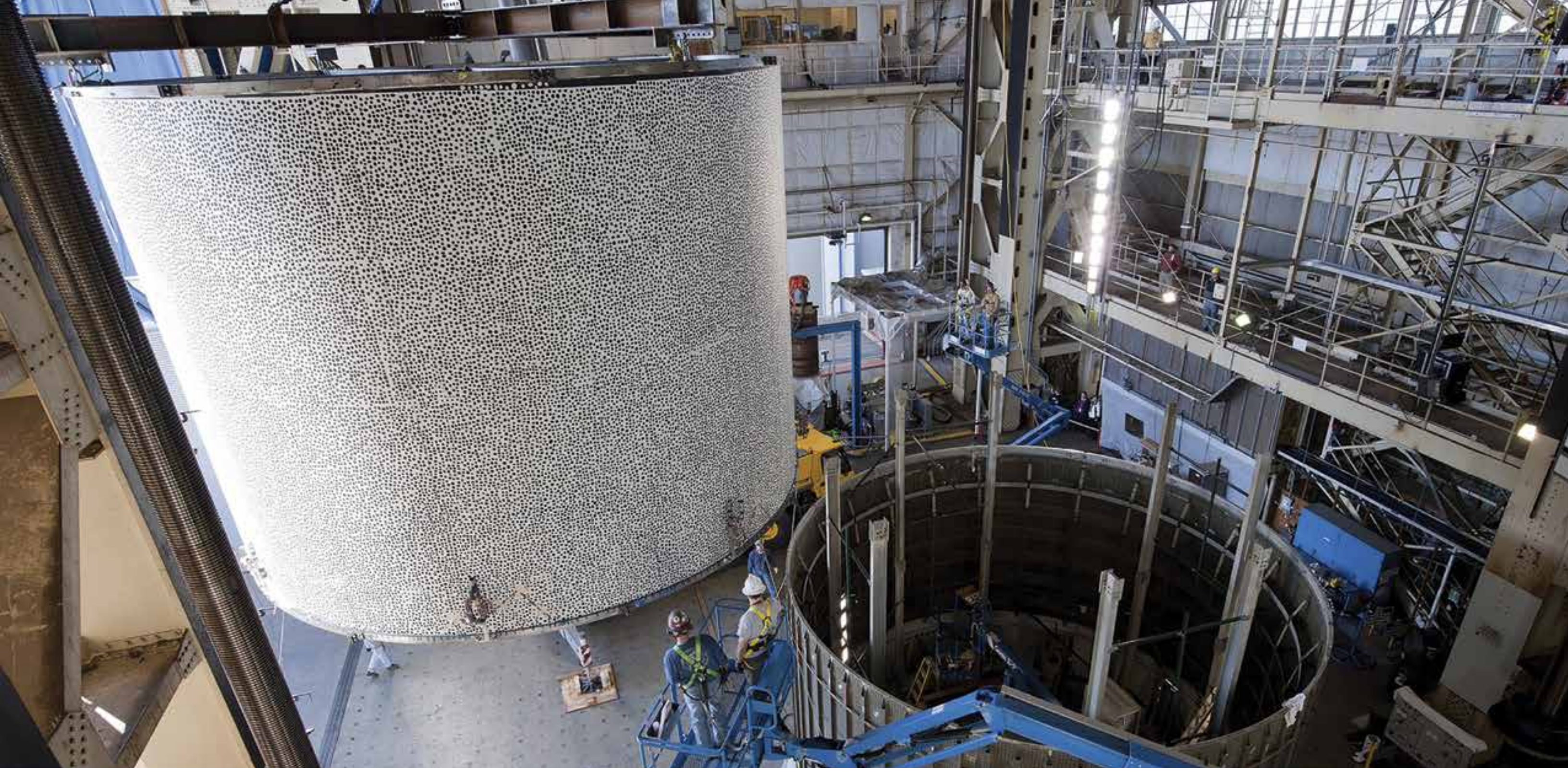
"We're fostering a concept that is long overdue," says Mr. Clint Cragg, NESC Principal Engineer working with the SBKF Team. The NESC recognized the potential benefit for NASA and industry programs and as a result has provided technical and program support, peer reviews, and advocacy for the SBKF Team. Cragg explains that new knockdown factors could shave hundreds of pounds from launch vehicles, which could reduce costs for getting into orbit, allow the option to add more payload, and increase the potential for traveling further into space.

After nearly 5 years of work, the NESC SBKF Assessment Team reached a significant milestone late last year. The team's newly-developed knockdown factors were brought forward by the Boeing Corporation, NASA's partner in the design of SLS, in its preliminary design review of the SLS core stage.

A look back

New knockdown factors will result in fundamental changes to the development of current and future spacecraft, so buy-in from the NASA community was crucial. "We're trying to change a longstanding design guideline that everyone is comfortable with," says Hilburger. To be successful in that endeavor required collaboration on a major scale. Soon after he initiated his proposal to develop new knockdown factors, Hilburger, who at the time was working with the Ares Program, began working with engineers, designers, and manufacturing experts.

"It was absolutely key to have them as part of the process



Section of space shuttle external tank covered in photogrammetry targets being mounted in shell buckling test fixture at MSFC.

to truly understand their work environment and see how they design," says Hilburger. That team concept carried through with workshops, meetings with chief engineers from multiple NASA Centers, and regular brainstorming sessions with potential end users of new knockdown factors. "This only made the whole project stronger," adds Hilburger.

As the team transitioned to developing knockdown factors for the SLS Program, collaboration continued with design trade studies and partnerships with contractors and the SLS Advanced Development Office.

"We were very excited," says Ms. Courtney Flugstad, Deputy SBKF Assessment Manager, about the SLS Program adopting the new knockdown factors. "It shows all the hard work everyone has put in, and that what we've been doing is worthwhile and appreciated."

From the development of new factors for its orthogrid- and isogrid-stiffened tanks and dry structure, the SLS Program has been seeing results. "As they reduce conservatism, they are making their designs lighter by using less material, which results in a reduction of material costs," says Hilburger. Additional benefits beyond mass savings are likewise coming to light. "The SLS Program is also focused on reducing design time, and the new factors provide certain structural detail information earlier in the design process. That directly translates into a shorter design schedule," he says.

Hilburger cites an example. "The barrels used to make tanks for SLS are actually made of several curved panels or arc segments that are welded together. Each weld land is an important structural feature that wasn't originally accounted for in preliminary designs. One of the new knockdown factors we've produced accounts for weld lands and allows them to be incorporated early in the design process."

"The science that comes from these tests is amazing ... It's invaluable for grounding our computer simulations."

— Dr. Mark Hilburger

Along with the NASA community, the NESC SBKF Assessment Team has been keeping the commercial spacecraft industry apprised of new developments. "All of the companies I have spoken with are very excited and want to work with us," says Flugstad.

A look forward

Starting in the fall of 2013, the SBKF Team performed another round of testing at MSFC, running additional subscale tests on 8-foot diameter cylinders and another full-scale test on a 27-foot diameter cylinder. Similar to the team's previous tests, which combined internal pressure and compression loads, the new tests subject the cylinders to a bending load to localize the buckling on one side.

"The science that comes from these tests is amazing," says Hilburger. "It's invaluable for grounding our computer simulations." From there, the team will be focused on analyzing the data and developing a final and formal set of knockdown factors. "We're also focusing heavily on documentation and archiving, so that 10 or 20 years from now, people can look back and see that the pedigree of data is well established. It's an important part of the process."

"This has been an amazing opportunity," adds Hilburger. "Once everyone warmed up to the fact that what we were doing was founded in good science, they were comfortable with the connection between the fundamental work of the Apollo era and how we built a logical path to new knockdown factors. Now we can implement them and safely say it is a new alternative design recommendation."

On visits to the NASA Centers, NESC Director Ralph Roe, Jr. (center) discussed lessons learned from the Columbia accident, shown with KSC staff.

Sharing Our Knowledge

Just as important as tackling NASA's most challenging engineering and technical issues is sharing what has been learned along the way.

In the last decade, the NESC has taken the knowledge it has gained over the course of more than 500 technical activities — the engineering data gleaned from countless independent tests and analyses — and shared it with NASA Centers and contractors, industry and academia, and most importantly, the next generation of engineers. That knowledge sharing comes in many forms, from technical reports to face-to-face workshops to online videos including webcasts.

The need for more in-depth, comprehensive reporting of engineering analysis and risk assessment was brought to light during the Columbia Accident Investigation. As a result, the NESC generates detailed technical reports with every NESC assessment. Particularly significant and noteworthy data are then turned into one-page, easily consumable technical bulletins or added to lessons learned databases, which have a broader reach into technical communities.

Often NASA Technical Fellows take a more educational approach, reaching out via the NESC Academy, a website that currently features more than 180 short, informative videos. NESC Academy videos have received more than 8,000 views since the Academy's inception and offer the audience a virtual classroom experience on a myriad of technical topics. Hundreds more are still in the developmental stages. The NESC also produces live webcasts by its Technical Discipline Team members, where viewers may send in questions to the presenter during the live broadcast. The webcasts feature topics relevant to current NASA issues and challenges.

More personal, face-to-face knowledge sharing opportunities also occur during the year through workshops, forums, and technical interchange programs. NASA Technical Fellows from varied disciplines organize and host these regular events.

The NESC also invites engineers in the early stages of their careers to join in on its larger assessments, another vital part of the knowledge share effort. Through its "Early Career Participant" initiative, the NESC brings early career engineers together with seasoned engineers, giving them hands-on experience in solving challenging problems, which they can then take back to their organizations and carry forward in their careers. The benefits to the Agency are broad reaching as these early-career engineers bring fresh perspectives to technical activities, and the

Knowledge products

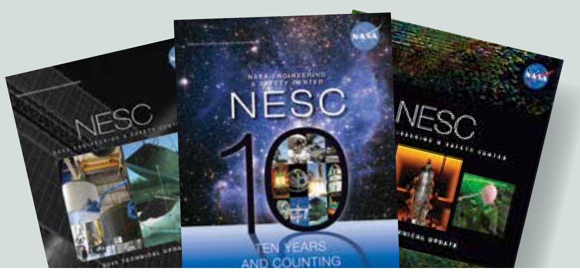
NASA NEN
NASA Technical Fellows share knowledge and lessons learned through their communities of practice.
nen.nasa.gov

NESC ACADEMY
An online learning site that uses webcasts and videos for sharing technical expertise and experiences through spoken word and storytelling, available at **nescacademy.nasa.gov.**

TECHNICAL BULLETINS
Sharing of new engineering knowledge gained through testing and analysis, available from **nesc.nasa.gov.**

Top Ten Viewed Lessons

1. Fundamentals of Aircraft Engine Control
2. High Voltage Power Supply Design Workshop, Part 1 - Day 1
3. Fundamentals of Spacecraft Attitude Control
4. Fundamentals of Launch Vehicle Flight Control System Design
5. High Voltage Power Supply Design Workshop, Part 1 - Day 2
6. Fundamentals of Aircraft Flight Control
7. Fundamentals of Deep Space Mission Design
8. The Evolution of Guidance, Navigation, and Control in Mars Entry, Descent, and Landing
9. Fundamentals of Kalman Filtering and Estimation
10. Metal Fatigue, Part 1



TECHNICAL UPDATES
Yearly summaries of NESC technical activities including lessons learned, available from **nesc.nasa.gov.**

expertise of veteran engineers is securely captured for future generations.

Along similar lines, some forums are designed specifically to benefit and train the next generation. The 2013 Structures, Loads, and Mechanical Systems (SLaMS) Young Professionals' Forum offers early-career engineers a chance to network with Agency experts to share their ongoing work and get valuable feedback.

The NESC also contributes to the NASA Engineering Network (NEN), an online space for communities of practice (COPs), led by NASA Technical Fellows, to collaborate and share all manner of experiences unique to individual COPs. The NEN is not only a lessons learned database, but a vast network that connects engineers with multiple information sources, and allows them to interact with their NASA Technical Fellow, subject-matter experts, and peers.

Whatever the approach, NESC knowledge sharing brings the data gathered in the field to the people it will benefit most, when, and how they need it. And it securely captures that knowledge for generations to come.

On a webcast for the Virtual PM Challenge, NESC Director Ralph Roe, Jr. (center) discussed lessons learned from the Columbia accident along with NESC Deputy Director Tim Wilson (left) and NASA Associate Administrator Robert Lightfoot.

2013 NESC Honor Award Recipients

(Left to right) David Ordway (MSFC); Brent Evernden (JSC); Gerardo Ortiz (JPL); Robert Maddock (LaRC); William Johnston (Science and Technology Corporation); Dwayne Morgan (WFF); Sotiris Kellas (LaRC); Regor Saulsberry (WSTF); Patricia Howell (LaRC); Rick Barton (Nielson Engineering and Research, Inc.); James Jeans (Structural Design and Analysis, Inc.); William Benson (KSC); Geoffrey Vining (Virginia Tech); Stephen McDougle (MEI Technologies, Inc.); Ralph Roe, Jr. (NESC Director/presenter); Michael Mendenhall (Nielson Engineering and Research, Inc.); Judith Jeevarajan (JSC); Paul Munafo (Teledyne Brown Engineering); Jeremy Kenny (MSFC); Robert Button (GRC); James Heineck (ARC); Lawrence Green (LaRC); Amri Hernandez-Pellerano (GSFC); David Coote (SSC); James Ross (ARC); Gregory Carr (JPL); Yuan Chen (LaRC); Lorie Grimes-Ledesma (JPL); Pat Forrester (NESC Chief Astronaut/presenter); Gloria Yamauchi (ARC). **Not pictured:** James Ainsworth (Collier Research); Mariah Champagne (KSC); and Richard French (JPL).

Recognizing those who Demonstrate a Commitment to a Strong Safety Culture

We have worked to cultivate a safety culture focused on engineering and technical excellence, while fostering an open environment. Each year we recognize those who demonstrate a commitment to a strong safety culture through their leadership, behavior, and expertise.

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 prevailing engineering truths.

Sotiris Kellas
In recognition of technical excellence in the professional and persistent pursuit of technical risks associated with the Orion Avcoat material test methods and by identifying and demonstrating a viable alternative with improved results

James C. Ross
In recognition of technical excellence in identifying high uncertainty in predicting the separated flow aerodynamics of entry capsules and executing a comprehensive test campaign to characterize these flows

NESC Leadership Award

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

Robert M. Button
In recognition of outstanding technical leadership of the Extravehicular Mobility Unit Lithium Ion Battery Assessment

Yuan Chen
In recognition of outstanding technical leadership of the Electrical, Electronic, and Electromechanical Commercial Off-The-Shelf Parts Case Study for the Commercial Crew Program

Brent A. Evernden
In recognition of outstanding technical leadership of the mechanical design of the NASA Engineering and Safety Center Titanium Orthogrid Alternate Heat Shield Carrier

Amri I. Hernandez-Pellerano
In recognition of outstanding technical leadership of the International Space Station Plasma Contactor Unit Utilization Plan Update Assessment

James W. Jeans
In recognition of outstanding technical leadership of the structural analysis and design of the NASA Engineering and Safety Center Titanium Orthogrid Heat Shield Carrier Structure

Dwayne R. Morgan
In recognition of outstanding technical leadership of the Ice Cloud and Land Elevation Satellite Advanced Topographical Laser Altimeter System Instrument Beam Steering Mechanism Quick Reaction Assessment

Regor L. Saulsberry
In recognition of outstanding technical leadership of the Expendable Launch Vehicle Payload Pyrovalve Reliability Assessment Team to successful conclusion and achievement of a value-added result for the Mars 2020 Program

NESC Engineering Excellence Award

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

James Ainsworth
In recognition of engineering excellence in the structural sizing on the NASA Engineering and Safety Center Titanium Orthogrid Heat Shield

Gregory A. Carr
In recognition of engineering excellence in support of the independent review of the Space Launch System electrical power system

Richard T. French
In recognition of engineering excellence in the development and implementation of the Thermal Performance Data Services Module; an Agency archive for historical and future thermal protection system performance data

Lawrence L. Green
In recognition of engineering excellence in the development of analytical techniques resulting in improved reliability predictions for the Orion Multi-Purpose Crew Vehicle Heat Shield

James T. Heineck
In recognition of engineering excellence in the development and implementation of a unique Particle Imaging Velocimetry capability in the NASA Ames Unitary Plan Wind Tunnel

Patricia A. Howell
In recognition of engineering excellence in the application of X-ray computed tomography to characterize damage progression in advanced materials used in the Orion Launch Abort System

Judith A. Jeevarajan
In recognition of engineering excellence in the support of NASA and industry efforts to understand and resolve lithium ion battery incidents

William M. Johnston
In recognition of engineering excellence in developing and conducting high priority Orion Avcoat material tests for the NASA Engineering and Safety Center

David O. Ordway
In recognition of engineering excellence and project leadership in the formulation and execution of the Pyroshock Characterization of Composite Materials Independent Assessment

G. Geoffrey Vining
In recognition of engineering excellence and dedication to continuously improve and stretch boundaries in mathematical analysis of real data and efficient test planning in support of the NASA Engineering and Safety Center

Gloria K. Yamauchi
In recognition of engineering excellence in the development, integration, and application of a three-dimensional Particle Image Velocimetry instrument to the Orion wake characterization wind tunnel test

NESC Administrative Excellence Award

Honors individual accomplishments or contributions that contributed substantially to support NESC's mission.

Mariah K. Champagne
In recognition of exemplary performance and sustained, dedicated support to the NASA Engineering and Safety Center as the Business Point of Contact for the Kennedy Space Center

NESC Group Achievement Award

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

Autonomous Aerobraking Development Team
In recognition of the successful development and demonstration of Autonomous Aerobraking in an operational readiness test

High Fidelity Data Acquisition System Development Team
In recognition of outstanding contributions to design, development, fabrication, and testing efforts supporting the High Fidelity Data Acquisition System Project

E-1 Test Facility Blast/Acoustic Effect Mitigation Tools Assessment Team
In recognition of tireless dedication and innovative solutions on the highly complex NASA Engineering and Safety Center E-1 Test Facility Blast/Acoustic Effect Mitigation Tools Assessment

Electrical, Electronic, and Electromechanical Parts Case Study Team
In recognition of outstanding contributions in support of the possible use of commercial off-the-shelf electrical, electronic, and electromechanical parts in critical human space flight applications

Continued next page

NESC Core Team members at the 2013 NESC Honor Awards Ceremony.

Continued from previous page

NESC Group Achievement Award

Expendable Launch Vehicle Payload Pyrovalve Reliability Team
In recognition of outstanding contributions in conducting a comprehensive assessment to evaluate the reliability of pyrotechnic-operated valves in controlling hazardous gases and fluids and providing recommendations to stakeholders that ultimately facilitated Mars 2020

Elevated Temperature on Chandra X-Ray Observatory Integral Propulsion System Composite Overwrapped Pressure Vessel Evaluation Team
In recognition of exceptional service in the expedited risk assessment of the Chandra X-Ray Observatory Integral Propulsion System Composite Overwrapped Pressure Vessel titanium liner and carbon fiber/epoxy composite

Ice Cloud and Land Elevation Satellite Laser Pointing Evaluations of Alternative Design Solutions Team
In recognition of outstanding accomplishments in evaluating the Ice Cloud and Land Elevation Satellite (ICESat-2) Advanced Topographical Laser Altimeter System Instrument Beam Steering Mechanism design and recommending alternative solutions for the ICESat-2 Project

NASA Engineering and Safety Center Multi-Purpose Crew Vehicle Drogue Parachute High Altitude Qualification Team
In recognition of outstanding contributions in assessing the crew module aerodynamic stability predictions and parachute tools validity to predict drogue parachute high altitude loads and performance

NASA Lithium Ion Thermal Runaway Assessment Team
In recognition of outstanding support in assessing the risk of thermal runaway in lithium ion batteries used in NASA systems

NASA Engineering and Safety Center Reinforced Carbon/Carbon-Silicon Carbide Materials Assessment Team
In recognition of outstanding support developing essential new understanding of reinforced carbon/carbon-silicon carbide material to ensure the safe operation of the Orion Multi-Purpose Crew Vehicle Launch Abort System

Orion Wake Characterization Test Team
In recognition of outstanding contributions to the acquisition of unique, unsteady wake flowfield data on an Orion capsule at transonic flight conditions

Probing Aircraft Flight Test Hazard Mitigation for the Alternative Fuel Effects on Contrails and Cruise Emissions Assessment Team
In recognition of exemplary support in conducting an independent aircraft loads analysis, margin assessment, and flight test risk characterization and mitigation resulting in improved flight test safety

Solar Probe Plus Upper Stage Performance Assessment Team
In recognition of outstanding contributions in support of the successful time-critical assessment of the Solar Probe Plus Upper Stage Performance

Learning and Leading

Our team members join the NESC for a period of time and then rotate back to their Centers in order to share the new knowledge, contacts, and broader perspective gained from participation in cross-Agency NESC assessments. Many NESC alumni have gone on to significant leadership positions across the Agency.

Core Leadership Team

Ralph R. Roe, Jr.

NESC Director

Mr. Ralph R. Roe, Jr. is the NESC's Director at Langley Research Center. Mr. Roe has over 30 years of experience in human spaceflight 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 at Langley Research Center. 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 32 years of engineering and management experience supporting the Space Shuttle Program.

Michael P. Blythe

NESC Deputy Director for Safety

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

Dawn M. Schaible

Manager, Systems Engineering Office

Ms. Dawn M. Schaible is Manager of the NESC's Systems Engineering Office at Langley Research Center. Prior to joining the NESC, Ms. Schaible worked in the International Space Station/Payload Processing Directorate at Kennedy Space Center. Ms. Schaible has over 26 years of experience in systems engineering, integration, and ground processing for the Space Shuttle and International Space Station Programs.

Patrick G. Forrester

NESC Chief Astronaut

Mr. Patrick G. Forrester is the NESC's Chief Astronaut and is resident at Johnson Space Center. Mr. Forrester began his NASA career in 1993 after serving in the U.S. Army. As a Master Army Aviator, he logged over 4800 hours in over 50 different aircraft. He was selected as an astronaut candidate in 1996 and flew on STS-105 (2001), STS-117 (2007), and STS-128 (2009). He has logged over 950 hours in space, including four spacewalks totaling 25 hours and 22 minutes of extra vehicular activity time.

Dr. Daniel Winterhalter

Chief Scientist

Dr. Daniel Winterhalter is the NESC's Chief Scientist and is resident at Jet Propulsion Laboratory (JPL). Dr. Winterhalter has over 35 years of experience as a research scientist at JPL. His research interests include the spatial evolution of the solar wind into the outer reaches of the heliosphere, as well as its interaction with and influence on planetary environments. In addition, as a member of several flight teams, he has been intimately involved with the planning, launching, and operation of complex spacecraft and space science missions.

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NASA Headquarters Liaison

Patrick A. Martin

NASA Headquarters Senior SMA Integration Manager

Mr. Patrick A. Martin 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. He was formerly the NASA Headquarters OSMA Manager for the Science Mission Directorates flight missions where he was responsible for assuring that safe and effective SMA programs were established and implemented throughout each phase of NASA's Earth and Space Science missions. Mr. Martin has over 30 years of experience in the aerospace systems safety and mission assurance disciplines and mishap investigations.

NESC Principal Engineers

Clinton H. Cragg

NESC Principal Engineer

Mr. Clinton H. Cragg is a Principal Engineer with the NESC at Langley Research Center. 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 35 years of experience in supervision, command, and ship-borne nuclear safety.

Dr. Nancy J. Currie

NESC Principal Engineer

Dr. Nancy J. Currie is a Principal Engineer with the NESC and is resident at Johnson Space Center (JSC). Dr. Currie was formerly the NESC Chief Engineer at JSC. Dr. Currie came to the NESC from JSC, where she served as the Deputy Director of the Engineering Directorate. Dr. Currie has over 24 years of experience in robotics and human factors engineering. Selected as an astronaut in 1990, Dr. Currie is a veteran of four space shuttle missions and has accrued 1000 hours in space.

Dr. Michael G. Gilbert

NESC Principal Engineer

Dr. Michael G. Gilbert is a Principal Engineer with the NESC at Langley Research Center (LaRC). Dr. Gilbert was formerly the NESC Chief Engineer at LaRC. Before joining the NESC, he was Head of the LaRC Systems Management Office. Dr. Gilbert has over 35 years of engineering, research, and management experience with aircraft, missile, spacecraft, Space Shuttle, and International Space Station Programs.

Michael T. Kirsch

NESC Principal Engineer

Mr. Michael T. Kirsch is a Principal Engineer with the NESC at Langley Research Center. Mr. Kirsch joined the NESC from NASA's White Sands Test Facility, 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 24 years of experience in managing projects and test facilities.

NESC Chief Engineers

Dawn C. Emerson

NESC Chief Engineer

Ms. Dawn C. Emerson is the NESC's Chief Engineer at Glenn Research Center (GRC). Ms. Emerson came to the NESC from GRC, where she most recently served as the Deputy Project Manager during formulation of the Solar Electric Propulsion Flight Demonstration Project. Ms. Emerson has over 28 years of management and technical experience with NASA and private industry.

Steven J. Gentz

NESC Chief Engineer

Mr. Steven J. Gentz is the NESC's Chief Engineer at Marshall Space Flight Center. Mr. Gentz was formerly a Principal Engineer with the NESC at Langley Research Center. Mr. Gentz has over 30 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.

R. Lloyd Keith

NESC Chief Engineer

Mr. R. Lloyd Keith is the NESC's Chief Engineer, as well as support and backup for the Center Chief Engineer, at the Jet Propulsion Laboratory. Mr. Keith has over 36 years of experience working in both technical and managerial positions. Mr. Keith has supported a number of flight projects, including the Mars Pathfinder Project, SeaWinds, Stardust, Mars '98, New Millennium Deep Space 1, and the Flight Hardware Logistics Program.

Nans Kunz

NESC Chief Engineer

Mr. Nans Kunz is the NESC's Chief Engineer at Ames Research Center (ARC). Mr. Kunz came to the NESC from the Systems Engineering Division at ARC. Mr. Kunz has over 35 years of engineering experience leading and managing NASA programs and projects, including serving as the Chief Engineer of the Stratospheric Observatory For Infrared Astronomy (SOFIA) Project.

Stephen A. Minute

NESC Chief Engineer

Mr. Stephen A. Minute is the NESC's Chief Engineer at Kennedy Space Center (KSC). Mr. Minute came to the NESC from KSC, where he served as the Chief of the Space Shuttle Safety, Quality, and Mission Assurance Division. Mr. Minute has over 29 years of engineering and management experience in the Space Shuttle and International Space Station Programs.

Joseph W. Pellicciotti

NESC Chief Engineer

Mr. Joseph W. Pellicciotti is the NESC's Chief Engineer at Goddard Space Flight Center (GSFC). Mr. Pellicciotti was formerly the NASA Technical Fellow for Mechanical Systems resident at GSFC. Mr. Pellicciotti served as the Chief Engineer for the GSFC Mechanical Systems Division before joining the NESC. Mr. Pellicciotti has over 25 years of combined private industry and NASA experience designing structure and mechanisms for commercial, military, and civil spacecraft.

Continued next page

NESC Chief Engineers *Continued*

Jill L. Prince

NESC Chief Engineer

Ms. Jill L. Prince is the NESC's Chief Engineer at Langley Research Center (LaRC). Ms. Prince came to the NESC from LaRC, where she served as the Head of the Structural and Thermal Systems Branch. Ms. Prince has over 12 years of technical experience in flight mechanics.

Michael D. Smiles

NESC Chief Engineer

Mr. Michael D. Smiles is the NESC's Chief Engineer at Stennis Space Center (SSC). Mr. Smiles joined the NESC from SSC, where he served as the Safety and Mission Assurance Manager. Mr. Smiles has over 28 years of management and technical experience with NASA at SSC and Marshall Space Flight Center.

Dr. James F. Stewart

NESC Chief Engineer

Dr. James F. Stewart is the NESC's Chief Engineer at Dryden Flight Research Center (DFRC). Dr. Stewart joined the NESC from DFRC, where he served as the Dryden Exploration Mission Director. Dr. Stewart has over 47 years of management and technical experience leading missile and aircraft programs.

T. Scott West

NESC Chief Engineer

Mr. T. Scott West is the NESC's Chief Engineer at Johnson Space Center (JSC). Mr. West came to the NESC from the Loads and Structural Dynamics Branch at JSC where he served as the Branch Chief. Mr. West has over 22 years of technical and management experience with Space Shuttle, International Space Station, Multi-Purpose Crew Vehicle, and Exploration projects with NASA and private industry.

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 Instrument Software Manager. Mr. Aguilar has over 37 years of experience on embedded software development.

Cornelius J. Dennehy

NASA Technical Fellow

Mr. Cornelius J. Dennehy is the NASA Technical Fellow for Guidance, Navigation, and Control (GNC) and is resident at Goddard Space Flight 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 33 years of experience in the architecture, design, development, integration, and operation of GNC systems, and space platforms for communications, defense, remote sensing, and scientific mission applications.

Dr. Michael J. Dube

NASA Technical Fellow

Dr. Michael J. Dube is the NASA Technical Fellow for Mechanical Systems and is resident at the Goddard Space Flight Center. Prior to joining the NESC, he served as the Discipline Deputy for the Mechanical Systems Technical Discipline Team. Dr. Dube has over 20 years of experience within NASA, academia, and in private industry in the areas of tribology and lubrication of moving mechanical assemblies.

Roberto Garcia

NASA Technical Fellow

Mr. Roberto Garcia is the NASA Technical Fellow for Propulsion and is resident at Marshall Space Flight Center. Mr. Garcia came to the NESC from the Solid Propulsion Systems Division, where he served as Division Chief. Mr. Garcia has over 22 years of experience in performing aerodynamic, hydrodynamic, and engine system design and analysis of rocket propulsion.

Oscar Gonzalez

NASA Technical Fellow

Mr. Oscar Gonzalez is the NASA Technical Fellow for Avionics and is resident at Goddard Space Flight Center (GSFC). Mr. Gonzalez came to the NESC from GSFC, where he served as the International Space Station/ Express Logistic Carrier Avionics Systems Manager. Mr. Gonzalez has over 35 years of NASA and private industry experience where he has held a variety of critical leadership roles in power electronics, electrical systems, instrument systems, and avionics systems.

Dr. Christopher J. Iannello

NASA Technical Fellow

Dr. Christopher J. Iannello is the NASA Technical Fellow for Electrical Power and is resident at Kennedy Space Center. Prior to joining the NESC, he served as the Discipline Deputy for the Electrical Power Technical Discipline Team. Dr. Iannello has over 24 years of experience with electrical power systems with NASA, academia, and private industry.

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. 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 33 years of engineering experience with expertise in stochastic structural dynamics, structural safety, and probabilistic engineering applications.

Daniel G. Murri

NASA Technical Fellow

Mr. Daniel G. Murri is the NASA Technical Fellow for Flight Mechanics and is resident at Langley Research Center (LaRC). Mr. Murri served as Head of the Flight Dynamics Branch at LaRC before joining the NESC. He has over 32 years of engineering experience conducting numerous wind-tunnel, simulation, light-test, and theoretical studies in the exploration of new technology concepts and in support of aircraft development programs.

Continued next page

NASA Technical Fellows *Continued*

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. 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 27 years of experience lecturing on Human Factors, and another 21 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 29 years of experience in the commercial nuclear power industry and over 19 years of experience in basic and applied materials research for several NASA programs.

Dr. William H. Prosser

NASA Technical Fellow

Dr. William H. Prosser is the NASA Technical Fellow for Nondestructive Evaluation and is resident at Langley Research Center (LaRC). Dr. Prosser joined the NESC from the Nondestructive Evaluation Sciences Branch at LaRC. Dr. Prosser has over 26 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 38 years of experience in structures, structural mechanics, and structural integrity.

Steven L. Rickman

NASA Technical Fellow

Mr. Steven L. Rickman is the NASA Technical Fellow for Passive Thermal and is resident at Johnson Space Center (JSC). Mr. Rickman joined the NESC from JSC's Thermal Design Branch, where he served as the Chief. Mr. Rickman has over 28 years of management and technical experience in passive thermal control.

Henry A. Rotter

NASA Technical Fellow

Mr. Henry (Hank) A. Rotter is the NASA Technical Fellow for Life Support/Active Thermal and is resident at Johnson Space Center (JSC). Mr. Rotter joined the NESC from the JSC Crew and Thermal Systems Division and the Space Launch Initiative Program, where he was Engineering Manager and the Orbital Space Plane Team Leader for life support and active thermal control teams. Mr. Rotter has over 46 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. 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 35 years of experience in the aerospace industry with expertise in aeroelasticity and integrated aerodynamic analysis.

Roberto Garcia, NASA Technical Fellow for Propulsion, passed away in October 2013. He was a valued member of our team and made many significant contributions to the NESC, Marshall Space Flight Center, and NASA. Our friend and colleague will be greatly missed.

Frank H. Bauer
NESC Discipline Expert for Guidance Navigation and Control (2003–04)

J. Larry Crawford
NESC Deputy Director for Safety (2003–04)

Dr. Charles J. Camarda
NESC Deputy Director for Advanced Projects (2006–09)

Kenneth D. Cameron
NESC Deputy Director for Safety (2005–08)

Steven F. Cash
NESC Chief Engineer at Marshall Space Flight Center (2005)

Derrick J. Cheston
NESC Chief Engineer at Glenn Research Center (2003–07)

Mitchell L. Davis
NASA Technical Fellow for Avionics (2007–09)

Dennis B. Dillman
NESC Chief Engineer at NASA Headquarters (2005–08)

Freddie Douglas, III
NESC Chief Engineer at Stennis Space Center (2007–08)

Patricia L. Dunnington
Manager, Management and Technical Support Office (2006–08)

Walter C. Engelund
NESC Chief Engineer at Langley Research Center (2009–13)

Wayne R. Frazier
Senior SMA Integration Manager (2005–12)

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

T. Randy Galloway
NESC Chief Engineer at Stennis Space Center (2003–04)

Dr. Edward R. Generazio
NESC Discipline Expert for Nondestructive Evaluation (2003–05)

Dr. Richard J. Gilbrech
NESC Deputy Director (2003–05)

Michael Hagopian
NESC Chief Engineer at Goddard Space Flight Center (2003–07)

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

Dr. Charles E. Harris
NESC Principal Engineer (2003–06)

Dr. Steven A. Hawley
NESC Chief Astronaut (2003–04)

Marc S. Hollander
Manager, Management and Technical Support Office (2005–06)

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

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

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

Michael W. Kehoe
NESC Chief Engineer at Dryden Flight Research Center (2003–05)

Robert A. Kichak
NESC Discipline Expert for Power and Avionics (2003–07)

Dr. Dean A. Kontinos
NESC Chief Engineer at Ames Research Center (2006–07)

Julie A. Kramer White
NESC Discipline Expert for Mechanical Analysis (2003–06)

Steven G. Labbe
NESC Discipline Expert for Flight Sciences (2003–06)

Matthew R. Landano
NESC Chief Engineer at Jet Propulsion Laboratory (2003–04)

Dr. David S. Leckrone
NESC Chief Scientist (2003–06)

Richard T. Manella
NESC Chief Engineer at Glenn Research Center (2009–10)

John P. McManamen
NASA Technical Fellow for Mechanical Systems (2003–07)

Brian K. Muirhead
NESC Chief Engineer at Jet Propulsion Laboratory (2005–07)

Dr. Paul M. Munafo
NESC Deputy Director (2003–04)

Stan C. Newberry
Manager, Management and Technical Support Office (2003–04)

Dr. Tina L. Panontin
NESC Chief Engineer at Ames Research Center (2008–09)

Dr. Shamim A. Rahman
NESC Chief Engineer at Stennis Space Center (2005–06)

Jerry L. Ross
NESC Chief Astronaut (2004–06)

Dr. Charles F. Schafer
NESC Chief Engineer at Marshall Space Flight Center (2006–10)

Steven S. Scott
NESC Chief Engineer at Goddard Space Flight Center (2008–09)

Bryan K. Smith
NESC Chief Engineer at Glenn Research Center (2008–10)

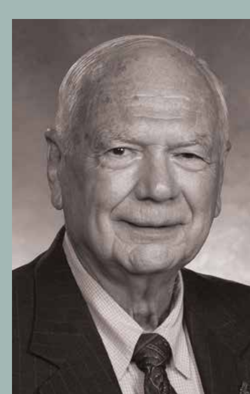
Daniel J. Tenney
Manager, Management and Technical Support Office (2009–13)

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

Timothy G. Trenkle
NESC Chief Engineer at Goddard Space Flight Center (2009–13)

Clayton P. Turner
NESC Chief Engineer at Langley Research Center (2008–09)

George Hopson, our colleague, friend and mentor, passed away in October 2013. George was a founding member of the NESC and our first NASA Technical Fellow for Propulsion. He had a distinguished 45-year career at NASA and was a true leader in his field. He will be remembered for his lasting contributions to the Agency.



NESC/NASA Published Technical Memoranda

1. Chandra X-Ray Observatory COPV Risk Assessment NASA/TM-2013-217793
2. Orion Docking Mechanism Jettison System (DMJS) Cheater Cut Testing NASA/TM-2013-217794
3. Impact of NASA Arc Jet Complex Consolidation on the Multi-Purpose Crew Vehicle (MPCV) Program and Thermal Protection System (TPS) Margins NASA/TM-2013-217962
4. High Strain Rate Fracture of the Space Shuttle Program (SSP) Orbital Maneuvering System/Reaction Control System (OMS/RCS) Thruster NASA/TM-2013-217970
5. Crew Module (CM) Crew Seat Load Attenuation and Isolation NASA/TM-2013-217987/Part 1
6. Crew Module (CM) Crew Seat Load Attenuation and Isolation Appendices NASA/TM-2013-217987/Part 2
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