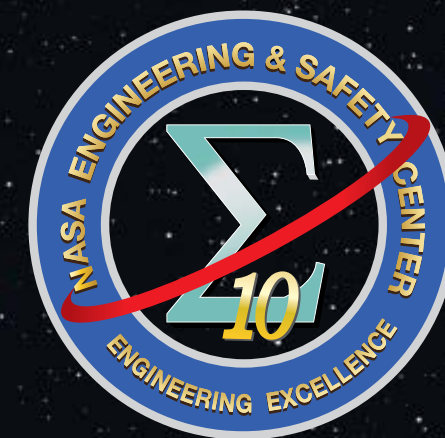




The NESC 2016 Technical Update



NASA Engineering
& Safety Center



NASA Engineering & Safety Center Technical Update 2016

For general information and requests
for technical assistance visit us at:

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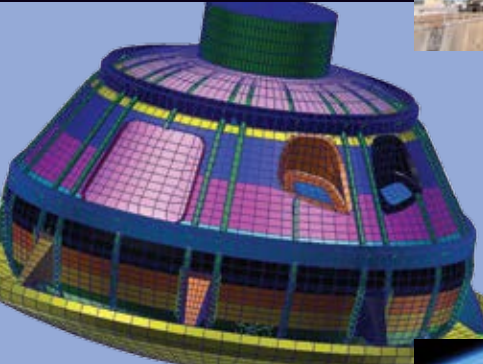
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Now in its 14th year and having logged in its 700th assessment in 2016, the NESC continues to demonstrate its depth and breadth of expertise as it remains a strong and reliable technical resource for the Agency. With more assessments initiated this year than ever before, the NESC focused on smaller, shorter duration activities that offered a varied portfolio of technical challenges. Their efforts reflect the Agency's work to mature several programs, such as the Orion Multi-Purpose Crew Vehicle, Space Launch System, and Ground Systems Development and Operations, toward qualification and flight readiness. They also engaged with the Agency's Commercial Crew Program as its commercial partners ready their own vehicles for spaceflight. Even with the vast assessment work, the NESC continues to refine Agency capability leadership roles, ensuring those capabilities are ready to support current and emerging NASA mission needs. With every new challenge it takes on, the NESC helps prepare the Agency for new opportunities in aeronautics, science, and space exploration.

Robert Lightfoot, NASA Associate Administrator



With five human spaceflight programs in development, the James Webb Space Telescope in critical testing, and ongoing achievements in maintaining the International Space Station, NASA was exceptionally busy in 2016. The NESC was busy as well in support of these programs – in 2016 they conducted their largest number of assessments since NESC's inception, helping to reduce or mitigate the Office of the Chief Engineer top technical risks in the Agency. In the midst of this progress, NASA has been evolving its operational model to include capability leadership, and the NESC stepped up to participate in the execution of this model by operating in the leadership roles crucial to the Agency's future. The NESC has always been dedicated to supporting NASA's vision. I am confident that as NASA looks forward to new exploration and discoveries, the NESC will continue to provide the technical expertise the Agency needs to keep its vision moving forward.

Ralph Roe, Jr., NASA Chief Engineer

Reducing NASA's Risks is NESC's Priority

Thirteen years ago, NASA was focused on safely returning the Space Shuttle fleet to service following the Columbia accident. Returning to flight meant NASA could resume construction of the International Space Station (ISS) and take crews and supplies to and from the ISS. Also that year, the NASA Engineering and Safety Center (NESC) was formed, and a substantial portion of the NESC's work was associated with getting the Space Shuttle Program ready to fly again.

Today, the Space Shuttle orbiters are museum exhibits. The ISS is complete and is a fully operational laboratory. NASA is developing the capability to transport astronauts to destinations beyond the ISS. Commercial providers bring supplies to ISS and are developing spacecraft to bring astronauts there as well. The NESC is as active as ever, with a much more diverse workload that supports different stakeholders with different missions and requirements.

The fundamental tenets from which the NESC was founded have not changed since 2003. Foremost is the philosophy that robust engineering is essential in promoting safety and mission success. The NESC realizes this philosophy by employing a network of scientists and engineers from across the country, coming from academia, government, industry, and all of the NASA Centers and installations. This network is organized by Technical Discipline Teams (TDTs), and most are led by a NASA Technical Fellow. The 21 TDTs serve as ready pools of engineering talent from which to draw support for NESC assessments that address the toughest technical problems arising from any of NASA's projects. These assessments are modeled after

the traditional tiger team concept of a streamlined, focused team dedicated to addressing a particular technical issue.

The TDTs are comprised of approximately 800 scientists and engineers from across NASA, industry, and academia. They do not work directly for the NESC, but make up the NESC extended team. The NESC core team — those badged to the NESC — is much smaller with around 50 employees spread throughout all 10 NASA Centers. The core team includes the NESC Director and his office, the Principal Engineers, the NESC Chief Engineers, the NASA Technical Fellows, the NESC Integration Office, and the Management and Technical Support Office.

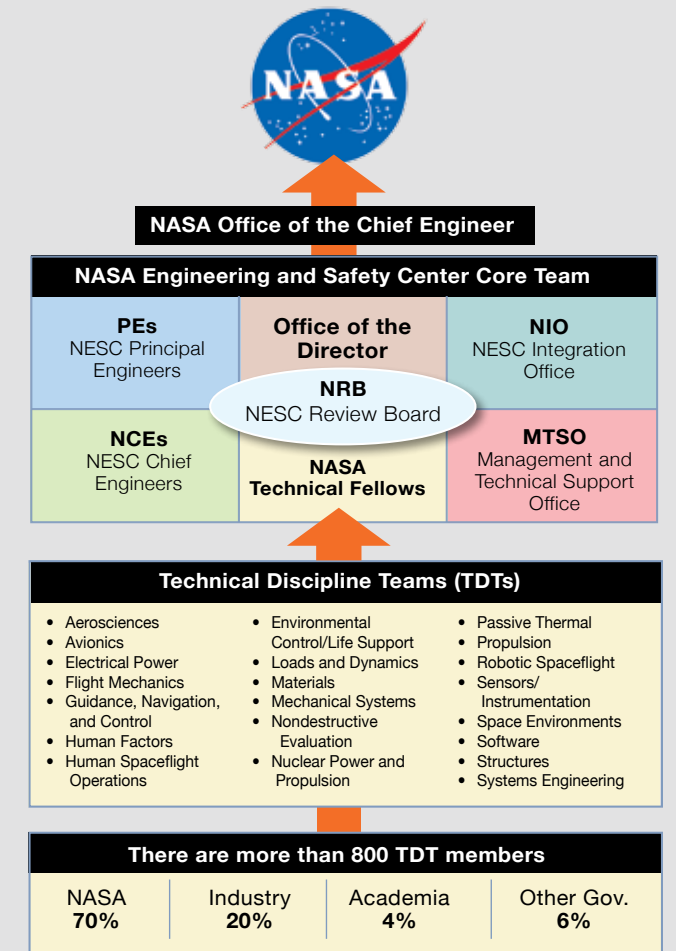
The NESC has the flexibility to direct and redirect its focus to the highest risks and highest priorities for the Agency and to address requests that come from anywhere within the Agency.

This core leadership team includes the NESC Review Board (NRB). The NRB demonstrates another tenet of the NESC: embracing diversity to produce decisions that are technically sound and robust. The findings, observations, recommendations, and reports resulting from NESC assessments must be approved by the NRB prior to release. The various technical disciplines of the NRB members provide a spectrum of points of view, which strengthens the pedigree and technical justification of the final products.

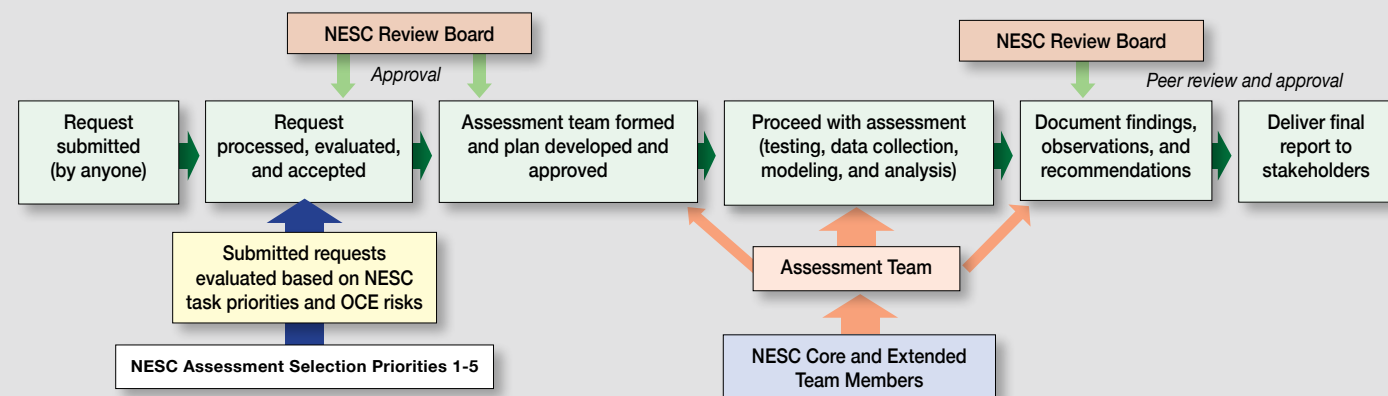
As NASA's priorities have evolved, the NESC has responded. There has been a shift within NASA over the past decade from projects in the flight/operational phase to those that are in the design phase. The NASA Office of the Chief Engineer (OCE) maintains a list of what the Chief Engineer considers to be the Agency's top technical risks. Because the NESC as an organization reports to the Chief Engineer, the NESC's priorities reflect the OCE's risks (see sidebar on page 5). For example, one of the top risks is obtaining adequate insight into the Commercial Crew Program's (CCP) design and process development. Some of the NESC activities to mitigate this risk include evaluation of CCP occupant (i.e. astronaut) protection approach, assessing CCP burst and proof pressure factors for pressure vessels, supporting parachute modeling capability, and reviewing CCP's engineering and integration processes. The NESC currently has over 80 active assessments, so the technical risk list is important as a tool to help prioritize which requests are accepted.

As missions end and new ones begin, there are new challenges to supplant the old ones. The NESC has the flexibility to direct and redirect its focus to the highest risks and highest priorities for the Agency and to address requests that come from anywhere. This flexibility is due in part to the NESC's independence from any one program, project, or mission directorate. The NESC functions as a resource for the entire Agency.

For more information or to submit a request, contact your Center's NESC Chief Engineer or visit www.nesc.nasa.gov

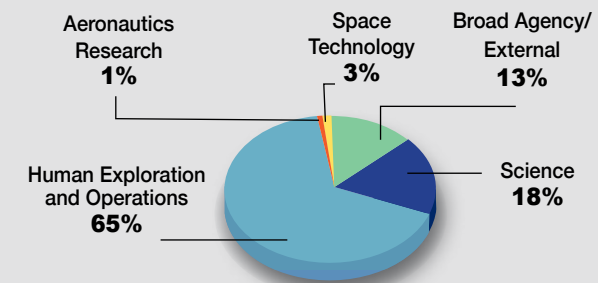


Performing NESC Assessments

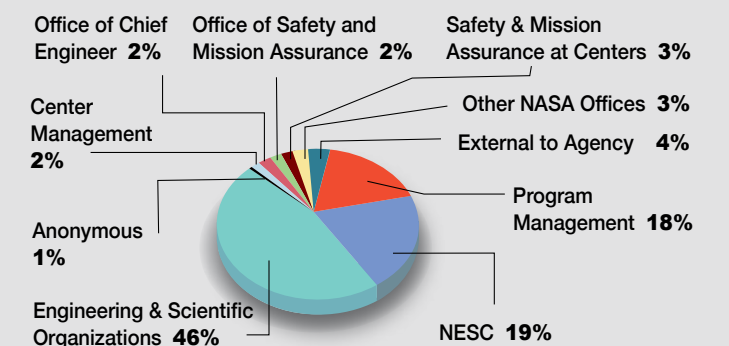


Accepted Requests Since 2003: 715 total, 68 for fiscal year 2016

Accepted Requests by Mission Directorate



Sources of Accepted Requests



Data as of September 30, 2016

Setting Priorities

How the NESC keeps its focus on technical risks

As the NESC Deputy Director, Michael Kirsch is navigating the NESC's technical portfolio through a rough fiscal climate – working within a fixed budget while juggling a constant influx of requests for the NESC's technical expertise. In this Q&A, he explains the delicate balance required to weigh those budget constraints against which assessments will offer the best opportunities to mitigate NASA's top technical risks.

You have held several positions at the NESC including Principal Engineer (PE), Manager of the Management and Technical Support Office (MTSO), and now Deputy Director. How have those positions prepared you to make decisions on what work the NESC will pursue?

As a PE, I led several independent technical assessments that included developing an independent Crew Exploration Vehicle (CEV) design, evaluating the use of carbon fiber composites on Orion's crew module primary structure, fabricating a full-scale composite crew module (CCM), and contributing to an alternate design of the Orion heatshield carrier structure. Those projects put my technical background from White Sands to good use, but they also offered me the chance to hone my management skills. Each assessment involved bringing in experts from different NASA Centers, multiple disciplines, and technical backgrounds. I had to keep that team focused, adjust plans, and resolve issues as we progressed toward the project objective, all within a cost and schedule constraint.

And in every assessment, I made a conscious effort to find ways to manage the financial aspects. I developed tools and techniques to manage cost estimates and progress against actual cost and performance, which I later used as the MTSO Manager and Deputy Director to help manage the total NESC technical portfolio. So my technical background combined with that management experience has helped me prioritize and figure out how best to apply our NESC resources.



The NESC receives a continuous influx of requests from NASA programs and projects. How do you mesh such a dynamic workload with a fixed budget?

Fortunately, the demand for our support has exceeded our capacity, which is a great place to be, but it also requires you to make judgments on what work will have the biggest benefit for the Agency. During 2015 and 2016, we were starting the year almost fully encumbered. There were many times that, in order to take on higher priority work, we had to make some tough decisions to descope some of the work, reduce the amount of test or development work that we had originally planned, or defer certain work to the following year. In some cases we were able to negotiate partnerships with our stakeholders

to share some of the expenses. For 2017, I have no doubt that early into the fiscal year (FY) we will be once again fully subscribed.

What is driving the increase in high priority work?

I believe the Agency may be as busy as it's ever been in terms of transitioning development projects into qualification testing. The Orion Multi-Purpose Crew Vehicle (MPCV) Program, the Space Launch System (SLS) Program, Ground Systems Development and Operations (GSDO), and the Commercial Crew Program (CCP) are all going into the development and test phase of their life cycles. And it's during development and test that many technical issues emerge. I think that's where the NESC has contributed and will continue to have good opportunities to help those programs achieve their objectives. The overall demand on NESC expertise and support is going to be as high as it's ever been. To me it's analogous to the days of the Shuttle's return to flight, but more so because it involves several programs.

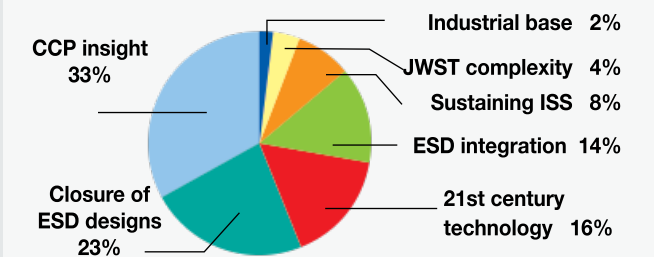
From a broader NASA perspective, how is the NESC helping to mitigate the Agency's top technical risks?

When former NESC Director Ralph Roe took the position of NASA Chief Engineer, he put emphasis on understanding what he considers to be the Agency's top technical risks. He spent time with the NASA's engineering directors, chief engineers, and programs to identify those risks. That helped focus the engineering community on prioritizing workloads. At the NESC, we are also prioritizing and aligning our portfolio with those top technical risks to ensure we are contributing to their mitigation. The NESC was formed to help the Agency solve its toughest technical challenges. Some of those top risks aren't in the NESC's mission, such as maintaining a broad industrial base for critical spacecraft skills, but helping the SLS, Orion MPCV, or GSDO close on their designs within their cost schedule and mass constraints are areas where the NESC can help.

As Deputy Director, how has your perspective on the NESC changed since your days as a PE?

As a PE, I was very singularly focused on the objective associated with my particular task. It was about delivering an alternate design for the CEV or delivering a CCM. As the MTSO Manager and now as Deputy Director, I want to know about NASA's exploration mission, science mission, or aeronautics mission. It's a much broader check on whether our day-to-day role is helping the Agency achieve its mission. The challenges are much bigger than developing an alternate design for

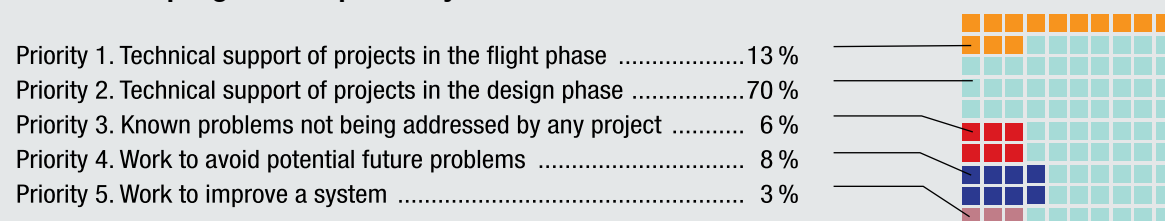
Percent of NESC FY 2016 Assessments Supporting Office of the Chief Engineer (OCE) Agency Technical Risks



OCE Agency Technical Risks Currently Supported by the NESC

- **CCP insight** into partner designs to enable their success and certify vehicles for human spaceflight
- **Exploration Systems Development (ESD) integration** of the three human spaceflight programs using a new model
- **Sustaining ISS** through 2024
- **James Webb Space Telescope (JWST) complexity** with cryogenic systems and the number of mechanisms and deployments required for mission success
- **Closure of ESD designs** of MPCV/SLS/GSDO
- **Industrial base** is shrinking along with cross-cutting supply chain issue
- **21st century technology** tools and methods successfully incorporated into NASA programs and projects

FY 2016 In-progress Requests by NESC Assessment Selection Priorities



the Orion heatshield. Our NESC technical leads – the NASA Technical Fellows, the Principal Engineers, and the NESC Chief Engineers – maintain a sharp focus on the individual technical goals of their tasks, but from the NESC's director's office perspective, we're trying to make sure the NESC portfolio is helping the Agency as a whole achieve its objectives.

Mastering the Art of Mentoring

Jon Haas & Ilse Alcantara

Ilse Alcantara drives about an hour from her home base in El Paso, Texas, to her Universities Space Research Association internship with the NESC in Las Cruces, New Mexico. But she does not mind the commute. The metallurgical and materials engineering graduate student is gaining invaluable experience in her field by performing materials testing on frangible joints, the explosive connections NASA uses to separate stages and fairings on spacecraft. And with guidance from her NESC mentors at NASA's White Sands Test Facility, Ms. Alcantara has honed skills that will serve her well throughout her career.

Having students or early-career engineers work on assessments is a tenet of the NESC, but the relationship between mentor and mentee can be tough to navigate, said Jon Haas, an Associate Principal Engineer working on the NESC assessment to analyze risks associated with these mission-critical joints. "Mentoring is a lot of work, but done right, the rewards are tremendous."

It begins with finding the right person. "You have to start with someone who not only has the right skill set, but also the right temperament," Mr. Haas said. After that, good mentoring becomes a balancing act. "It's giving the guidance and feedback they need to do the job, while at the same time not being so involved that they don't have the opportunity to develop as a professional."

"Students are transitioning from being dependent on the institution to becoming independent engineers and scientists. You need to keep them engaged in work



Graduate student Ilse Alcantara and NESC Associate Principal Engineer Jon Haas inspect the pre-test instrumentation set-up of a frangible joint at White Sands Test Facility.

that's interesting, yet not too far afield from their skill set; give challenging assignments while keeping an eye on their development; and most importantly, listen, because they are bringing a new perspective to your work."

Ms. Alcantara appreciates the team's mentoring approach. "In some aspects they have really mentored me, and whenever I have questions, I have them available to answer. But on my main project, I also work independently. It's a challenge, but I've really enjoyed it."

The team has been pleased with her efforts to characterize the physics and mechanics of how frangible joints break. She has designed test samples, prepped them for testing, and performed statistical analysis on test data, which feeds into the team's computational models of frangible joint operation. "We've given her several assignments and she's been so enthusiastic," Mr. Haas said. "Her work is high quality."

"It's a great group of scientists and professionals who are obviously really great at what they do," added Ms. Alcantara. "I'm learning about all aspects of frangible joints, working with

statistics, design of experiments, and reliability — things I would have never heard of in school. I've grown so much. I feel I'm a better engineer."

From the NESC perspective, "We benefit by bringing in another viewpoint and a creative mind," said Mr. Haas. "The work she's doing has had a positive impact on this complex project. And the level of curiosity and motivation with students adds to the diversity in the NESC model. As for me, there's a great deal of personal satisfaction when mentoring someone well. It makes me feel useful."

The key to shaping the next generation of engineers

Scott West & Juan Carlos Lopez

When Juan Carlos Lopez joined the NESC Risks of Frangible Joint Designs assessment, he brought a number of key skills to the team, particularly in programming. But the aerospace engineer, still early in his career at JSC, found that some aspects of finite element analysis (FEA) and modeling were new to him. And the assessment required quite a bit of statistical analysis.

"I took a foundations of statistics class in college, but that was it," said Mr. Lopez, who during the assessment, managed to find a host of mentors willing to help him along the way.

First among them was NESC Chief Engineer at JSC, Scott West, who brought Mr. Lopez on board, offering him the chance to gain experience in test data processing and analysis, as well as nonlinear dynamic analysis with LS-DYNA. "He explained the project, the structure of the team, and where I fit in. He wanted me to understand the big picture and the team's overall goal," said Mr. Lopez. As time went on, Mr. West offered feedback on his performance, which Mr. Lopez used to gauge how well his new skills were improving.

When it came to the assessment's statistical aspects, Mr. Lopez turned to another mentor, Ken Johnson, an NESC statistician at MSFC. Even though Mr. Johnson was located in Huntsville, Alabama, it did not impede the mentoring process. "We took advantage of Skype to chat over the internet. Ken answered questions for

me, and even pulled together slides and presentations on basic concepts to help me understand," Mr. Lopez said. "That made me realize how the metrics I was collecting would be used and how they would impact the project's overall results."

During the assessment, Mr. Lopez was able to pull out important metrics of function and graphically display the results for analysis and comparison by writing Matrix Laboratory (MATLAB) code that processed the numerous gigabytes of test data.

"I mainly focused on FEA to investigate the effects of various parameters in a frangible joint's performance," he said. He developed and ran a series of finite element models in LS-DYNA, identified performance metrics, and worked with the team to assess the data. He also developed innovative tools in MATLAB to automate and efficiently process computational and empirical data.

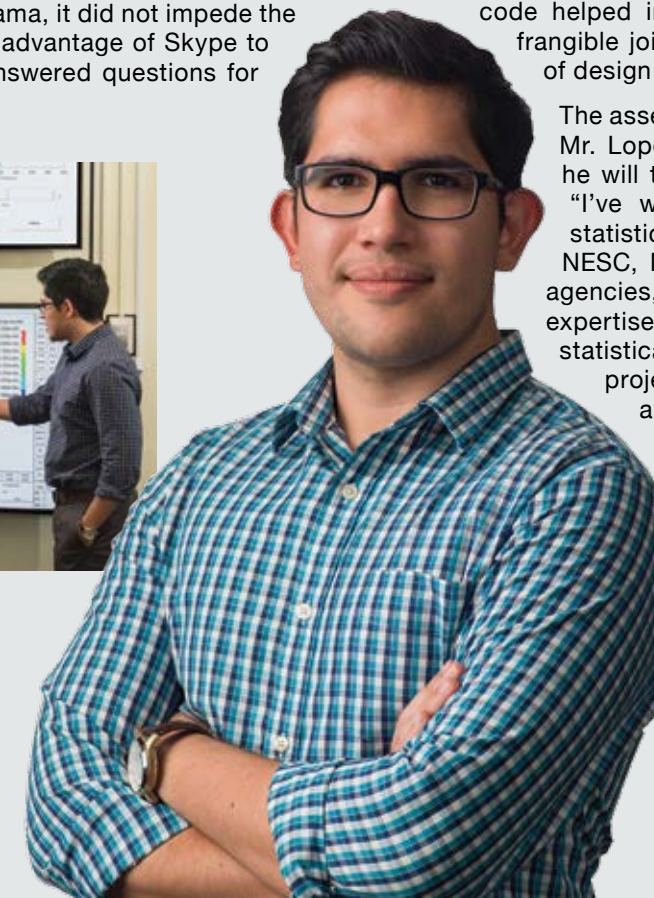
When Mr. Lopez needed help with new FEA concepts, he called on mentor and engineer Claude Bryant. "I usually went to Claude with questions and concerns on the models I was working on. I was grateful to have someone willing to share some of his knowledge with me."

Mr. Lopez's work allowed the processing of data from hundreds of tests and thousands of LS-DYNA analysis runs, many of which he conducted. His MATLAB code helped in the team's understanding of frangible joint performance under a variety of design parameters.

The assessment is in its final stages, but Mr. Lopez is already confident of what he will take away from the experience. "I've worked closely with engineers, statisticians, and technicians from NESC, NASA Centers, and contracting agencies, and I've enhanced my technical expertise in FEA, testing, data processing, statistical analysis, modeling, and project management." Mr. Lopez also gained a network of mentors, which combined with his newly acquired skills will be an asset in future projects with JSC's structural engineering division. "This is probably one of the most challenging and rewarding projects I've participated in so far."



Juan Carlos Lopez (right) discusses an FEA model with mentor and NESC Chief Engineer at JSC, Scott West.



Ames Research Center

The NASA Ames Research Center (ARC) supports many Agency and NESC activities by leveraging its unique and diverse capabilities including aeronautics research; computational fluid dynamics; wind tunnel testing; entry, descent, and landing (EDL); arc jet testing of advanced thermal protection system (TPS) materials and systems; life science and human factors research; planetary and space science; astronomy and astrophysics; intelligent system design; and high-speed computation. Many of these areas of expertise have been brought to bear on NESC technical assessments and in support of the Technical Discipline Teams (TDTs) throughout 2016. ARC has representatives on 14 of the NESC TDTs.

NESC assessment support has been varied and diverse as well, with ARC leading or supporting work on 11 assessments over the past year. These include an ARC-led study of aerodynamic load buffeting on launch vehicles using pressure sensitive paint and high-speed pressure sensors, participation in the investigation of Avcoat TPS material cracking for the Orion crew module, numerous independent EDL modeling studies for the Commercial Crew Program (CCP), and review of major structures and test requirements also for CCP.

New Techniques for Measuring Buffet

In late 2015, Dr. James Ross put his expertise in experimental aerodynamics to work in the ARC transonic wind tunnel to find out if unsteady pressure sensitive paint (uPSP) combined with unsteady pressure transducers could help engineers better predict the potential for high buffet environments on launch vehicles. The wind tunnel tests, which were conducted as part of the NESC assessment, *Launch Vehicle Buffet Verification Testing*, were successful. Dr. Ross and his team are excited about how the development of new buffet measurement techniques will benefit NASA's new Space Launch System as well as the aerospace industry. The ability to better understand and predict unsteady flows and buffeting during the ascent of a launch vehicle will be a significant advancement in the aerosciences discipline, said Dr. Ross. "A lot of people are interested in our results."



Dr. James Ross

"When you have an interesting group of people who are excited about doing the testing, the team is a lot more productive, and you get exposed to people you wouldn't normally work with ..."

— Dr. James Ross



Kenneth R. Hamm, Jr.
NESC Chief Engineer

31 ARC employees supported NESC work in FY16

During wind tunnel testing, NASA and commercial companies sent in people to observe. "They wanted to see what we were doing and figure out how much these new techniques could help their own processes," he said. As with his work on previous NESC assessments, such as characterizing wake for the Orion Multi-Purpose Crew Vehicle (MPCV), Dr. Ross appreciates the wide variety of people involved in the assessments. "When you have an interesting group of people who are excited about doing the testing, the team is a lot more productive, and you get exposed to people you wouldn't normally work with in your day-to-day work at NASA."

A Detail-Driven Approach to Understanding TPS

Because of his expertise in TPS for atmospheric entry, the NESC has enlisted Dr. Peter Gage to work on assessments involving the Orion MPCV heatshield.

Dr. Gage has brought his extensive background and experience, gained through two decades of work at ARC, to the NESC's understanding of the material properties of Avcoat, which is used in TPS, and to the determination of the root causes of discrepancies that arose during the processing of the Orion crew module heatshield. His interest in the systems engineering aspects of root cause and risk analysis helped with the development of fault trees and prioritization of tests to isolate effects of candidate causes. His working knowledge of the many disciplines that go into thermal protection has been integral to the NESC's study of the TPS architecture planned for Exploration Mission-1.

"I liked the rigor the NESC could bring to the root cause investigation. That approach has significantly increased our understanding of the Avcoat material behavior," said Dr. Gage. The patience to drive down to the details is something he has taken back to his work on materials development activities at ARC, which he said has improved the precision with which he tackles test planning and execution.



Dr. Peter Gage



Dax Rios (L) and Christopher Kostyk.



The FOSS Team (left to right): Dr. Patrick Chan, Jeff Howell, Allen Parker, Francisco Peña, and Anthony Piazza.

Armstrong Flight Research Center

The Armstrong Flight Research Center (AFRC) provided engineering technical support and expertise to several NESC assessments including *Assessing Risks of Frangible Joint Designs*, *The Shell Buckling Knockdown Factor (SBKF) Project*, the *Composite Pressure Vessel Working Group (CPVWG)*, and the *Electrical Power System Review* assessment for the Commercial Crew Program (CCP). In early 2016, AFRC collaborated with JSC to assist the Stratospheric Observatory for Infrared Astronomy Project in developing a simplified methodology to estimate the maximum liquid helium cryostat pressure from a vacuum jacket failure. AFRC engineers were also invited by four NASA Technical Fellows to give presentations at technical discipline team face-to-face meetings and monthly seminars.

Quantifying the Risk of Frangible Joints Through Testing

As the recipient of the 2015 NESC Engineering Excellence Award, Christopher Kostyk continued to serve in his role as the leader of the data team for *Assessing Risks of Frangible Joint Designs*. In this capacity, Mr. Kostyk led the design of the high-speed instrumentation suite that would capture the ephemeral activity associated with the detonation event. Mr. Kostyk continued to apply his expertise in extracting quantitative data from the high-speed video footage that helped inform the team on various aspects of the short life of a frangible joint.

Advanced Instrumentation Support for Multiple NESC Projects

AFRC's Fiber Optic Sensing System (FOSS) Team supported several NESC projects in 2016 including the CPVWG, *Space-X Electrical Power System Review* assessment, and an internal study led by JSC to develop new techniques to detect impact damage on spacecraft.



Dr. W. Lance Richards
NESC Chief Engineer

10 AFRC employees supported NESC work in FY16

The multidisciplinary team included Dr. Patrick Chan, optics engineer; Jeff Howell, aerospace instrumentation technician; Anthony Piazza, instrumentation specialist; Allen Parker, electrical engineer; and Francisco Peña, an aerospace engineer hired by AFRC in 2015.

One of the largest, most complex efforts that the FOSS Team supported was the SBKF Project. This activity involved exploiting the benefits of fiber optic sensing technology to dramatically increase insight into the physical response of an 8-foot diameter composite barrel structure subjected to large-scale testing at MSFC. The SBKF activity is a multi-Center assessment focused on designing leaner and more efficient rocket shell structures through new designs, simulations, and testing. The FOSS Team designed the sensor layout and applied nearly 16,000 fiber optic strain sensors

located on the inner and outer surfaces of the barrel in a 9-day period. Activities also included designing communication and data acquisition interfaces with test systems at MSFC to support testing. The large data set has helped the engineers verify their buckling prediction models for large-scale shell structures with the goal of reducing mass and increasing payload.

Mr. Howell enjoyed participating on the SBKF Team and the challenge of tackling the requirements of the project. He was responsible for developing new sensor installation methods that dramatically reduced installation time and travel costs. According to Project Manager Dr. Marc Schultz, "The AFRC FOSS Team was great to work with during the testing of our first 8-foot diameter composite cylinder test. The FOSS Team was very responsive and modified real-time displays each day to better interrogate behavior seen the previous day. During testing, the fiber-optic strain sensors were instrumental in understanding the behavior of the test article near the boundaries where other instrumentation was ineffective."

Glenn Research Center

The Glenn Research Center (GRC) provided a broad spectrum of technical expertise in support of NESC assessments and the NESC Technical Discipline Teams (TDTs). GRC supported 18 NESC assessments and 17 of the NESC TDTs with 56 engineers. These activities supported all mission directorates as well as some crosscutting discipline activities. Significant contributions this year were in support of the many lithium-ion battery assessments as well as continued support for composite overwrapped pressure vessel (COPV) assessments. The Discipline Deputies for the Nuclear Power and Propulsion and Electrical Power TDTs are resident at GRC.



Robert S. Jankovsky
NESC Chief Engineer

56 GRC employees supported NESC work in FY16

Reliability of COPVs in Space

As an aerospace engineer in the GRC Structures and Materials Division, Dr. Pappu Murthy has brought his expertise in composite mechanics, probabilistic methods, and optimization to the NESC's investigation on the safety of COPVs. Dr. Murthy has built reliability models and developed user-friendly software based on the COPV test data gathered at NASA's White Sands Test Facility. "Our aim is ensuring the reliability of COPVs deployed in many space missions and on the International Space Station (ISS)," he said. "We develop and validate our models based upon data obtained by testing subscale vessels and composite strands."

Dr. Murthy's work with the NESC dates back to the Kevlar-based pressure vessels used during Space Shuttle missions. Carbon fiber-based composites have since replaced Kevlar, but the need to understand COPV reliability remains. "Probabilistic approaches are my passion," said Dr. Murthy, and he brings that to his work with COPVs. "These methods enable us to compute component reliability for a given mission. Reliable operation of COPVs is mission critical as they store high pressure gasses, and any breach could lead to a catastrophic loss of mission and crew."

A variety of discipline experts on the NESC team is key to

ensuring COPV safety, he added. "We have experts in statistics, testing, reliability, and composites from all over NASA as well as academia working on this assessment. It's a close-knit team."

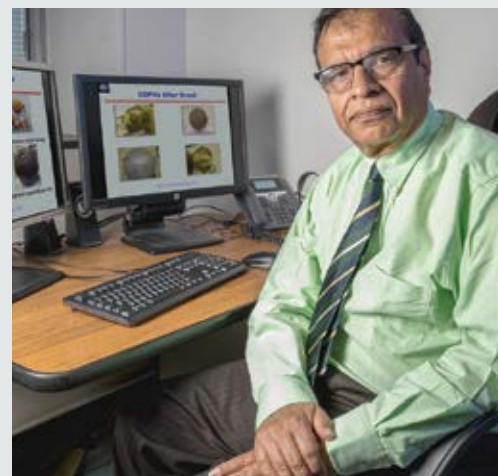
Making Battery Technology Safer

Ms. Concha Reid, a battery specialist in the Photovoltaics and Electrochemical Systems Branch at GRC, has worked on several NESC assessments, most recently on the *Simplified Aid for Extravehicular Activity Rescue (SAFER) Battery Assessment*. The SAFER battery is used in self-propelled jet packs to allow astronauts outside the ISS to maneuver safely back to the airlock in an emergency.

The battery used in the SAFER jet packs is lithium-based. "After some high profile cases in industry of thermal runaway with lithium-ion batteries, NASA is looking at the design of its lithium-based batteries to ensure we're following proper engineering principles to mitigate thermal runaway propagation from a failure or internal short," said Ms. Reid.

Working with the NESC has given Ms. Reid a new perspective on her work. "NESC has a way of challenging you and getting you out of your comfort zone. Being a key member of the SAFER team, I've contributed in ways I hadn't imagined by having an immediate impact on human missions." And she is applying what she has learned to her work at GRC.

"Things I'm learning about the consequences of packing cells too closely together in a battery and not allowing for adequate heat rejection paths informs my design work for other projects, such as the Gondola High Altitude Planetary Balloon System (GHAPS). Now that we've done all the ground work to understand best practices to design a battery to be robust against thermal runaway propagation, I know what additional factors to consider when I design new batteries for NASA applications, such as the GHAPS battery."



Dr. Pappu Murthy

"We have experts in statistics, testing, reliability, and composites from all over NASA as well as academia working on this assessment. It's a close-knit team."

— Dr. Pappu Murthy



Concha Reid



Dr. Kusum Sahu



Dwayne Morgan

Goddard Space Flight Center

The Goddard Space Flight Center (GSFC) supported 15 assessments and investigations in 2016, leading the assessments for the *Effects of Storage and Humidity on Dry Film Lubricant Performance*; *Electrical, Electronic, and Electromechanical (EEE) Parts Testing for Commercial Crew Program (CCP)*; and *CCP Avionics Architecture Review*. GSFC provided expertise to 17 Technical Discipline Teams in 2016 with 72 engineers, technicians, and scientists. GSFC is the resident Center for the NASA Technical Fellows for Systems Engineering; Guidance, Navigation, and Control; Mechanical Systems; and Avionics.

Gaining Insight on EEE Parts

Dr. Kusum Sahu of the GSFC Parts, Packaging, and Technology Branch is helping the NESC analyze and test the EEE parts used on the CCP. Her analysis will help the NESC better understand the procurement specifications for EEE parts used by our CCP partners and how the reliability of these parts compares to military or space-grade parts.

Dr. Sahu has extensive experience in managing EEE part programs for spaceflight hardware, from parts selection and approval to procurement, testing, and kitting for assembly on printed circuit boards. She has also played a key role in analyzing anomalies or failures that might occur during the board-, box-, or system-level testing to determine the root cause of failures. "We then advise on how the failures could be avoided by proper application of the parts or suggest alternative parts."

That expertise led her to work on the NESC assessment *EEE Parts Testing for CCP*. "We are conducting limited testing in our parts analysis lab to gather reliability information and independently determine any manufacturing defects and the impact of environmental stresses such as high temperature cycling or moisture creep into the package," she said. Dr. Sahu is also helping to determine the pros and cons of part-level vs board-level vs box-level testing of



George L. Jackson
NESC Chief Engineer

72 GSFC employees supported NESC work in FY16

flight hardware and testing of many state-of-the-art commercial off-the-shelf parts.

"We are gaining insight into the approaches used by our commercial crew partners," said Dr. Sahu. "And we're trying to find ways to add value to their processes in terms of selecting and testing of EEE parts in a cost effective manner."

Improving Avionics Reliability and Safety

While his desk is at the NASA Wallops Flight Facility, Dwayne Morgan has had the opportunity to work with all of the NASA Centers over the years, as well as the NESC. With expertise in avionics design and development, Mr. Morgan is the technical lead for the NESC's *CCP Avionics Architecture Review* assessment, where he is helping to evaluate the fault tolerance and redundancy of a proposed flight avionics architecture for crewed missions.

"Avionics encompasses a large field," said Mr. Morgan, which affords him the chance to work on many different programs at NASA. "It's a great opportunity to continue learning and see how this discipline is evolving, and how we get data securely to distant planets, as well as our own planet, in ways that are reliable and safe."

Prior to this work, Mr. Morgan was the avionics lead on the NESC's *Ice, Cloud, and Land Elevation Satellite-II (ICESat-2) Laser Pointing* assessment where the NESC was asked to review the function of the Advanced Topographical Laser Altimeter System beam steering mechanism. The team performed a system-level study of the ICESat-2 architecture. "We looked at the avionics, the optical bench, and the accuracy they were trying to achieve under dynamic loads. It was a challenge," he said.

"Communication, collaboration, cooperation, and compromise—when you bring all four together, there's nothing you can't do," he added. "I've been able to see that happen within the NESC with problems I thought were impossible to solve. It amazes me."

Jet Propulsion Laboratory

The Jet Propulsion Laboratory (JPL) in 2016 has provided engineering support for 20 assessments and actively supports the NESC Technical Discipline Teams (TDTs). Several JPL staff have supported NASA Technical Fellows in their respective disciplines. The investigations supported include modeling and simulation; exploration systems development verification and validation; Orion Multi-Purpose Crew Vehicle (MPCV) guidance, navigation, and control (GNC) and environmental control and life support; several Commercial Crew Program assessments; and vibroacoustic environments. JPL leads the Composite Overwrapped Pressure Vessel Working Group and related assessments, the Robotic Spaceflight TDT, and the RAD750 qualification testing effort. The NESC supported the Soil Moisture Active Passive Project in the study of the deployment of its mesh antenna, successfully completed on orbit. The NESC Chief Scientist and Discipline Deputy for Electrical Power, GNC, and Software are resident at JPL.

Strengthening GNC

Aron Wolf has spent much of his NASA career working at JPL in mission design and navigation. He designed orbital tour trajectories for the Galileo mission to Jupiter and the Cassini mission to Saturn, and served as navigation lead for the Stardust-NExT (New Exploration of Tempel-1) encounter with comet Tempel 1. Assisting both the Aerosciences and GNC Technical Discipline Teams, he has participated in several NESC assessments, including the *Cassini Titan 70 Flyby Review*. As Discipline Deputy for GNC, he supported the *Orion MPCV GNC Fault Detection, Identification, and Recovery Independent Review* where he analyzed and documented multiple failure scenarios; the *Kepler Spacecraft Hybrid Attitude Control Concepts Evaluation* assessment to determine ways to allow the space observatory to continue its science mission; and the *Commercial Crew Program Avionics Architecture Review* assessment to evaluate the effects of avionics failures on vehicle controllability.

Mr. Wolf has led mission studies and technology development efforts in entry, descent, and landing (EDL) including the development of terrain-relative navigation for the Mars 2020 mission. His work has been important in developing EDL system architectures and understanding requirements for



R. Lloyd Keith
NESC Chief Engineer

104 JPL employees supported NESC work in FY16

sensors during the various EDL mission phases. He provided GNC and EDL technical expertise to the *Commercial Crew Program Verification and Validation Integration and Mapping* assessment. Mr. Wolf has brought his NESC experience to his study of the EDL architecture for robotic missions beyond Mars 2020, expanding his knowledge of the applicability of robotic mission work to future human missions. "It has definitely improved my understanding of NASA and how the Agency functions," he said. "The NESC offers an interesting and unique viewpoint and a lot of variety in technical work. I've enjoyed that challenge."

Applying Model-Centric Engineering

Working in systems engineering at JPL, Kim Simpson has supported and led many assessments for the NESC. Most recently, she has been applying model-based systems engineering (MBSE) to more accurately develop architectures, perform system engineering, and conduct analyses on the *Commercial Crew Program Verification and Validation Integration* assessment, and the *Mapping and Review of Orion-European Service Module Interfaces* assessment. Her focus has been on finding gaps and weaknesses in the interfaces of complex architectures related to human exploration such as NASA's upcoming Exploration Mission-1 and -2.

"My experience in how systems come together and understanding the complexities of integrating cross-program architectures has helped me lead these assessments and provide insight on what products to analyze and types of gaps to look for," she said.

Referring to her NESC assessment work, "We've built an expansive suite of capabilities using MBSE to analyze interfaces, command and telemetry flows, launch behaviors, and verification and validation of EDL events associated with returning commercial crew to Earth." Ms. Simpson hopes to find opportunities to apply what she has learned at JPL. "There are a lot of similarities. I'd like to see if what we've developed is applicable to our missions here."

Ms. Simpson has enjoyed the opportunity to work with the NESC. "It's an Agency organization that allows you to shed Center biases. It facilitates finding the right people and getting the work done at a technical level, regardless of what Center you're from."



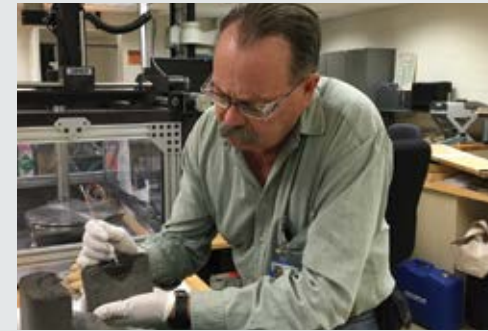
Aron Wolf

"It's an Agency organization that allows you to shed Center biases. It facilitates finding the right people and getting the work done at a technical level, regardless of what Center you're from."

— Kimberly Simpson



Kimberly Simpson



Mark McClure



Fred Martin



Alan Davis

Johnson Space Center

The Johnson Space Center (JSC) and the White Sands Test Facility (WSTF) provided engineering analysis, design, and test expertise for the continuous operation of the International Space Station, development of the Orion Multi-Purpose Crew Vehicle, and consultation for Commercial Crew Program (CCP) vehicles. The NESC Deputy Director for Safety; an NESC Principal Engineer; NASA Technical Fellows for Environmental Control/Life Support, Loads and Dynamics, and Passive Thermal are resident at JSC. JSC personnel provided expertise and leadership to numerous assessments within the Agency relating to CCP entry, descent, and landing; Orion heatshield molded Avcoat block bond verification; frangible joint designs; and lithium-ion battery thermal runaway. The JSC NASA Technical Fellows joined with other Agency discipline leaders to strengthen technical community connections through joint sponsorship and participation in activities such as the Structures, Loads, and Mechanical Systems Young Professionals Forum; the Thermal and Fluids Analysis Workshop; and Capability Leadership Teams to help define the future of NASA technical disciplines.

WSTF Chemistry has Agency-wide Impact

Mark McClure is WSTF's Chemistry Lab Manager with 26 years of experience in chemical/material testing and compatibility assessments. Mr. McClure has been called on to work a number of NESC assessments including *Assessing Risks of Frangible Joint Designs*, where he tested pyrotechnic cords to measure the explosive; *Multi-Purpose Oxygen Generator Swelling*, where he developed methods for sampling the device's pressure and reaction gases; and *Replacement Material Evaluation for Kalrez 1045 Spacecraft Propulsion Component Seals*, where he is testing the material properties of four different manufacturers' perfluoroelastomer (FFKM) products for compatibility with monomethyl hydrazine and nitrogen tetroxide to find a suitable replacement for Dupont's recently discontinued Kalrez 1045. FFKM products are used by multiple NASA projects, so Mr. McClure's work will have an Agency-wide impact. He believes involvement in these NESC assessments "will advance WSTF/JSC materials science



T. Scott West
NESC Chief Engineer

61 JSC employees supported NESC work in FY16

and provide lasting systems and protocols for more detailed tests for qualifying new materials, and develop a deeper understanding of currently accepted materials."

SLS Aerosciences Independent Consultation and Review

Fred Martin, from JSC's Applied Aeroscience and Computational Fluid Dynamics (CFD) Branch, is currently serving as the team lead for the NESC's *Space Launch System (SLS) Aerosciences Independent Consultation and Review* assessment team. Mr. Martin brings 36 years of experience solving fluid dynamics-related issues for the Space Shuttle and X-38, and the assessment team comprises 17 Agency experts and consultants in wind tunnel testing, CFD analysis, database creation, and structural loads. The team is

reviewing the aerodynamic database substantiation reports written by the SLS Ascent Aerodynamic Team to ensure the proper balance of accuracy, conservatism, and uncertainty in the engineering testing, analysis, and database products. Mr. Martin has "enjoyed the opportunity to work with many Agency experts who are the leaders in their technical field. Our discussions of the challenges involved in performing preflight predictions for the SLS launch vehicle have been rewarding for all of us."

Hypervelocity Impact Testing of COPVs

Bruce "Alan" Davis is a Jacobs Technology engineer and is the Lead Test Engineer for the Hypervelocity Impact Technology (HVIT) Group in JSC's Exploration Science Office. Mr. Davis brought 16+ years of hypervelocity impact (HVI) damage assessment experience to the *Micrometeoroid and Orbital Debris (MMOD) Pressure Vessel Failure Criteria* assessment, where he has led the testing of multiple carbon overwrapped pressure vessel (COPV) HVI tests being conducted at WSTF and assessed the resulting visible damage. Mr. Davis' outstanding work is helping to increase the fidelity of risk assessment for spacecraft with COPVs. He reflected, "It's always a pleasure to work with the NESC assessment team; it brings together some of the sharpest minds in our industry to find answers to the many challenges presented by the MMOD risk."

Kennedy Space Center

The NESC was involved in numerous activities for programs at the Kennedy Space Center (KSC) including Commercial Crew Program (CCP) frangible joint testing; CCP entry, descent, and landing modeling; and Ground Systems Development and Operations Program crew module landing and recovery loads analysis. Likewise, KSC provided expertise to 23 different NESC activities and Technical Discipline Teams in 2016. The NASA Technical Fellows for Electrical Power and Materials reside at KSC. KSC was engaged in a variety of NESC assessments including CCP frangible joint sensitivity testing; CCP electrical power systems review; Exploration Systems Development independent flight modeling; and nonlinear slosh damping analysis for launch vehicles. NESC also invested in two KSC physics and electronics laboratories to resolve Agency issues.



Stephen A. Minute
NESC Chief Engineer

46 KSC employees supported NESC work in FY16

opportunity that comes her way. As a structural analyst in KSC's Engineering Analysis Branch, she has participated in the NESC Structures, Loads, and Mechanical Systems Young Professionals Forum (YPF) for the past 2 years. The YPF lets Ms. Yohpe showcase her work to a NASA-wide audience.

In 2015, she presented Correlating Experimental and Finite Element Analysis on Areas of Stress Concentration. "You have an opportunity to present work you are passionate about and receive feedback from experts in the field," said Ms. Yohpe. "It's a great way to network and discuss with experts from all over the Agency who you wouldn't normally have the opportunity to meet."

She also works with the Structures and Loads and Dynamics Technical Discipline Teams, led by NASA Technical Fellows. "Agency-level

problems are intriguing, and I love seeing how KSC fits into the NASA vision."

Analysis through Imagery

As an electrical and materials failure/image analyst at KSC, Larry Batterson specializes in advanced imagery analysis, infrared (IR) imaging, high-speed video, micro-focus x-ray, and photo documentation. During his work on the NESC assessment of a commercial partner's electrical power system, he focused on avionics flight fuse and wire testing. "I learned a great deal about designing board-level test fixtures, modifying complex board assemblies for testing, and effective heat sinking of circuit protection components and their effect on fuse performance," said Mr. Batterson.

With more than 30 years of imaging and electrical failure testing experience, he was an integral part of the test set construction team, assisting with fabrication and instrumentation. Using IR and still photography, he recorded fuse runs and edited IR video of the fuse separation, documenting single point IR temperature measurements and linear temperature histogram plots of the fuse heat profiles. "Going through board design variations, test set changes, and the evolution of the NESC's comprehensive test plan allowed me a 20,000-foot-view of how an advanced technology system like the commercial partner's comes to fruition, moving from the theoretical to flight ready."

Factoring in the Human Component

Improving the interfaces between humans, their tools and equipment, tasks, and work environments is where Katrine Stelges excels. As part of the Test and Operations Support Contract at KSC, Ms. Stelges brought her human factors and industrial engineering expertise to several NESC projects including *Orion Multi-Purpose Crew Vehicle (MPCV) Avcoat Bond Verification* and applying a state-of-the-art human factors analysis tool using motion capture and ergonomics. For a *Ground Operations Human Factors Task Analysis*, she evaluated access and mobility issues for ground crew personnel in pressurized protective suits on the crew access arm between the launch tower and the Orion MPCV.

Ms. Stelges' work can involve physical or virtual mockups; monitoring a task to determine space, visibility, or access issues; performing feasibility studies; or using motion capture technology to evaluate an activity. "We assess any concerns and then look for mitigation options, trying to implement improvements before those concerns become risks," she said. This helps eliminate performance barriers and time delays, while improving safety, operability, and efficiency.

Benefits of Early-Career Networking

Megan Yohpe is taking advantage of every learning



Katrine Stelges



Larry Batterson

Megan Yohpe



Dr. Yuan Chen



Dr. Sotiris Kellas



Patricia Howell

Langley Research Center

The Langley Research Center (LaRC) continues to support the NESC mission to address the Agency's high risk programs and projects. LaRC engineers and scientists contributed wide-ranging technical expertise to lead and support multiple NESC assessments. The assessments reached across the Aeronautics Research, Exploration Systems, Human Exploration and Operations, Science, and the Space Technology Mission Directorates. LaRC is the host Center for the NESC Director's Office, Principal Engineers Office, NESC Integration Office, and the Management and Technical Support Office. The NASA Technical Fellows for Aerosciences, Flight Mechanics, Nondestructive Evaluation, Sensors and Instrumentation, Software, and Structures reside at LaRC.

Understanding the Risk and Reliability of EEE parts

Dr. Yuan Chen's specialty is in electrical, electronic, and electromechanical (EEE) parts and reliability. One of her current efforts is in understanding the different approaches to using commercial parts in critical avionics applications. "It's not just one single part," said Dr. Chen, who works in the Electronic Systems Branch at LaRC. "We have to understand the parts technology, manufacturing process, how parts are selected, reviewed, approved and procured, how parts are used in missions, what environments they will see, their lifetime expectancy, and how they fit into the overall avionics architecture. We have to understand the whole picture so we can understand the risks."

The NESC has requested Dr. Chen's expertise on several assessments involving EEE parts and avionics. "As a part of these teams, either as technical lead or team member, I feel I can make my own contribution and also grow from both technical and leadership perspectives."

Advancing Structural Design

Dr. Sotiris Kellas works in the LaRC Engineering Directorate in the Atmospheric Flight & Entry Systems Branch, where he specializes in the design, fabrication, and testing of composite structures. "I design passive landing systems, most of which are made of composites. We can choose how to combine the materials and get creative in designing lightweight energy absorbers for these systems," he said.



Paul W. Roberts
NESC Chief Engineer

207 LaRC employees supported NESC work in FY16

Dr. Sotiris served as the Test and Verification Lead for the *NESC Composite Crew Module Pressure Vessel* project. He also served as the test lead for the Orion Multi-Purpose Crew Vehicle (MPCV) Thermal Protection System (TPS) carrier structure redesign and helped evaluate the effects of the carrier structure on the TPS as well as how TPS (honeycomb Avcoat) material property measurements were obtained.

Most recently he served on the NESC team for the *MPCV Avcoat Study and the Bond Verification Plan* for Orion's Molded Avcoat Block Heatshield Design Team. The team is working with the commercial partner to develop verification methods for the block Avcoat architecture. "I feel fortunate to be part of these high profile projects," said Dr. Kellas. "They are very unique, challenging, and exciting."

NDE Techniques Benefit Multiple NESC Assessments

As part of the Nondestructive Evaluation Sciences (NDE) Branch at LaRC, Patricia Howell has used her thermography and x-ray expertise to assist the NESC in thermography inspections of the reinforced carbon-carbon leading edge of the Space Shuttle's wings, inspections of the NESC's pathfinder composite crew module, and in analyzing infrared imagery of radiators aboard the International Space Station. More recently she participated in carbon-carbon silicon carbide material characterization, helping to develop a certification path for the attitude control motor pintle and pintle guide for the launch abort system of the Orion MPCV. She is also assisting with the NESC's *Micrometeoroid and Orbital Debris Pressure Vessel Failure Criteria* assessment.

Ms. Howell's role involves analyzing and quickly compiling countless data, gathered from her NDE techniques, to discover the microscopic signals left by flaws or defects. NDE work allows her the "ability to affect safety and that's rewarding," she said. Working on the assessment teams also gives her insight into other technical disciplines. "I get to see why our NDE data is so important and how it is helping them."

Marshall Space Flight Center

In 2016, the Marshall Space Flight Center (MSFC) provided engineer, scientist, and technician support to over 25 NESC assessments and investigations. These activities involved the areas of exploration systems development, space operations and environmental effects, science, and crosscutting discipline activities.

Some of the more significant efforts include: composite shell buckling, additive manufacturing, high temperature insulations, advanced chemical propulsion, modeling and simulation of complex launch vehicle/spacecraft interfaces, and human factors task analyses. The NASA Technical Fellows for Propulsion and Space Environments and the Discipline Deputies for the Human Factors, Nondestructive Evaluation, Propulsion, Nuclear Power and Propulsion, Software, and Space Environments Technical Discipline Teams (TDTs) are resident at MSFC. MSFC provided critical support to numerous NESC investigations and 20 of the 21 NESC TDTs with over 125 engineers and scientists.



Steven J. Gentz
NESC Chief Engineer

125 MSFC employees supported NESC work in FY16

Design and Integration Division, Mr. McRight began to serve in 2015 as a part-time Discipline Deputy for Propulsion, and a senior technical advisor for the Propulsion Systems Department. His NESC involvement ranged from developing rationale for NASA's future propulsion facility needs to developing independent recommendations regarding the costs vs. benefits of nondestructive evaluation after proof tests. Mr. McRight has taken on special projects to energize the NASA propulsion community including: developing a quarterly newsletter, coordinating technical briefings for TDT meetings, and reinvigorating the propulsion community web page. Mr. McRight said that "working with the NESC has been enormously satisfying because the issues that come to us for evaluation are consistently challenging. Experiencing the NESC's ability to tap the brightest minds across the community while helping to solve important problems is a reward in itself."

Slosh Testing Team

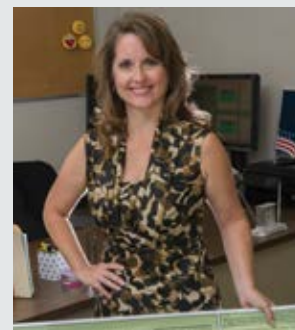
Russel (Rusty) Parks has worked as a dynamic analysis and test engineer for over 27 years. His branch is primarily responsible for vibration, acoustic, and modal testing, but has expanded scope to support slosh testing almost a decade ago under the Constellation Program. In 2015, Mr. Parks was joined by Alex McCool and Marlon Holt to perform NESC-sponsored slosh testing for scaled SLS core stage and exploration upper stage propellant tanks. Mr. Parks, who joined NASA this year through the co-op program, commented that his NESC experience has been a "good building block for a young engineer. It isn't hitting any important, expensive hardware with a hammer, and it isn't in someone else's building/lab where we have limited access or time. This allows for more of a learning experience." Mr. Parks joined NASA as an electrical power engineer in 2009, and moved to the Structural Dynamics Test Branch in 2015. Together, the slosh testing team is paving the way for the development of empirically based nonlinear slosh damping models to replace the traditional lower-fidelity, more-conservative linear damping models. This improved damping characterization is anticipated to have positive implications on the baffle designs and launch vehicle control performance within and outside of NASA.

Space Environments TDT Support

Linda Parker is a space physicist with over 20 years of experience working on numerous NASA projects and programs including: the International Space Station, Chandra X-ray Observatory, James Webb Space Telescope (JWST), Deep Space Climate Observatory, Space Launch System (SLS), and the Commercial Crew Program. Ms. Parker brings expertise in particle acceleration at shocks in the heliosphere, spacecraft charging, and space plasma environment definition to her TDT support. Her background includes space environments theory, modeling, data analysis, and particle instruments. Ms. Parker currently supports the NASA Technical Fellow for Space Environments as his Deputy for Space Weather and Spacecraft Charging and is serving as the technical lead for the *JWST Space Environment Launch Constraints* assessment.

Propulsion TDT Support

Patrick McRight is a propulsion engineer with over 27 years of experience with NASA. Formerly the branch chief for MSFC's Spacecraft Propulsion Systems Branch and, more recently, the chief of the Liquid Propulsion Systems



Linda Parker



Rusty Parks, Marlon Holt, and Alex McCool



Patrick McRight



Rebecca Deschamp

Stennis Space Center

The Stennis Space Center (SSC) provided expert technical support to the NESC, including materials expertise to an oxygen purity Technical Interchange Meeting at KSC. SSC has members on several NESC Technical Discipline Teams (TDTs) including members on the Human Factors, Nondestructive Evaluation, and Systems Engineering TDTs. SSC enabled the open exchange of ideas and collaborative decision making by utilizing the unique locale, transportation capabilities, and cost effectiveness by hosting five TDT yearly face-to-face meetings at nearby Michoud Assembly Facility and SSC facilities.

Transitioning to an MBSE Environment

As a technical data architect who ensures all engineering design data generated at SSC is gathered into one common location, Rebecca Deschamp is very familiar with the development of collaborative engineering environments. Her work serves her well in her role as a member of the Systems Engineering TDT, where she is part of a small model-based system engineering (MBSE) pathfinder team. "We're doing the up-front work to blaze the path for future teams who are operating and transitioning to an MBSE environment."

Assigned to the Sounding Rocket Program Mission Shadowing Team, Ms. Deschamp and the team are focused on taking documents used at design review and modeling them in the systems engineering tool. "Our team has been focusing on creating model libraries so future sounding rocket teams may take our model and our libraries and use them as templates so they aren't starting from scratch."

The team has found several important areas where early conceptual models could provide benefit not only to the program office but also contractors and mission customers, she said.

"As everyone's models have become more mature, we're all beginning to see the value of common systems engineering libraries and glossaries, standardization, and

"And if I have a problem, even if it's not related to mechanical systems, I have an entrée to that Center and within three phone calls, I can get help on any problem I need."

— Thomas Jacks



Thomas Jacks



Michael D. Smiles
NESC Chief Engineer

18 SSC employees supported NESC work in FY16

reuse. We've had a chance to talk to the customer and the engineers and really get insight from them on what their issues are and address them in the model. So we have a good start on a model that can be re-used across the Agency."

Network of Technical Experts

For about 6 years, Thomas Jacks has been a member of the Mechanical Systems TDT, which includes scientists and engineers who specialize in mechanisms and tribology from each NASA Center as well as industry. Together and in small groups, they take on some of NASA's toughest engineering problems in mechanical systems. "The team has performed numerous failure analyses that are models of engineering investigation," said Mr. Jacks. Over the years, he has "been impressed with the thoroughness

that goes into a proper engineering assessment, the need for patient rigor, and designing the solution to the problem at hand."

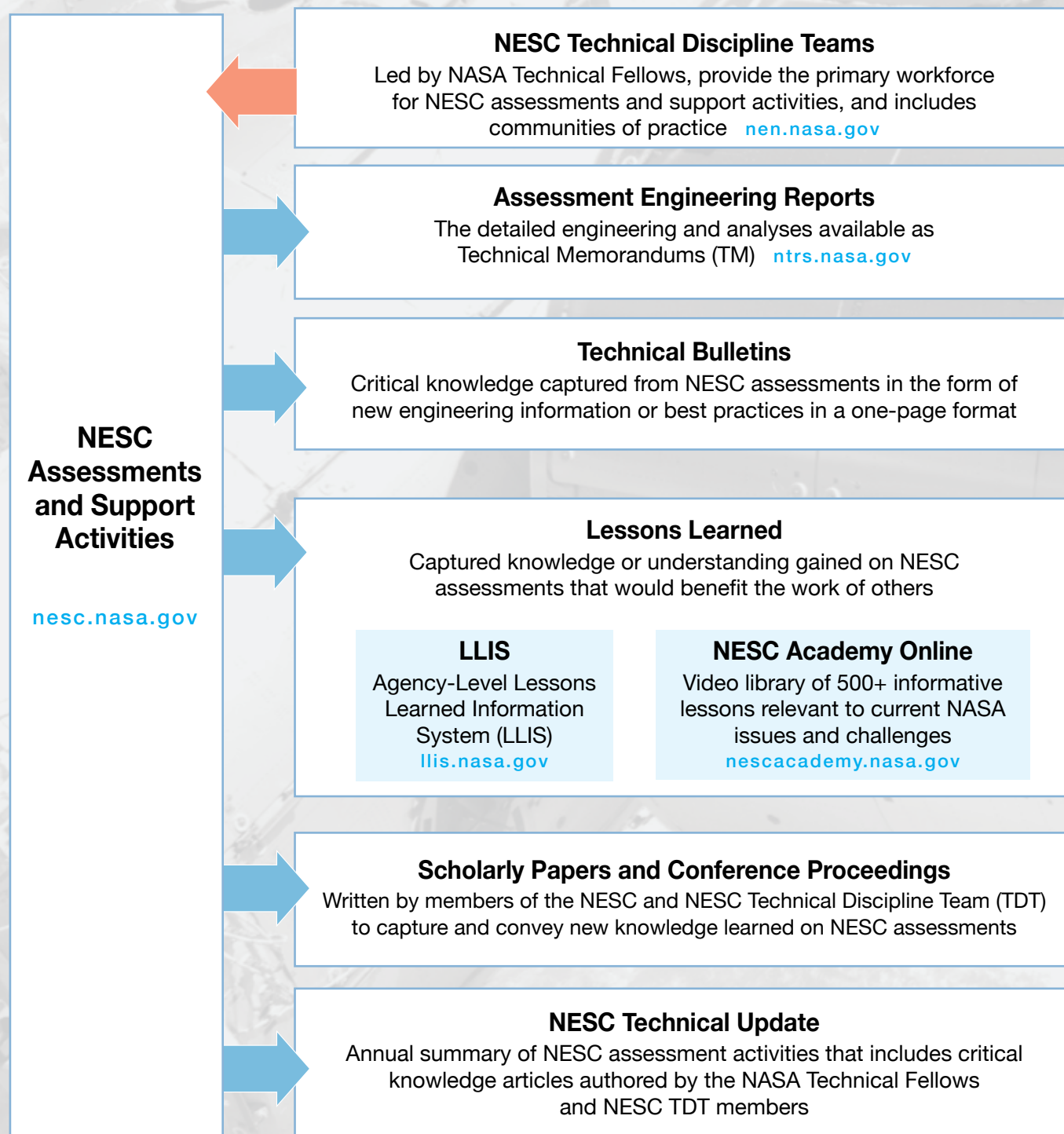
At SSC, Mr. Jacks is the Deputy Chief of the Mechanical Design and Analysis Branch, which performs design for rocket test facilities, special test equipment, special components, and cryogenic systems — all things geared for rocket propulsion tests. That expertise in propulsion testing operations at SSC guided his feedback to the TDT recently when he reviewed a propellant loading study involving a commercial partner.

Working with the TDT offers a continuous learning experience, he said. "It's very insightful to see what other Centers in the Agency are doing — the types of engineering problems they are encountering that are out of my bailiwick. And if I have a problem, even if it's not related to mechanical systems, I have an entrée to that Center and within three phone calls, I can get help on any problem I need. It's a very valuable network of technical experts to have."

NESC Knowledge Products

Capturing and preserving critical knowledge for the future

The NESC is engaged in activities to identify, retain, and share critical knowledge in order to meet our future challenges. To disseminate that knowledge to engineers – within NASA, industry, and academia – the NESC offers a wide variety of knowledge products that can be readily accessed from technical assessments reports to technical bulletins to video libraries.



NESC Academy Online

The NESC Academy Online is an innovative video library featuring informative lessons on topics relevant to current NASA issues and challenges. The NESC Academy presents live and on-demand content from researchers, engineers, and field experts in numerous disciplines. It delivers over 400 hours of interviews, tutorials, lectures, and lessons learned in an engaging format that features side-by-side video and slides, powerful search capabilities, downloadable course materials, and more. Viewers can learn from NASA's senior scientists and engineers as well as recognized discipline experts from industry and academia. In calendar year (CY) 2016, more than 107 new video lessons were released with such varied topics as heating mechanisms of lithium-ion batteries, model-based systems engineering, human factors considerations for flight, and possible future exploration of Mars' moon, Phobos.

The NESC Academy offers the audience a virtual, self-paced classroom experience based on a state-of-the-art video player for education, which enables dual video streams for content, typically one for the presenter and another for presentation materials. Desktop and mobile devices are supported.

A popular feature of the NESC Academy is live technical webcasts provided as a service to the discipline communities, which are archived for later viewing. Viewers can send in questions to the presenter during the broadcasts for two-way interaction.

The NESC Academy videos have received more than 50,000 views since inception, with more than 15,000 views in CY 2016, illustrating the popularity of this approach among NESC Academy users. The NESC Academy video catalog is available at nescacademy.nasa.gov.

Most Viewed Videos by Discipline for CY 2016

Discipline	Video
Assessments	Focusing on the Factor, Shell Buckling Knockdown Factor Past to Present
Aerosciences	Ares Launch Vehicle Transonic Buffet
Avionics	Electromagnetic Compatibility (EMC): Antennas - Lecture, Part 1
Electrical Power	High Voltage Engineering Techniques for Space Applications: Part 1, Background Engineering Discussion
Flight Mechanics	Standard Check-Cases for Six-Degree-of-Freedom Flight Vehicle Simulations
GNC	Autonomous Deep Space Navigation
Human Factors	How To Make the Most of Your Human: Design Considerations for Single Pilot Operations (Webcast)
Life Support/ Environmental Control	EVA Development and Verification Testing at NASA's Neutral Buoyancy Laboratory
Loads & Dynamics	Shock & Vibration: 01. Natural Frequencies, Part 1
Materials	Apollo 13 Pressure Vessel Failure
Mechanical Systems	An Overview of Fastener Requirements in the new NASA-STD-5020
NDE	Introduction to Probability of Detection (POD) for Nondestructive Evaluation (NDE)
Passive Thermal	Rationale for Selected MIL-STD-1540E Thermal Test Requirements
Propulsion	Saturn Launch Vehicles: Engine Restart and Propellant Control in Zero-g
Software	Introduction to Software Engineering 01: Course Introduction
Structures	Buckling, Shells, Knockdown Factors, and Validation Testing
Systems Engineering	Model-Centric Engineering, Part 1: Introduction to Model-Based Systems Engineering
Other	Rapid Development Projects



Top three viewed videos

- 1. Human Factors - How To Make the Most of Your Human: Design Considerations for Single Pilot Operations**
- 2. Systems Engineering - Model-Centric Engineering, Part 1: Introduction to Model-Based Systems Engineering**
- 3. Life Support/Active Thermal - EVA Development and Verification Testing at NASA's Neutral Buoyancy Laboratory**

NESC Priority 1: Technical support of projects in the flight phase

Priority 1: Completed Work



Columbus module integrated into the ISS.

ISS Columbus Module Moderate Temperature IFHX Temperature Response Test

In December 2013, a valve failure in the external thermal control loop on the International Space Station (ISS) resulted in conditions that might have damaged the Columbus module interface heat exchanger (IFHX). The heat exchanger allows the transfer of heat from a water loop, bringing heat from the interior of the ISS, to an ammonia loop, which rejects heat into space via the radiators. During the anomaly, the NESC was asked to assist with analysis to determine if the IFHX was damaged.

The NESC remained engaged with the ISS Program until the system was operating nominally. During mission support activities and the follow-on close call investigation, concerns that were raised led to improved IFHX analysis capabilities, which were needed due to the great number of similar heat exchangers used on board the ISS. The NESC conducted thermal response testing to gather data suitable for anchoring thermal response models. *This work was performed by JSC and LaRC.*

Priority 1: In Progress

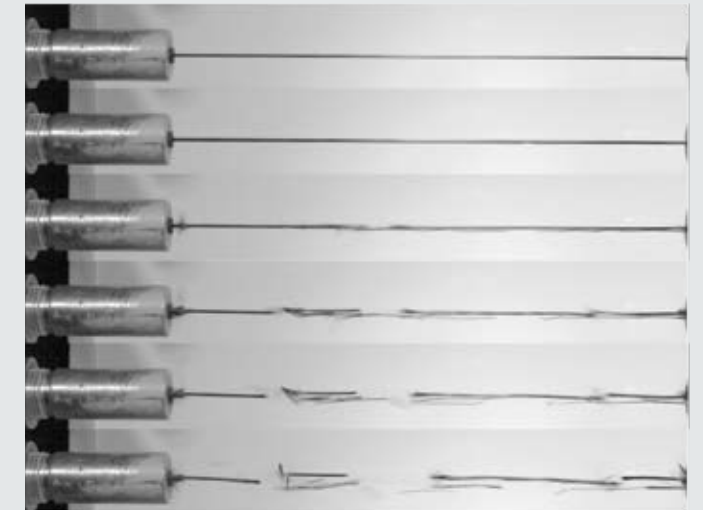
- ISS Solar Boom Array Thermal Issues
- Human Spaceflight-1 Mishap Recurring Factor Study
- Minimum Wear Life for the ISS Pump Control Valve Package Rotor Bearing System
- Ground Testing to Assess the ISS Ultrasonic Leak Location Concept
- Multi-Purpose Oxygen Generators Swelling
- ISS/Extravehicular Activity Lithium-Ion Battery Thermal Runaway Severity Reduction Measures
- SpaceX Failure Investigation Support
- Composite Overwrapped Pressure Vessel Liner Inspection Capability
- Rapid Slews for Lunar Reconnaissance Orbiter
- Best Practices for Organizational Resilience in the ISS Program
- Mars Organic Molecule Analyzer Wide Range Pump Qualification Model Failure Review Board
- Extravehicular Mobility Unit Water Pump Redesign
- Hubble Space Telescope Gyro 1 & Gyro 2 Elevated Motor Current Investigation
- Simplified Aid for Extravehicular Activity Rescue Safety Battery
- ISS Plasma Interaction Model Independent Review
- NASA Docking System Non-Compliance Review
- Center Burst Cracks Present on Bearing Balls in NASA Mechanisms
- Express Logistics Carrier Reverse Capacitor Follow-on Testing
- Chandra X-Ray Observatory Advanced Composition Explorer Real-Time Data Support

NESC Priority 2: Technical support of projects in the design phase

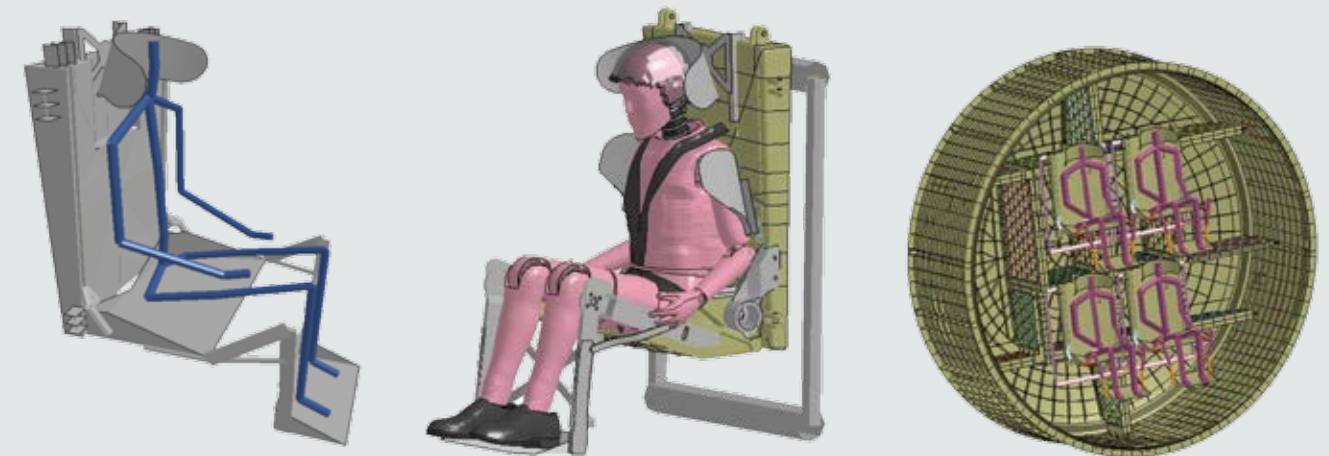
Priority 2: Completed Work

Carbon Fiber Strand Tensile Failure Dynamic Event Characterization

Composite overwrapped pressure vessels (COPVs) are essential elements of most modern spacecraft. The NESC identified the need to incrementally improve the database regarding COPV mechanics and physics of failure by pulling carbon fiber strands to failure and recording and characterizing the process with high-speed photography and photogrammetry. This effort provided failure-related information that is additional and complementary to data being gathered from test articles under the NESC assessment *COPV Stress Rupture Reliability* and NASA Composite Pressure Vessel Working Group activities. *This work was performed by LaRC, MSFC, and JPL. NASA/TM-2016-219188*



Failure of a carbon strand test specimen captured by high-speed video.



Human vibration FE model (left), anthro-pomorphic test dummy FE model (center), and representative seat placement for coupled loads analysis (right).

Human Vibration Modeling for Orion Multi-Purpose Crew Vehicle Coupled Loads Analysis

The use of impact test dummies and their surrogate finite element (FE) models are important tools used to investigate human response and occupant protection measures to adverse environments. The advantage of high-fidelity FE models is the ability to more quickly analyze environments and the benefits of occupant protection approaches prior to conducting tests with full-size anthropomorphic test dummies. The NESC identified the need to develop a more accurate FE model of a representative crew member

to include a more correct distribution of a human's mass and vibration response. The scope of the two-phased assessment included developing a higher fidelity FE model for use in coupled structural loads assessments, providing a more realistic distribution of human mass and vibration response, and developing a low-level human subject vibration test plan. *This work was performed by LaRC, JSC, and GRC. NASA/TM-2016-219208*

NESC Priority 2: Technical support of projects in the design phase

Priority 2: Completed Work *continued*

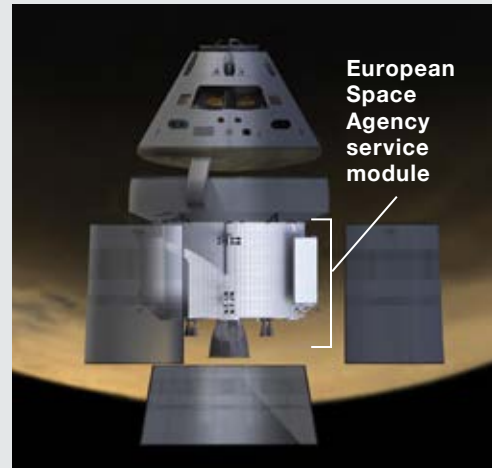
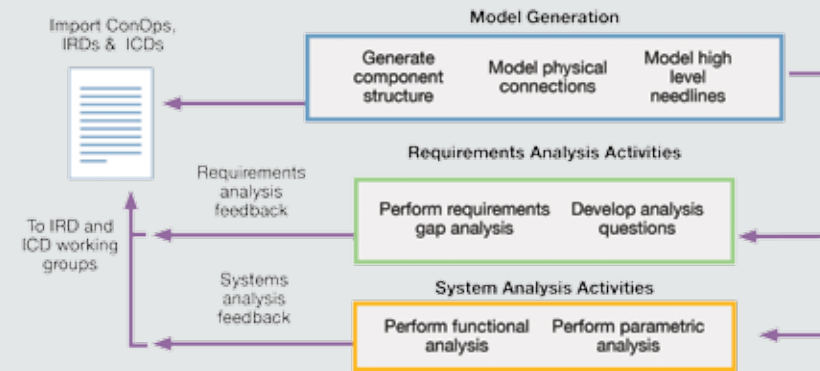


Illustration of the Orion MPCV.



A model-based systems engineering approach was used to determine completeness of CM-ESM interfaces.

Review of MPCV Program CM-ESA Service Module Interfaces

Interfaces let major system components exchange electrical signals and information in an agreed upon manner and enable independent development, provided component developers adhere to the interface requirements. The MPCV Program Chief Engineer requested that the NESC perform an assessment of the MPCV Program crew module (CM)-European Space Agency Service Module (ESM) interfaces including the government-furnished equipment embedded in the ESM to ensure there are no

gaps or miscommunications regarding exchanges across the interface. The assessment focused on analyzing the CM-ESM interface requirements document using a model-based systems engineering approach to check for technical gaps and inconsistencies that may have existed in the design documentation but have been difficult to uncover via the document-based review process applied to date. *This work was performed by GSFC, MSFC, JPL, and GRC. NASA/TM-2016-219212*



Many NASA satellites rely on single-board computers.

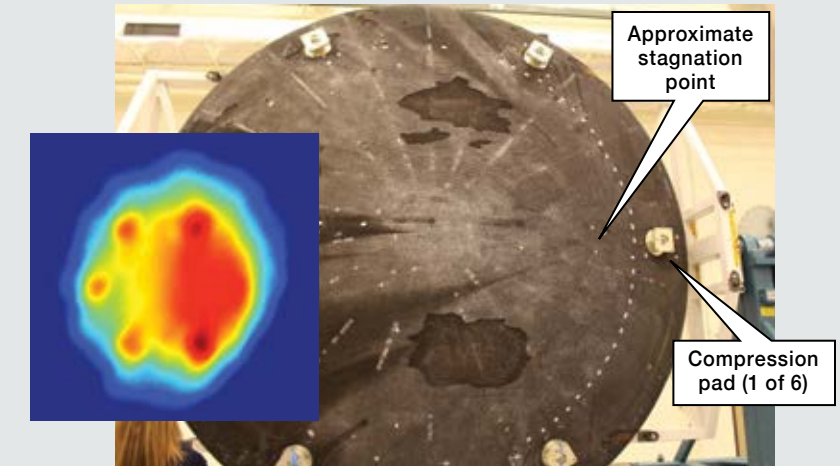
Single-Board Computer Panels

Satellites rely on the volume and mass savings provided by single-board computers (SBCs). The GSFC Electrical Engineering Division requested that the NESC assess the latest version of SBC printed circuit board (PCB) panels being considered by multiple contractors for use on NASA spaceflight missions. GSFC performed earlier investigations into this SBC reliability. In Phase I of this two-phase assessment, the NESC team was tasked to determine if manufacturer changes to the SBC PCBs were sufficient to allow consideration of this product for future flight use. In Phase II, the NESC evaluated changes to the SBCs incorporated by the manufacturer based on recommendations from the Phase I study, and performed tests and reviewed manufacturer test data to help identify problems early in the manufacturing process to give NASA greater confidence about the SBC reliability. *This work was performed by LaRC and GSFC. NASA/TM-2016-219187*

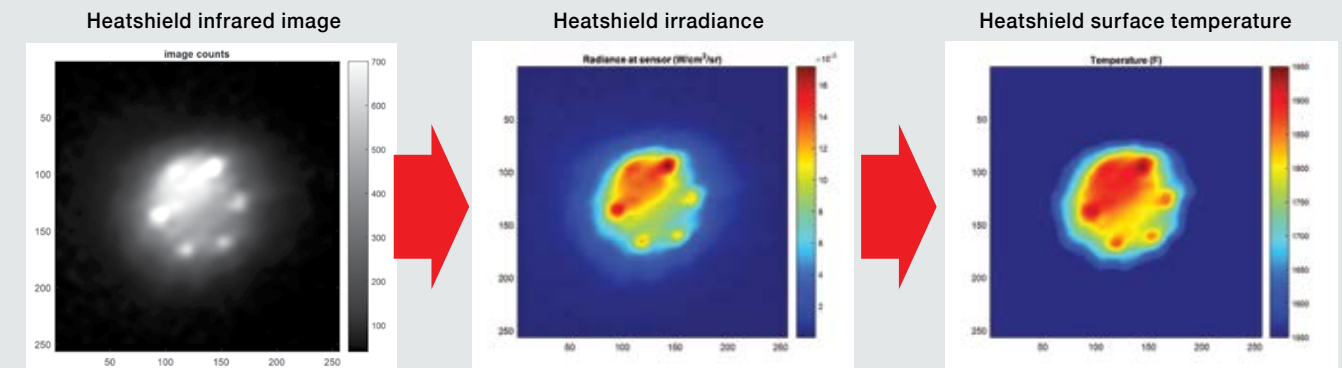
NESC Priority 2: Technical support of projects in the design phase

Remote Imaging of EFT-1 Entry Heating Risk Reduction

Exploration Flight Test 1 (EFT-1) was conducted in December 2014 and was the first entry flight test for the Orion crew module. A flight test objective was to measure heatshield surface temperatures during peak heating. JSC personnel requested NESC support in executing a remote imaging campaign to collect EFT-1 aerothermal environment data during entry. The NESC effort included a flight test data collection effort and a data processing phase that converted infrared imaging data into useful temperature data. *This work was performed by LaRC.*



EFT-1 flown heatshield with corresponding temperature map.



Conversion from infrared pixel counts to heatshield temperature map.

Orion MPCV Program Window Wavefront Measurement Capability Development

To verify that uninstalled flight window assemblies for the Orion MPCV have minimal distortion, KSC's Applied Physics Laboratory partnered with the NESC in the development of a wavefront measurement capability at KSC in close proximity to the MPCV crew module assembly site. The measurement required the construction of an optical interferometer-based wavefront measurement system consisting of an off-the-shelf interferometer and a custom scanning system. Training, testing, and analysis was required to ensure the system could meet the new flight requirement. *This work was performed by LaRC, KSC, and JSC. NASA/TM-2016-219207*



Wavefront measurements were used to characterize Orion CM window flatness.

See: [Measuring Window Flatness Using Optical Interferometry, Page 39](#)

NESC Priority 2: Technical support of projects in the design phase

Priority 2: Completed Work *continued*



Ground test of a full-scale ACM for the LAS (left). ACM seen operating during the Pad Abort-1 flight test.

ACM C/C-SiC Component Performance Testing Approach for Certification

The MPCV launch abort system (LAS) is designed to provide reliable crew safety over the launch trajectory to orbit in the event of a launch vehicle mishap. The Orion MPCV Chief Engineer requested that the NESC assist the LAS Project Office (LASO) in developing a path for certification of the attitude control motor (ACM) pintle and pintle guide. The recently completed Phase II carbon/carbon-silicon carbide (C/C-SiC) material characterization and modeling

assessment recommended an empirical performance testing approach be pursued for ACM critical component certification. The NESC assisted the LASO in conducting a knowledge gap study, supporting the development of a risk mitigation plan, and hot-fire testing. The assessment's scope included a go-forward strategy consultation with LASO and hot-fire testing. *This work was performed by LaRC, JSC, and MSFC.*

Stability of the SLS Flight Control System with Adaptive Augmentation

The newest and largest NASA launch vehicle ever built will include a modern flight control system. The Space Launch System (SLS) flight controls lead requested that the NESC assess the SLS adaptive augmenting control (AAC) algorithm's stability and flight readiness, in partnership with the SLS Program, by providing a consolidated and comprehensive set of internal and external analyses in support of the rationale for flight readiness. The AAC modifies the total attitude control system response to provide the classical gain-scheduled control architecture with additional performance and robustness. Multiple analysis methods that specifically targeted the SLS AAC techniques were used to analyze stability and assess flight readiness, with each technique adding its own insights. *This work was performed by LaRC and MSFC.*



The SLS will use the AAC algorithm in the vehicle's flight control system.

NESC Priority 2: Technical support of projects in the design phase

Priority 2: Completed Work



Artist illustration of NASA's SLS launch vehicle and Orion spacecraft on the mobile launcher at Launch Pad 39B at KSC.

Modeling of Crawler-Transporter, Mobile Launcher, and Forcing Functions

When stacked on the mobile launcher (ML), the Orion MPCV and SLS vehicles will weigh in excess of 5.5 million pounds. And like other NASA launch vehicles before it, it will use the crawler-transporter (CT) to move the ML from the assembly building to the launch pad. The NESC identified the need to perform modeling and test correlation using ADAMS and NASTRAN to characterize

both the dynamic response of the CT/ML and the forcing functions generated by the roller and tread interaction with the roadway and provide accurate modeling of the dynamic response of the integrated MPCV/SLS stack on the CT/ML during rollout to the launch pad. *This work was performed by JSC, GSFC, JPL, LaRC, and KSC.*

Orion MPCV GNC/FDIR Independent Review

Fault detection, isolation, and recovery (FDIR) technology is becoming an important approach to incorporating resilience and robustness into space systems. The guidance, navigation, and control (GNC) FDIR system is part of the Orion MPCV onboard flight software. The NESC performed an independent technical review of the MPCV GNC FDIR system's requirements flowdown process, the detailed design of individual algorithms, and plans for verification and validation testing. *This work was performed by GSFC, LaRC, JPL, ARC, JSC, and GRC.*

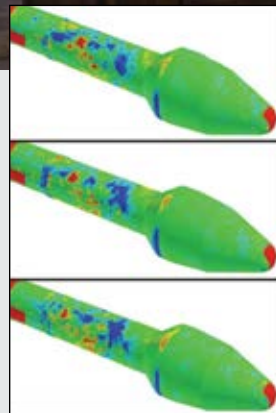


NESC Priority 2: Technical support of projects in the design phase

Priority 2: Completed Work *continued*



Generic launch vehicle of Coe and Nute covered with pressure sensitive paint and pressure taps.



Fluctuating pressure distributions at three consecutive time steps derived from uPSP.

Investigation of uPSP and a Dynamic Loads Balance to Predict Launch Vehicle Buffet Environments

Aerodynamic loads due to unsteady flow are difficult to predict and model. Presently, buffet environment data for launch vehicles are acquired through wind tunnel testing of models using hundreds of unsteady pressure transducers. Even with this large number of sensors, this coverage is not sufficient to provide unsteady integrated loads on the vehicle, and the coarse spacing of the sensors results in buffet environments that are conservative in their prediction of buffet loads between the transducers. The NESC identified the need to investigate innovative test techniques for acquiring launch vehicle buffet data using a combination of unsteady

pressure sensitive paint (uPSP) and a dynamic loads balance to investigate their potential to better predict vehicle buffet environments. The assessment's scope included tests that demonstrated the ability of uPSP to measure buffet loads on a launch vehicle configuration and high spatial-density measurements to verify current processing techniques for computing buffet forcing functions. The work also verified computational fluid dynamics methods for computing time-accurate flow over a launch vehicle. *This work was performed by LaRC, ARC, MSFC, and JSC. NASA/TM TBD.*

See: [Unsteady Pressure Sensitive Paint for Measuring Launch Vehicle Dynamics Buffet – Page 38](#)

MMAC Loads Analysis Methodology

Over the past 25 years, JPL has successfully developed and applied an effective and cost saving modal mass acceleration curve (MMAC) loads analysis methodology for computing launch loads for spacecraft structural design. In recent years, strong interest in this methodology has been shown, but the only available MMAC documentation was from 1989. JPL requested that the NESC develop a report that details MMAC loads analysis methodology for

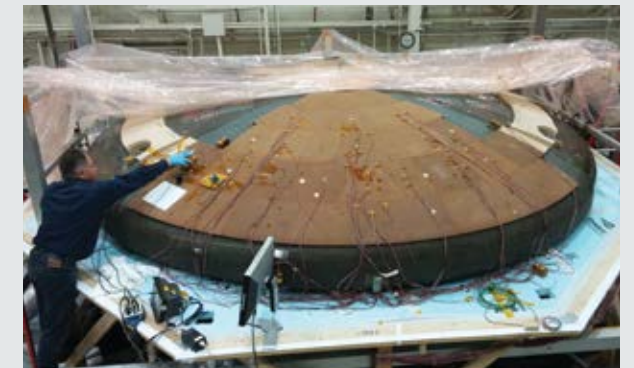
use by the Loads and Dynamics Community of Practice. This assessment generated a comprehensive report that details the theory, application, and example results for distribution to the wider community. Data processing, parameter sensitivity studies, and several case studies comparing MMAC-derived loads with those determined through coupled loads analysis are included. *This work was performed by LaRC, JSC, and JPL.*

NESC Priority 2: Technical support of projects in the design phase

Priority 2: Status Brief

Avcoat Block Bond Verification Support

The NESC is providing technical support to the MPCV Program for the development of a molded Avcoat block heatshield to be used on the Orion CM for the Exploration Mission-1. Support includes nondestructive evaluation (NDE) strategies to assist in the verification of the critical bond between the ablative material and the heatshield carrier structure. Dr. Shant Kenderian, of The Aerospace Corporation, is pictured performing an inspection of the bonding condition between the Avcoat block and composite substrate. The NESC/Aerospace team developed a new ultrasonic NDE technique to evaluate the bond quality by passing the signal through the ablative blocks of material.



Prototype Orion CM heatshield.

See: [Bond Quality Inspection for Orion Heatshield Blocks – Page 36](#)

Priority 2: In Progress

- Peer Review of the MPCV Aerodynamic/Aerothermal Database Models and Methods
- LAS Risk Mitigation
- Exploration Systems Independent Modeling and Simulation
- SLS Aerosciences Independent Consultation and Review
- Independent Modeling and Simulation for Commercial Crew Program Entry, Descent, and Landing
- Evaluation/Validation of Range Safety LAST Distance Focusing Overpressure Model
- SLS RS-25 Nozzle Flow Transient Acoustics Design Load Specification Refinement
- Analysis of Anthropomorphic Test Dummy Response for Proposed Orion Crew Impact Attenuation System
- Human Factors Review of Space Network Ground System Sustainment Project
- Assessing Risks of Frangible Joint Designs
- Orion Tube Weld Digital Radiography
- MPCV Avcoat Study
- Stress Ruptures COPV
- Composite Pressure Vessel Working Group
- Effects of Humidity on Dry Film Lubricant Storage and Performance
- Commercial Crew Provider Electrical Power System Review
- Soil Moisture Active Passive Radar Boom Assembly Deployment Risk
- Independent Assessment of the Backshell Pressure Field for Entry, Descent, and Landing (Mars 2020)
- Stratospheric Aerosol and Gas Experiment-III Interface Adapter Module Subsystem Anomaly
- Nonlinear Slosh Damping Analysis for Launch Vehicles
- Development of a Manned Vehicle Reentry Thermal Protection System Damage Assessment and Decision Plan
- Evaluation of Micrometeoroid/Orbital Debris Risk Predictions with Available On-orbit Assets
- Risk Reduction of Orion Government-Furnished Environmental Control and Life Support System
- Infrared Laser Sensor Technology Readiness and Maturation
- SLS Vibroacoustics Plans and Analysis (Follow-On)
- Alternative Orion Small Cell Battery Design
- Application of System Identification to Parachute Modeling
- CCP Avionics Architecture Review
- Bond Verification Plan for Orion's Molded Avcoat Block Heatshield Design
- Solar Probe Plus: FIELDS Whip Antenna
- Orion Titanium Hydrazine Tank Weld - Sustain Load Cracking Issue
- SLS Program Block I Booster Element Alternate Internal Insulation Risk Reduction
- Exploration Systems Development Verification and Validation Plan
- Electrical, Electronic, Electromechanical Parts Testing for CCP
- Independent Review of Additive Manufacturing Development Plans
- James Webb Space Telescope Space Environment Launch Constraints
- Independent Verification of Abort Loads
- Commercial Crew Aerodynamics Peer Review
- CCP Verification and Validation Integration and Mapping
- Static Software Analysis of the NASA Autonomous Flight Termination Software
- Support for Metallic Tank Diaphragm Fracture Test
- Exploration Mission-1 Thermal Protection System Flight Data Augmentation

Continued next page

NESC Priority 2: Technical support of projects in the design phase

Priority 2: In Progress

Continued from previous page

- NESC Peer Review of Exploration Systems Development Integrated Vehicle Modal Test, Model Correlation, Development Flight Instrumentation, and Flight Loads Readiness
- James Webb Space Telescope Shaker Anomaly
- Fracture and Reliability of Propulsion/ Environmental Control and Life Support System Valve Bellows Seals
- CCP Review of NDE of SpaceX Additive Manufacturing
- Parts-level vs. Board-level and Box-level Screening Testing
- Proof Factor Assessment for COPVs
- Burst Factor Assessment for Pressure Vessels
- CCP Turbopump Cracking Concern
- CCP Systems Engineering and Integration Processes
- CCP Incremental Risk
- NISAR Micrometeoroid/Orbital Debris Independent
- Ascent Abort-2 Independent Review Team
- Independent Verification of SLS Block 1 Pre-Launch, Liftoff, and Ascent Gust Methodology and Loads
- B-2 SLS Green Run Handling Processes
- CCP Load and Go Assessment
- SLS Liftoff Environment Models
- JPL Battery Failure Study
- Independent Peer Review of GSDO/SLS System Umbilical Modeling
- Flight/Load Indicator Development and Usage
- Evaluation of Occupant Protection Requirement Verification Approach by CCP Partners
- Viscous Effects on Launch Vehicle Ground Wind Induced Oscillations
- ESM Major Propulsion Design Upgrades
- Orion SIMULINK GNC Code Generation
- Potential Common-Cause Controller Issues: Plumbrook Mechanical Vibration Facility and GSFC James Webb Space Telescope Systems
- Parachute Modeling Capability Gap Discussions
- Electrical Power for High-Voltage DC Battery Close-Call Investigation at AFRC
- Commercial Crew PCB Short-Circuit Destructive Testing (SpaceX PCB Test)
- Orion CM Well Deck Recovery Conditions Dynamics Analysis
- Commercial Crew Aerodynamics Boeing Peer Review

NESC Priority 3: Known problems not being addressed by any project

Priority 3: In Progress

- Shell Buckling Knockdown Factor Proposal
- Rad750 Qualification Testing
- Implementation of JR-A Methodology into the NASGRO/FADD Codes to Improve Crack Instability Analysis
- Micrometeoroid/Orbital Debris Pressure Vessel Failure Criteria
- Development of Softgoods Design Factors of Safety
- Additive Manufacturing Structural Integrity Initiative Project Oversight and Support
- CubeSat Radiation Environments and ISS Radiation Dose Data
- Replacement Material Evaluation for Kalrez 1045 Spacecraft Propulsion Component Seals

Priority 3: Status Brief



Sector views of failed composite shell.

Another Milestone Reached in Shell Buckling Assessment

Watching an 8-foot tall, 8-foot in diameter composite cylinder buckle under a near 900,000 pound load was the fun part. “Now the real work begins,” said Dr. Marc Schultz, who led the test on a subscale barrel meant to simulate a launch vehicle. The test is part of the NESC’s ongoing *Shell Buckling Knockdown Factor* assessment.

Since 2007, the NESC has spearheaded the effort to determine if conservatism applied to Apollo-era knockdown factors (KDFs), which account for the unknown variability in cylinder buckling loads, are still warranted with today’s advanced technology. New KDFs will help shave weight from today’s space structures, like NASA’s Space Launch System, allowing room for more payload — a necessity for trips to Mars and beyond. The assessment reached a milestone in 2013 as the NESC team’s new KDFs for metallic cylinders were used in the design of the SLS core stage. The use of these new factors resulted in a 5-8% mass savings.

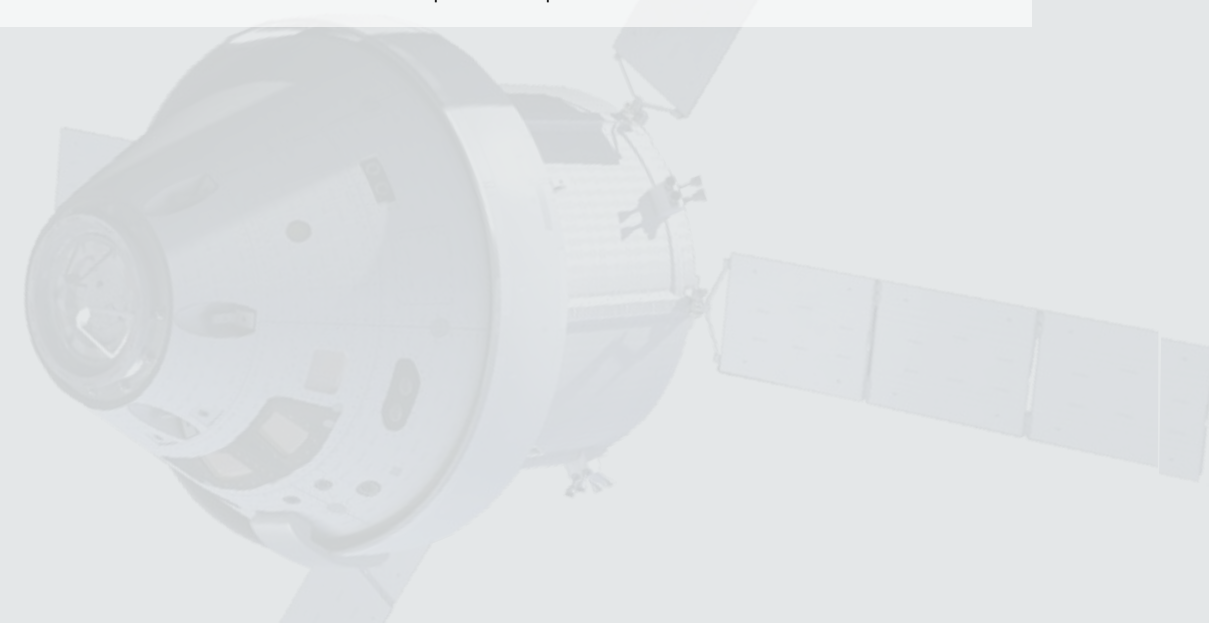
This successful composite cylinder test, conducted in March 2016 at MSFC, marks yet another milestone, said Dr. Schultz. The work had begun about a year earlier with the final preparation of the Northrop Grumman-built test article. In the week before the final test to failure, the NESC team conducted a series of subcritical tests to exercise the cylinder to increasing loads. On the final day, the loads were steadily increased over the course of 2 to 3 hours until the cylinder finally buckled under the load. “The failure load was within 1% of our pretest prediction,” he said. “I thought it would be within a small percentage, but the fact that it was within 1% was pleasantly surprising.”

Since the test, the team has been poring through the data. “Most of our effort has been in putting the data in forms that we can document. There haven’t been a lot of surprises from the tests. We felt we had excellent agreement between the tests and the analysis so a lot of work is to verify that good agreement.”

At the same time, the team is planning ahead. “We have four additional tests to do. Our focus is on the detailed design of those remaining test articles, all of which will be made at MSFC along with the tool on which the articles will be made.”

“The test articles are all sandwich composites structures, which are composed of carbon fiber and epoxy faces separated by a lightweight, honeycomb core,” said Dr. Schultz. The carbon fiber, which is strong and stiff, is embedded in an epoxy matrix. “The fibers are responsible for most of the strength and stiffness, and the matrix holds the fiber and transfers load between fibers as well,” he said. “Each of the remaining four test articles are meant to interrogate a different portion of the design space, so they will be of varying thickness and stiffness.” The plan is to test one article each year for the next 4 years.

“The tests are really the big, visible part of the work, higher profile and more fun,” said Dr. Schultz, “but that’s not the end product. The underlying methodology behind the shell buckling project is to develop analysis-based design guidelines, and the tests are really just to anchor our analyses and make sure our methodology is valid,” he said. “Ultimately, we intend to modify the existing guidelines for this select class of sandwich composites and cylinders.”



NESC Priority 3: Known problems not being addressed by any project



NESC Technical Bulletin 16-01: Buckling Knockdown Factors for Composite Cylinders

It took decades to figure out the complex buckling behavior of metallic cylindrical launch vehicle structures and the KDFs that account for the unknown variability in the geometry, loading, and material imperfections. The KDFs, established by Apollo-era engineers, are still in use today by NASA and by industry world-wide, as captured in NASA SP-8007 *Buckling of Thin-Walled Circular Cylinders* from 1968. Developed with conservatisms warranted by the technology of the time, these KDFs are likely adding unnecessary weight to today's modern aerospace structures. That was the catalyst behind Dr. Mark Hilburger's NESC-sponsored proposal to develop and implement updated shell buckling KDFs, now in use by the SLS Program.

Designers of composite cylinders, however, still turn to SP-8007, often using KDFs for which the technical justification is unclear. As a result, Dr. Marc Schultz, working with Dr. Hilburger, is investigating KDFs for modern composite cylinders. Their work has led to the development of this Technical Bulletin, which emphasizes that composite cylinders are outside the scope of SP-8007 and why caution must be taken when using the universal KDF in composite designs.

More NESC Technical Bulletins can be found at nesc.nasa.gov

NESC Priority 4:

Work to avoid potential future problems

Priority 4: In Progress

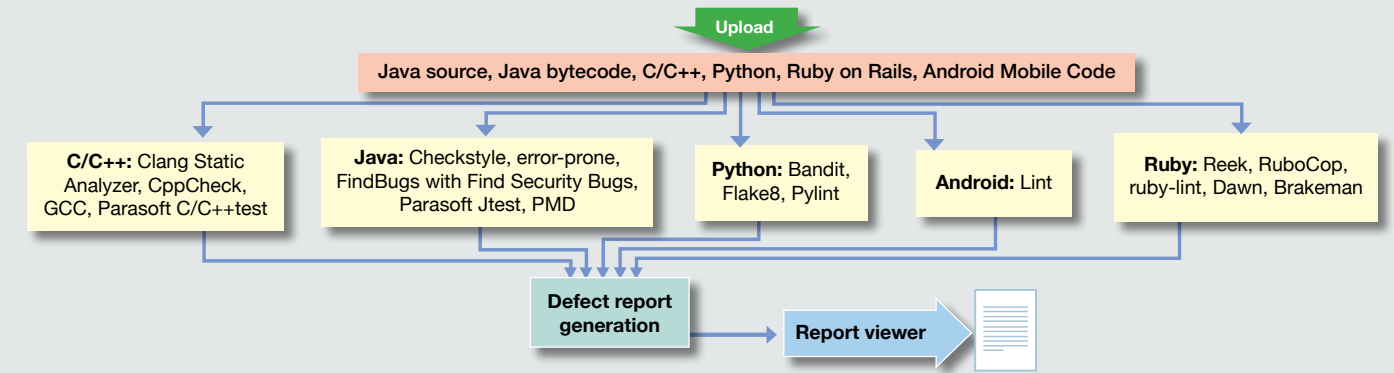
- Peregrine Sounding Rocket Redesign
- Additive Manufactured Fuel Turbopump Disassembly/Inspection and Post-Test Data Evaluation
- Fluid Structure Interaction in Prediction of Parachute Performance
- Space Weather Action Plan Extreme Surface/Internal Charging Environment Benchmarks
- Peer Review on Wind Induced Oscillation

NESC Priority 5:

Work to improve a system

Priority 5: In Progress

- Empirical Launch Vehicle Explosion Model Evaluation
- Fracture Control Standard and Handbook
- Orion Alternate Heatshield Study
- Fast Coupled Loads Analysis via Norton-Thevenin Receptance Coupling
- Improved Design and Optimization of Complex Trajectories



Improving Software Assurance - the NASA SWAMP

Dealing with Software Complexity

Static program analysis is a critical part of software assurance and is performed to discover specific types of coding defects (commonly referred to as bugs) and security issues without actually executing the program.

Numerous commercial and open source tools have been developed to automate manual static analysis, a significant improvement over manual code inspections, which were limited to about 300 lines of code per inspector per day. These manual inspections are impractical for programs like the Orion Multi-Purpose Crew Vehicle, for example, which incorporates more than two million lines of source code.

Automated open source code checkers use numerous heuristics to inspect the code for issues of coding standard violations, variable assignments, divide by zero possibilities, questionable syntax, consistency issues, complexity measures, unchecked input values, and numerous other well-known defects that historically have caused failures. The checkers can report defects that may impact code maintenance or defects that produce security flaws. The National Security Agency maintains a suite of code (Juliette Test Suite) that includes examples of historical errors. When the Juliette Test Suite is analyzed by a static analysis tool, the results indicate how effective the tool is at detecting these historical errors.

Applying Static Code Analysis for Improved Software Assurance

"The NESC was requested to perform a static code analysis of safety-critical software used to automate key aspects of launch vehicle range safety," said Michael Aguilar, NASA Technical Fellow for Software.

"We formed a multi-Center team that included key personnel from NASA's Independent Verification and Validation (IV&V) Facility, ARC, and JPL to initiate a static code analysis of the NASA Autonomous Flight Termination System (AFTS). Our objective was to provide extensive implementation analysis of the source code and related AFTS support tools."

The NESC team performed an initial static analysis of the AFTS code in February 2016 that included 10 automated

analysis tools (CLANG, Coverity, Codesonar, CppCheck, Fortify, Polyspace, Semmler, Understand, IKOS, and SeaHorn). Some AFTS operations support tools, written in ADA, were also analyzed.

"When static analysis tools are run, we find they have very little overlap. They find and miss different defects. Running several tools allows for better results," Mr. Aguilar said.

Improving Access to Static Analysis Tools

During the assessment, the NESC team investigated the use of a Software Assurance Market Place (SWAMP*), a portal that enables software developers and researchers to access multiple tools to perform static code analysis. "The bare-bones SWAMP uses free and open source tools. Comparing the tools, we found a combined set of free and open source outputs from several tools produced very good results," Mr. Aguilar said. Key to the usage of static analyzers is identifying a core set of important defects that affect both operation and security — a "must fix" set of defects that could become a future software implementation standard.

Leveraging this assessment experience, the NASA IV&V Facility is currently developing a NASA SWAMP that would allow software projects access to analyze source code Agency-wide, behind the NASA firewall. "We plan on releasing SWAMP configured with these free and open source tools. SWAMP can be reconfigured to include commercial tools the project has licenses for," Mr. Aguilar stated.

"We would like to implement two flavors. The first would be "SWAMP-in-a-Box" that installs on the software developers infrastructure to enable developers to access the static code tools that are included with the SWAMP. We also envision a NASA SWAMP portal, potentially hosted on the NASA Engineering Network, which would be accessible to all NASA code developers. By implementing an Agency-wide access to static analysis, many more NASA software projects will be able to run static analysis on their developed source code."

* The SWAMP concept is the result of a Broad Agency Announcement from Department of Homeland Security, as implemented by several universities and industry.

Understanding the Potential Dangers of Spacecraft Charging

In April 2010, the Galaxy 15 telecommunications satellite was set adrift, wandering away from its assigned place in geosynchronous orbit. Ground controllers had lost contact with the spacecraft and were powerless to upload the commands it needed for executing station keeping maneuvers. As a result, the satellite began an uncontrolled drift in longitude, with the threat of getting in the way of other satellites, and potentially interfering with their transmissions. This uncontrolled drifting went on for months.

Reports in the scientific literature and space technology trade journals suggested Galaxy 15 was a victim of spacecraft charging. Hot electrons roaming the outer radiation belt had pelted the satellite, causing a negative charge to build on its surface—a charging event. And much like walking across a carpet and then touching a door knob, an electrostatic discharge ensued that knocked out its communications systems. It could no longer receive radio contact from its owner, Intelsat. It took 8 months to reestablish contact and successfully reposition the satellite in its desired orbit.

“Luckily for Galaxy 15, it wasn’t a loss of mission,” said Dr. Joseph Minow, NASA Technical Fellow for Space Environments. “They were able to establish a work around to recover use of the satellite.” Other satellites have not been so lucky. The Advanced Earth Observing Satellite 2 (ADEOS-II) in a high inclination low Earth orbit lost its power system in October 2003 and was never recovered. Engineering teams investigating the failure identified charging by high energy auroral electrons followed by an electrostatic discharge between the primary power cables as the likely cause of the power system damage. “The mission was a total loss. In geostationary orbit, there are a lot of hot electrons and during geomagnetic storms they build up. It’s a classic charging environment. Auroral charging is a similar problem, with hot electrons generated in the electric field structures above the Earth’s auroral zone that produce the northern and southern lights. Satellite designers have had to deal with these problems for years,” he said.

“Space is an interesting place. You tend to think of it

as a big, empty void,” said Dr. Minow, who has worked to characterize space environments for space system design and operations for many NASA programs including the Space Shuttle, International Space Station, and James Webb Space Telescope (JWST). But while space is a vacuum, it is far from empty, he explains. “For spacecraft operating in a space environment, hazards lurk everywhere. And with the exception of meteoroids and orbital debris, most of those hazards are the product of a high energy charged particle radiation environment that are not even visible to the naked eye. And given that environment, spacecraft charging is inevitable,” said Dr. Minow. “Every spacecraft charges. It’s just a question of whether it has a detrimental impact on the spacecraft or not.”

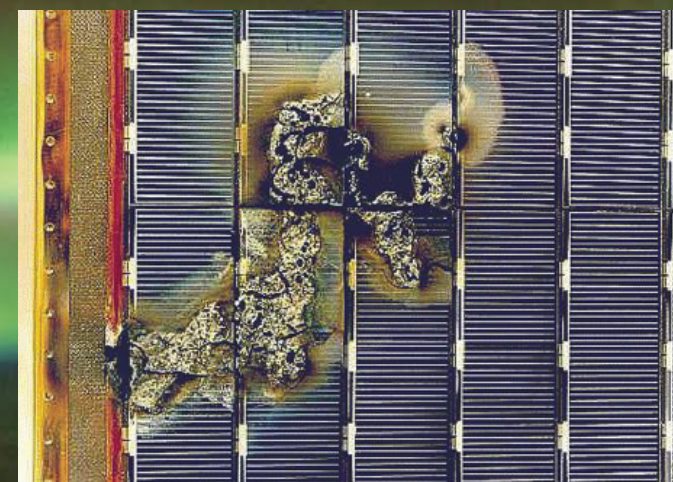
A Hazard for Spacecraft

“The hazards caused by spacecraft charging are varied,” said Dr. Minow. If a charge builds up that is too big for the spacecraft’s material to hold, discharge arcs, which are essentially strong electrical currents, will occur. And depending on where those arcs go, they can damage electronic components, destroy sensors, or damage important materials such as thermal control coatings.

“They can also show up in electrical systems as phantom commands,” he said. The arcs can spoof the attitude control system, for example, causing attitude changes or spin anomalies. The arcs also emit electromagnetic radiation and cause interference and noise that can hamper both incoming and outgoing command and control as well as science data signals.

“Charging can have big impacts on solar arrays and photovoltaic power systems,” added Dr. Minow. “You can get arcing between solar cells on the solar array. Currents can get bigger and bigger, which sustains the arcing, which can destroy the entire solar array. There have been cases where satellites have lost major parts of or all of their power systems. And that’s catastrophic. You can completely lose the mission.”

Even seemingly benign charging that does not affect the spacecraft itself can have a major impact on science



ESA EURECA satellite solar array sustained arc damage.



Arc damage in laboratory tests of the chromic acid anodized thermal control coating covering ISS orbital debris shields.

satellites that measure charged particles, such as the Magnetospheric Multiscale Mission, which employs several satellites to study the Earth’s magnetosphere. Even a small charge on the spacecraft can interfere with the satellites’ detection abilities of low energy “thermal” plasma. Active charge control systems are frequently employed by these kinds of science missions to suppress charging during times when critical measurements are to be made.

Mitigating the Hazard

In his role as the NASA Technical Fellow for Space Environments, Dr. Minow has assembled teams to work on NESC assessments to help mitigate spacecraft charging threats to NASA missions. For example, the JWST spacecraft and telescope systems are well designed and well equipped for its stay in orbit about the Sun-Earth Lagrange point 2 (L2) about 1.5 million kilometers from Earth. However, mission risks can be reduced by avoiding exposure to extreme solar flare particles and severe charging events during transit of the Earth’s radiation belts in the hours right after launch. He and the NESC team will help the JWST Program develop and assess the effectiveness of proposed launch constraints designed to protect the spacecraft during the first three quarters of a day on its month-long journey to L2.

“Charging has always been a problem,” said Dr. Minow, for as long as NASA and other space programs have been sending vehicles into space. “There were a lot of charging related anomalies in the 70s and 80s, but the

number is dropping, because the more we understand it, the better we can build satellites to operate successfully,” he said. “Every time there is a failure due to charging, we figure it out to make sure it doesn’t happen again. On average, the failures per decade is going down, which is good. It means we understand what is happening and spacecraft designers are following good design practices that mitigate charging.”

Dr. Minow said, “The best solution to mitigating charging hazards is good design. Just turning off the sensitive systems to avoid geomagnetic storms isn’t practical for most satellites. Good material selection is important. If we build satellites for geostationary orbit with conductive coatings on the outside, the arc will go out into space. Differential charging is the worst because arcs originating in one location on a spacecraft can damage systems on another part of the spacecraft. Fortunately, design techniques to minimize the amount of differential charging are well understood.” Along with good design is testing, particularly in environments that expose the spacecraft components to arcing. And more design and testing is being done with computer modeling, he notes. “We can simulate the charge build up and variations in voltage across the vehicle. We can see the motion of the particles. A combination of both analytical work and testing yields the best satellite design,” he said.

The study of space environments has kept Dr. Minow captivated for many years. “It is really interesting—the interaction of spacecraft with the space environment. It’s a mix of fundamental physics and science, with a really important application,” he said. “It’s a nice combination of basic and applied science.”

GNC Perspectives on Piloted Spacecraft

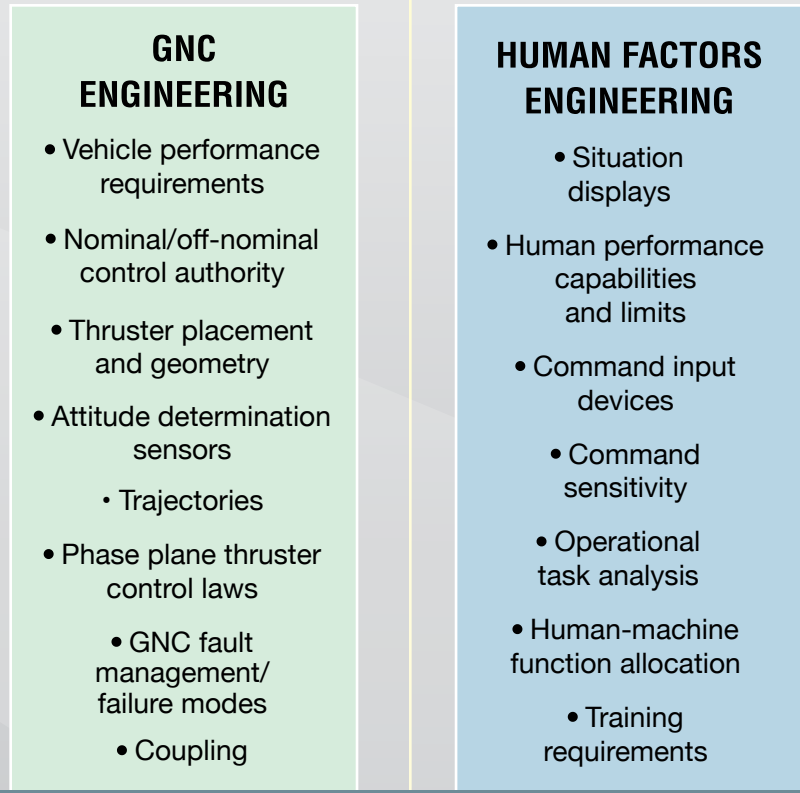


There is an unprecedented level of piloted spacecraft system development going on at NASA and with the Agency's Commercial Crew Program (CCP) industry partners. The Orion Multi-Purpose Crew Vehicle is moving toward its Exploration Mission -1 flight in 2018, while both Boeing and SpaceX are developing the CTS-100 and Dragon 2 spacecraft, respectively. This new generation of piloted spacecraft has resparked an interest in piloted spacecraft handling qualities - "those qualities or characteristics of an aircraft that govern the ease and precision with which a pilot is able to perform the tasks required in support of an aircraft role" (see reference 1).

These same qualities apply to manual flight operations (i.e., "piloting") of spacecraft. The term "Spacecraft Handling Qualities" (SHaQ) captures the multi-discipline aspects of analyzing and characterizing the ease and precision with which a spacecraft pilot can perform challenging functions such as proximity operations, docking, and landing. A lack of sufficient understanding of SHaQ can lead to increased crew training requirements, increased pilot in-flight mental workload, undesirable flight control system interactions, and an inability to perform the mission/task.

Unsafe, high-risk vehicle operations can result from a lack of good SHaQ and/or the inadequate application of human factors engineering practices. In extreme cases, it can lead to a loss of crew, as seen in a recent NESC independent analysis of a fatal X-15 aircraft in 1967. Incremental instrument panel changes such as the addition or moving of switches and indicators eventually left all three X-15 aircraft with different instrument panels. In addition, each X-15 vehicle had slightly different emergency procedures. On the day of the accident, an additional modification was made to support a specific science objective, which led to a lack of mode indication on a critical flight instrument. This resulted in increased pilot workload and confusion, which the NESC concluded was a primary contributing factor to the accident. Particularly in times of high stress, highly trained pilots rely on consistent, well-learned interfaces and procedures that give them an unimpeded ability to maintain safe flight control of the vehicle.

While guidance, navigation, and control (GNC) technology trends are moving toward on-board autonomous systems, the expectation is that crewed spacecraft will always have some form of manual control available to pilot(s).

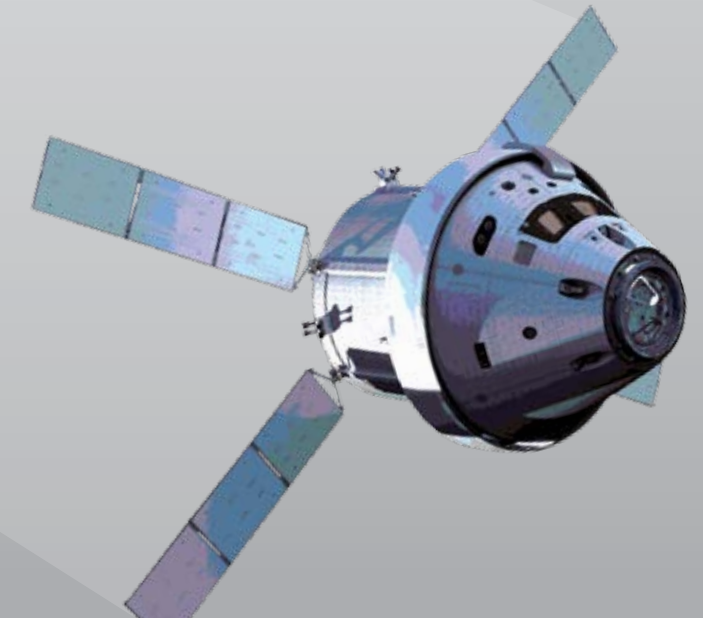
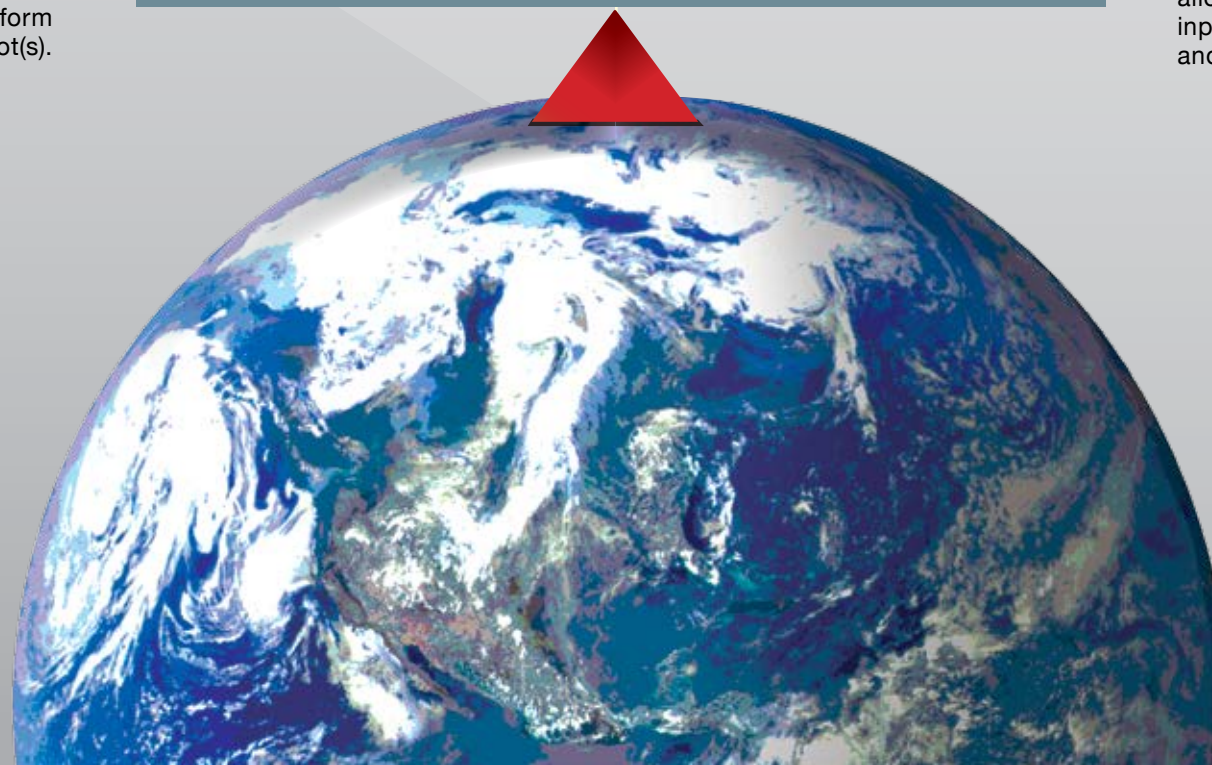


As in the past, striking a balance between performing tasks manually versus autonomously will likely be a topic of on-going debate over human versus automation. The study of SHaQ goes well beyond GNC stability and control analysis. The coupled "pilot/vehicle" dynamic system must be fully understood. SHaQ is a system-level problem requiring a balanced, integrated GNC-Human Factors engineering solution. Provisions for understanding, accommodating, and verifying handling qualities need to be incorporated directly into the spacecraft flight control system's design and not considered as an afterthought. This will be a challenge for the GNC community because currently there are no established SHaQ design standards.

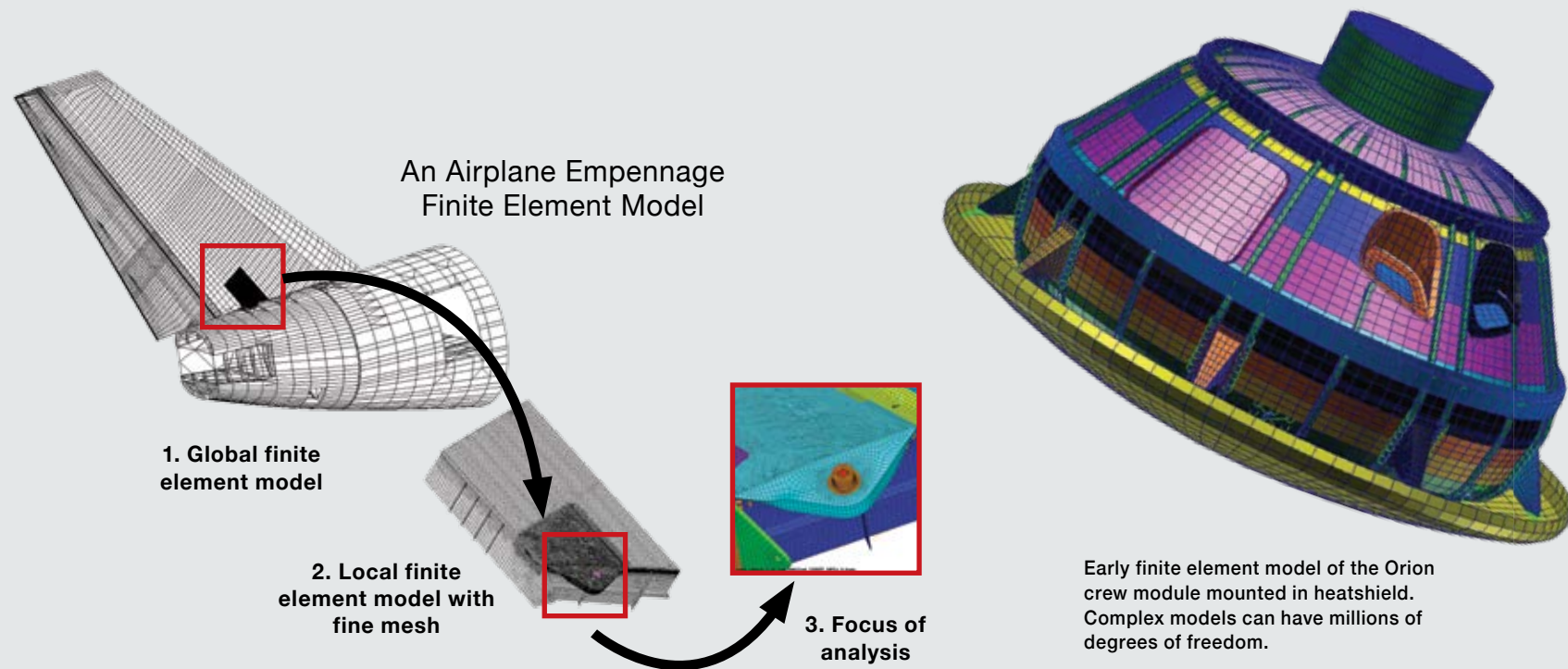
SHaQ requirements need to be an integral element of the GNC systems engineering process for a piloted spacecraft. One cannot simply wait until a spacecraft flight control system is designed to "paint on" handling qualities. The spacecraft GNC team must balance analysis of automated flight control modes/tasks with in-depth examination and testing of allowable and appropriate pilot inputs, based on offline pilot models and human-in-the-loop simulations.

A variety of testbeds are needed to verify satisfactory SHaQ characteristics as well as to ensure crews "train as they will fly," especially for complex challenging GNC-related tasks such as docking and landing. These SHaQ testbeds typically include fixed-base, motion, and flying simulators.

SHaQ was an active research area under the Constellation Program from 2007 to 2010, during which a NASA report was written, which reviews, documents, and captured SHaQ experiences, best practices, and lessons-learned from previous United States spacecraft developments (see reference 2) to guide current and future SHaQ research and development. But research declined once the Constellation Program ended, and there is no broadly applicable research on SHaQ design standards being done today at NASA. SHaQ standards development will be critically needed for future NASA human exploration missions, where pilots will be tasked with performing demanding docking and landing maneuvers. To revitalize SHaQ to again be a broad research area, the first and most important step would be to develop and define implementable design standards for spacecraft handling qualities.



References: [1] Cooper, G.E. and Harper, Jr., R.P.: The Use of Pilot Rating in the Evaluation of Aircraft Handling Qualities, NASA TN D-5153, April 1969. [2] Randall E. Bailey, E. Bruce Jackson, Karl D. Bilimoria, Eric R. Mueller, Chad R. Frost, and Thomas S. Alderete: Cooper-Harper Experience Report for Spacecraft Handling Qualities Applications, NASA/TM-2009-215767, June 2009.



Finite Element Analyses

Not all beautiful color plots are precise or accurate

For more than 40 years, Dr. Ivatury Raju, NASA Technical Fellow for Structures, has watched structural analysis grow by leaps and bounds. Giant mainframe computers used to plug away for months to generate sophisticated finite element analyses (FEA). Today, desktop computers can produce FEA results with complex 3D models in a matter of days. But with this progress, Dr. Raju and the structures greybeards are witnessing some alarming and worsening trends.

Many early-career engineers, proficient in the use of modern computers, computing engines, and complex software packages such as NASTRAN, ANSYS, and ABAQUS, are performing intricate FEA analyses without a sufficient background in engineering mechanics and are blindly accepting the quality of the results. Dr. Raju's concern reached a tipping point when he read a comment on a popular social networking site for scientists and researchers: *The model exactly looks like the part. The analysis ran to completion without any errors; the results are displayed as contour plots in color — how could the analysis and results be wrong?*

"This analyst believed that the results displayed were satisfactory and accurate, and there was no need to check the results," said Dr. Raju. "These questions point to inadequate formal training in engineering mechanics and FEA theory. That was the motivation for me to write this paper," said Dr. Raju, who co-authored *Some Observations*

on the Current Status of Performing Finite Element Analysis, with fellow engineers Dr. Norman Knight and Dr. Kunigal Shivakumar. "We had to raise this flag," he said. The paper has allowed Dr. Raju and his coauthors to draw attention to some of these trends and offer guidelines and suggestions to help overcome them. (See Sidebar: Undesirable Current Trends).

Adept at meshing — but not at modeling

What Dr. Raju has noticed over the last few years is that early-career engineers, analysts, and other users of FEA software are quite adept at performing swift and accurate meshing of components for complex aerospace structures. But not all of those users have mastered the art of modeling. The authors point out that meshing requires expertise in using a software package, while modeling involves expertise in idealization of the structure and in understanding the structural response to loads and restraints.

Dr. Raju said users need to understand the implications associated with selecting one element type over another. "In a way, modeling involves knowing the answer before you get it. So unless you have experience, you don't know where to put the fine mesh," he said. Choices associated with the element shape function order (linear, quadratic, p-versions), element continuity requirements, placement of mid-side nodes, and faceted modeling of curved surfaces do influence the results.

Dr. Raju has seen similar issues with 3D modeling, with 3D mesh models currently more common than plate or shell models. "A 3D model has its own difficulties," he said. Computer-aided design packages treat all geometry as 3D, he notes in the paper. Engineering judgment is necessary to extract representative planes out of the 3D model so that accurate shell models can be built. Lacking those judgment skills, early-career engineers are relying on the automesh button, which may generate large numbers of solid elements, making it more difficult to interpret results for bending, transverse shear, and other quantities.

And when it comes to bolts and bolt modeling, "There are numerous ways you can model bolts," said Dr. Raju. "And any way you do it has its own pitfalls. So you have to know what you are doing." For example, analysts are simply smearing the thickness of the fastened parts together and ignoring the discrete bolts; introducing discrete constraints or a beam element at every fastener location and ignoring features of the bolt; and including the fastener as one or more beams to simulate the bolt shank with sets of constraints to simulate the bolt head and nut. "Most analysts appear to be unaware of all of these pitfalls in bolt modeling and lack the knowledge of how a preloaded bolted joint works."

The paper highlights many more examples of these trends and provides guidelines, suggestions, and tricks of the trade specifically aimed at analysts, senior engineers, and educators.

Reversing the trend

"The technology is moving at an astonishing rate," said Dr. Raju, of the pace at which hardware and software is changing and improving. As for the engineers just starting their careers, computers are second nature for them, "but they don't always know theory," he said. "And they don't always have time to learn everything. That's why they need mentorship with senior engineers." It's one of the recommendations Dr. Raju and the authors direct toward senior engineers and educators as a way to help reverse this trend. "If they can see you in action, they will understand," he said. "They can ask you questions." (See Sidebar: Recommendations for Analysts and Senior Engineers).

For the engineers and analysts, the authors note that fundamental core engineering courses are key. And they suggest studying the software developers' manuals. "The software developers who actually make the finite element codes are telling you the things you need to do," said Dr. Raju. "They can tell you what to watch out for."

References: [1] Raju, I. S.; Knight, N. F.; and Shivakumar, K. N.: Some Observations On The Current Status of Performing Finite Element Analyses, Paper presented at the AIAA SCITECH 2015, January 5-9, 2015, Kissimmee, FL, Paper AIAA-2015-2070, 2015; [2] T. Rose: "Your Answers are Wrong!!!," Presentation to the combined Loads & Dynamics and Structures NESC Technical Discipline Teams, April 14, 2014; [3] L. Proctor: "Modal checkout in MSC.NASTRAN," MSC Lunch-n-Learn Series, April 2008; [4] ANSYS: FEA-Best Practices, Document can be downloaded from: http://innomet.ttu.ee/martin/MER0070/Loengud/FEA_Best_Practices.pdf.

Undesirable Current Trends

- General lack of understanding of basic assumptions in engineering mechanics is observed.
- Finer meshes where they are not needed and coarse meshes where large gradients exist are frequently observed, suggesting lack of knowledge of structural and engineering mechanics.
- Black box software packages are being used without engineering knowledge about finite element theory, and there is a blind acceptance without any quality checks and interpretation of results.
- The use of building block approaches in finite element modeling and analysis is very rare.
- A well-thought-out plan to modeling the analysis region is rarely evident.

Recommendations for Analysts and Senior Engineers

For analysts:

- Study software developers' manuals.
- Actively pursue verification and validation of your finite element models.
- Experiment with various elements to develop a personal library of elements and report card test cases.
- Be your own worst critic.
- Do your analysis results support your conclusions?
- Does your analysis support the assumptions made?

For senior engineers and educators:

- Ensure junior engineers receive proper grounding in classical methods, finite element theory, simple yet bounding models, hand calculation techniques, and methods for evaluating finite element results.
- Invest time in mentoring junior engineers.
- Teach best practices and "tricks of this analysis trade."
- Teach processes to evaluate finite element results before they accept them.



The wavefront measurement system is composed of a 6-inch aperture phase shifting interferometer on a vibration isolated optical table with a 2-D scanning system. This allows the optical path length to be measured across large spacecraft windows as well as individual panes.

Measuring Window Flatness using Optical Interferometry

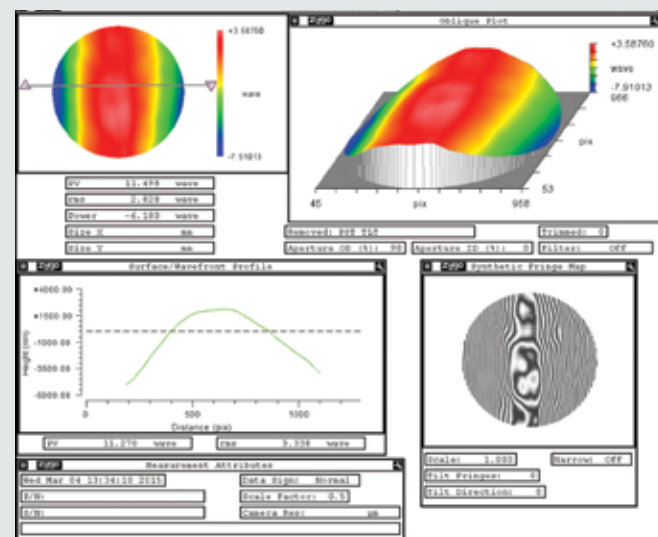
In response to the revised requirement levied onto the Multi-Purpose Crew Vehicle (MPCV) Program to verify that uninstalled flight window assemblies have minimal wavefront variation, KSC's Applied Physics Laboratory partnered with the NESL in the development of a wavefront measurement capability at KSC, in close proximity to the MPCV crew module assembly site. The measurement required the construction of an optical interferometer-based wavefront measurement system consisting of an off-the-shelf interferometer and a custom scanning system. Training, testing, analysis, and an engineering assessment were required to ensure adequate system operation and that the deliverables provided could allow certification of window assemblies.

The system utilizes a phase shifting interferometer to provide optical path length measurements through an individual window pane or through a fully stacked window assembly. Variations in the window's optical path length lead to wavefront perturbations and can cause images seen through the window to be distorted. The revised NASA requirement on spacecraft windows sets maximum allowed values for the wavefront perturbation, but other organizations, such as the Department of Defense, place maximum allowable values on the window's distortion, a window attribute that can be difficult to quantify using ASTM or ISO methodologies. One of the breakthroughs of this work was the realization that the distortion of a window is easily calculated from the optical path length of the window, allowing phase shifting

interferometry to replace some of the older less precise distortion measurement approaches (see references).

After establishing the window wavefront measurement system for MPCV, the International Space Station (ISS) Program requested that it be used to help evaluate

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An output from the phase shifting interferometer looking through an acrylic window pane. Note the fringe pattern in the lower right and the subsequent calculated optical path length information shown in the other display boxes.

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new scratch panes to cover the inside of windows on the ISS. The successful operation of the system in that evaluation has led to further ISS requests for window/material evaluation, including a request to perform modulation transfer function (MTF) measurements. MTF evaluation is a common optical approach for determining the imaging resolution capability of an optical system. However, measuring the MTF of a window has previously required measuring the MTF of a camera system with and without the window and comparing the results. Using software already programmed into the phase shifting interferometer MTF measurements of just the window can be obtained from the optical path length data, greatly simplifying the measurement of this important parameter. For more information, contact Robert Youngquist, Kennedy Space Center - robert.c.youngquist@nasa.gov



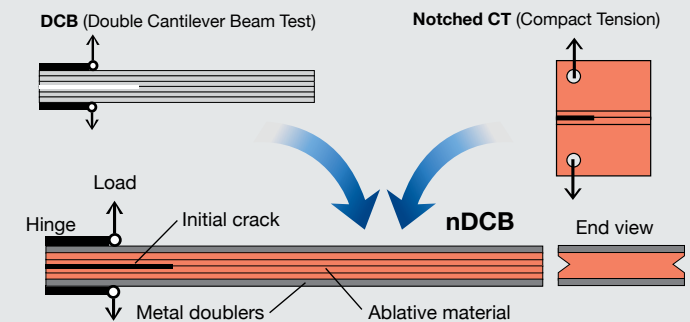
The Orion crew module.

References: [1] Youngquist, R. C.; Skow, M.; and Nurge, M. A.: Optical Distortion Evaluation in Large Area Windows Using Interferometry, 14th International Symposium on Nondestructive Characterization of Materials, Marina del Rey, CA, June 2015, published on-line in NDT.net Vol. 20, No. 9 September 2015. [2] Youngquist, R. C.; Skow, M.; and Nurge, M. A.: A Comparison of Three Methods for Measuring Distortion in Optical Windows, NASA TM 2015-218822.

Mode-I Fracture Toughness of Complex Materials with the nDCB Test

The notched double cantilever beam (nDCB) test has been successfully used to measure the mode-I fracture toughness of an anisotropic ablative material used on the Orion crew module heatshield. The nDCB test was developed by combining the strengths and avoiding the weaknesses of two existing standard test methods, namely the double cantilever beam test and the compact tension test. The double cantilever beam test is a standard test for measuring the mode-I fracture toughness (G_{Ic}) of layered composite materials.

This test method has several strengths, such as its simplicity of execution and adaptability for use in environmental chambers. It also allows a compliance calibration method of fracture toughness calculation, which can be more robust when dealing with complex material systems. However, when this test method was used with the ablative material of interest, the crack front wandered away from the mid-plane of the specimen, violating the self-similar crack growth assumption inherent in measuring G_{Ic}. With a notched compact tension (CT) test specimen, planar crack growth was maintained, but it produces a toughness in terms of the critical stress intensity factor (K_{Ic}). Converting K_{Ic} back to a G_{Ic} needed for the analysis is not trivial due to the anisotropy of the material and introducing additional uncertainty in the toughness allowable. The notched computed tomography test is also focused on the initiation value of toughness while with complex nonhomogeneous



Combining the nDCB and notched compact tension tests into the new notched nDCB test.

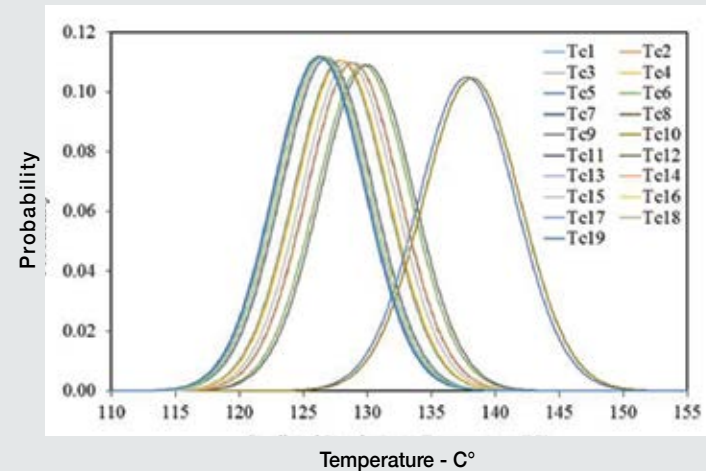
materials where a damage field develops, a propagation value may be more appropriate. The nDCB test allows for propagation values to be calculated over several inches of crack growth. By combining the standard tests into the nDCB, a test was achieved that delivers a G-based fracture toughness over a significant distance of self-similar crack propagation using robust data reduction methods that are very similar to the standardized test. For more information, contact Dr. James Ratcliffe, LaRC - james.g.ratcliffe@nasa.gov or Vinay Goyal, The Aerospace Corporation - vinay.k.goyal@aero.org

Spreadsheet-Based Wire Bundle Thermal Modeling Tools

Spreadsheet-based thermal analysis tools have been developed to analyze current carrying capacity of wire bundle configurations. Wire bundles composed of up to 50 elements may be solved within the spreadsheet tool itself. Larger bundles, composed of up to 150 elements, utilize a spreadsheet-based complex wire bundle thermal model builder where user inputs are processed into a thermal network model and output in the System Improved Numerical Differencing Analyzer (SINDA) format for solution. The resulting models include the effects of temperature varying resistance, wire gauge, insulation jacket properties, external radiation and convection, wire-to-wire thermal contact, radiation, and air conduction. Current procedures using published standards limit the types of configurations that can be assessed using graphical data. The goal of this effort is to provide analysis capability allowing assessment of a variety of configurations including bundles with internal smart shorts, combinations of wire gauges, and external jacket properties. Monte Carlo-based analysis capability is included in the tools and allows analysts to explore the solution sensitivity to uncertainties in a variety of input variables. Accurate thermal modeling of wire bundles ensures the design is robust against smart shorts within the wire bundle. Additionally, a model-based approach may allow for design efficiencies resulting in reduced wire bundle weight within an aerospace vehicle. For more information, contact Steven Rickman, JSC, steven.l.rickman@nasa.gov



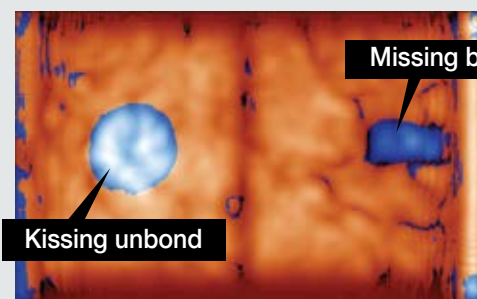
Sample wire bundle analysis configuration schematic.



Sample steady-state temperature distributions resulting from a Monte Carlo analysis.



Avcoat NDE Raw Scan



Avcoat NDE Processed Scan

Bond Quality Inspection for Orion Heatshield Blocks

The NESC is supporting an effort to inspect the condition of the bondline between the thermal protection system (TPS) and the composite substrate of the Orion spacecraft. A failure mode of concern is loss of a block due to an incipient flaw propagating during reentry heating conditions. Several nondestructive inspections were explored, but all of them had significant limitations. Mostly, they were unable to detect unbonded surfaces that are in intimate contact

kissing unbond. To inspect the mechanical condition of the bond, a mechanical wave such as ultrasound, rather than an electromagnetic wave was necessary. The challenges of using ultrasound were quickly recognized, and a set of remedies were implemented by the NESC.

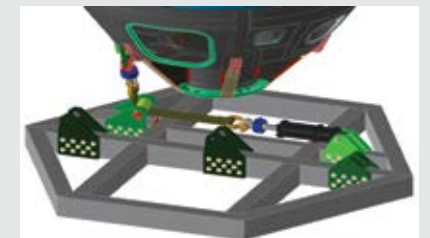
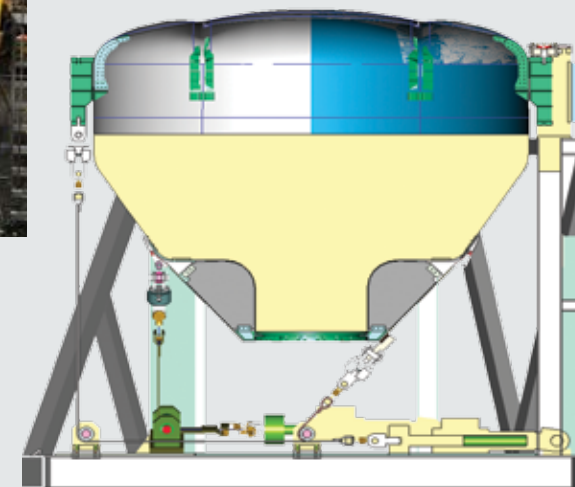
To penetrate the TPS, low frequency ultrasound is used at the cost of having long wavelengths, which result in poor resolution between consecutive echoes, and a

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large transducer footprint, which results in poor spatial resolution. Special transducers are used with a particular coupling medium that allowed sound to be injected into the highly attenuative TPS material with minimal losses. The echo returning from the bondline between the TPS and composite substrate is normalized against the echo returning from the back wall of the substrate. This neutralizes the inhomogeneity and scattering effects that are typically experienced by sound in the TPS. Additional signal processing techniques are applied to analyze the phase and shape of the bondline echo as a discriminating factor between "bond" and "no bond" conditions. The

Synthetic Aperture Focusing Technique is then applied to significantly improve the sharpness of these scans and restore some of the spatial resolution that was lost by the large footprint of the transducer. The probe is connected to two string encoders such that a real-time image is produced as the inspector performs a freehand scan of the spacecraft. This technique has shown significant promise in detecting unbonds and debonds in various blind studies and are now considered as one of the primary inspection techniques for the heatshield. For more information, contact Dr. Shant Kenderian, The Aerospace Corporation - shant.kenderian@aero.org



Innovative mechanism that uses low-stretch straps to route point loads to a structure.

Large Point Load Application Technique

The NESC investigated the construction and testing techniques of a composite pressure vessel for the Orion crew module. The full-scale Composite Crew Module was built by Alliant Techsystems (ATK), at luka, Mississippi, and delivered to LaRC for testing in September 2009. The main test matrix included 11 load cases consisting mostly of combined point loads and internal pressure. Point loads were applied to the crew module's fittings such as the parachute attachment points. To facilitate testing, a self-reacting loading frame was designed and built (also in luka), which additionally served as the skeleton for the shipping container.

Because the majority of the fittings were located on the upper half of the module, the test article was mounted in the test frame upside down. This allowed for all heavy hardware (actuators, brackets, etc.) to be mounted securely

to the base of the frame. Another advantage afforded by the upside configuration was easy access to the tunnel hatch where all cable harnesses feed-throughs and air inlet port were located.

Point loads to fittings were applied using an innovative technique to route load from the hydraulic actuators to the fittings through a low-stretch strap (less than 1% extension). Mounting the heavy actuators horizontally on the base of the test frame and routing the straps through heavy duty rollers to achieve the desired load vector proved to be very effective. Since none of the heavy actuators had to be repositioned, this method allowed for quick test reconfiguration. To account for possible friction, two load cells were used to monitor the load at each end of the strap. For more information, contact Dr. Sotiris Kellas, LaRC, sotiris.kellas@nasa.gov

Unsteady Pressure Sensitive Paint for Measuring Launch Vehicle Aerodynamic Buffet

A new approach has been developed for measuring fluctuating aerodynamic-induced pressures on wind tunnel models using unsteady pressure sensitive paint (uPSP). During ascent through the atmosphere, a launch vehicle and its payload experience strong aerodynamic loads. These loads have large fluctuating levels that are difficult to measure. The structural design of a launch vehicle must account for both steady and unsteady loads in order to ensure safe flight to orbit. During the design process, these loads must be estimated accurately, and wind tunnel buffet testing is still the best option.

Buffet tests require accurate measurement of the steady and fluctuating pressures at as many points on the surface as possible. However, the finite size of pressure sensors sets an upper limit of approximately 400 sensors that can be placed in a wind tunnel model, resulting in very sparse pressure measurements over the vehicle.

Early wind tunnel tests of the Space Launch System indicated that buffet loads were larger than expected.

Measurements from 213 individual pressure sensors were augmented by the use of uPSP. Results showed the extremely dense uPSP measurements provide accurate load estimates at up to 5 kHz without any approximations.

Subsequent testing indicated that the buffet estimates were very sensitive to the details of sparse, unsteady pressure data integration. The work was performed to evaluate the integration techniques by using a relatively new measurement technique.

The new approach increases the density of pressure measurements by using uPSP. PSP has been commonly used in wind tunnels for 20 years to measure time-average pressure but until recently, did not have a sufficiently fast response to measure unsteady pressures. Advances in both camera technology and the chemistry of PSP have enabled the measurement of unsteady pressures.

The uPSP measurements are made by illuminating the painted model in the wind tunnel with blue light. The uPSP fluoresces red, and the brightness of the fluorescence is proportional to the pressure acting on the paint. Pressure fluctuations at up to 5,000 Hz can now be resolved and measured.

The uPSP measurement technique was verified in a large production wind tunnel (the 11- by 11-foot Transonic Wind Tunnel) during a recent test, in which traditional pressure measurements were compared to those made by uPSP. The verification testing of uPSP was based on measuring the unsteady loads on a wind tunnel model of a generic launch



Unsteady pressure sensitive paint applied to generic launch vehicle model in the 11- by 11-foot Transonic Wind Tunnel at ARC.

vehicle (see picture). Measurements from 213 individual pressure sensors were augmented by the use of uPSP. Results showed the extremely dense uPSP measurements provide accurate load estimates at up to 5 kHz without any approximations. Comparing the uPSP loads with the estimates from the pressure sensors showed the strengths and weaknesses of the sparse-data correction schemes.

In most areas of the generic launch vehicle model, the sparse data integration methods overestimated the buffet loads. However, in some areas, buffet loads were underestimated. More work is underway to determine ways of identifying features of the unsteady pressure field that lead to over- and under-prediction of the unsteady buffet loads.

The uPSP measurement technology used in these tests is the result of government-funded research by NASA and the U.S. Air Force Arnold Engineering and Development Center (AEDC). The particularly fast PSP used for this test was developed by Innovative Scientific Solutions, Inc. The system used for the test was developed at the AEDC. This test is the first time uPSP has been employed in a large transonic wind tunnel at NASA and is another in a series of PSP collaborations between AEDC and NASA.

For more information, contact Robert Youngquist, KSC, robert.c.youngquist@nasa.gov



Post-processing of failed composite shell from latest Shell Buckling Knockdown Factor test in March 2016.



Left to right: (Front row) Nancy Currie-Gregg (NASA Astronaut/presenter); Craig Ohlhorst (LaRC); Vinay Goyal (The Aerospace Corp.); Reggie Kidd (AMA); Wayne Branch (HPES); Larry Starritt (Jacobs Technology); Loren Plante (JSC); Timmy Wilson (NESC Director/presenter); Michael Kirsch (NESC Deputy Director/presenter); (Second row) James Beaty (LaRC); Susan Danley (KSC); Brian Davis (LaRC); Marc Schultz (LaRC); James Ross (ARC); Jeffrey Somers (KBRwyle); (Third row) David Dawicke (AS&M); James Reeder (LaRC); Eric Dyke (LaRC); Shant Kenderian (The Aerospace Corp.); Eric Burke (LaRC); Shawn Brechbill (MSFC); (Last row) James Ratcliffe (LaRC); Kyongchan Song (AMA); Norman Knight (SAIC); Hank Rotter (NESC)

Not pictured: Marvin Sellers (Arnold Engineering and Development Center) and Eugene Ungar (JSC)

NESC Directors Award

Norman F. Knight

In recognition of technical excellence and the consistent, professional pursuit of technical risks in the conduct of multiple NASA Engineering and Safety Center assessments

NESC Leadership Award

James R. Reeder

In recognition of outstanding technical leadership of the material property testing and analysis in support of the assessment and verification of the Multi-Purpose Crew Vehicle Exploration Mission-1 heatshield

Larry W. Starritt

In recognition of outstanding technical leadership of the Frangible Joint Test Team for the NASA Engineering and Safety Center Assessing Risks of Frangible Joint Designs Assessment

NESC Engineering Excellence Award

James R. Beaty

In recognition of engineering excellence in the feasibility, definition, objectives, performance prediction, and range safety for the Taurion/Sprint Flight Test Project

Shawn E. Brechbill

In recognition of engineering excellence for the NASA Engineering and Safety Center Fracture and Reliability of Valve Bellows Assessment

David S. Dawicke

In recognition of engineering excellence in the innovative analysis of frangible joint behavior for the NASA Engineering and Safety Center Assessing Risks of Frangible Joint Designs Assessment

Richard E. Dyke

In recognition of engineering excellence and leadership in the structural design, analysis, launch, and recovery of Taurion for the Taurion/Sprint Flight Test Project

Vinay K. Goyal

In recognition of engineering excellence in support to assess the integrity of the critical bond of Avcoat material on the Orion heatshield

Shant Kenderian

In recognition of engineering excellence leading to the development of a novel Non Destructive Evaluation technique that provides previously unobtainable full inspection of the critical Orion heatshield bondline

Reggie T. Kidd

In recognition of engineering excellence in design and integration of the Taurion and Sprint vehicles for the Taurion/Sprint Flight Test Project

Craig W. Ohlhorst

In recognition of engineering excellence in the innovative analysis of frangible joint behavior for the NASA Engineering and Safety Center Assessing Risks of Frangible Joint Designs Assessment

James G. Ratcliffe

In recognition of engineering excellence leading to advancements in fracture mechanics testing and analysis of Avcoat material used in the Orion heatshield

Marvin E. Sellers

In recognition of engineering excellence in the integration and demonstration of an advanced unsteady pressure sensitive paint capability in NASA wind tunnels for launch vehicle buffet prediction

Kyongchan Song

In recognition of engineering excellence in the structural analyses support for multiple NASA Engineering and Safety Center assessments

Eugene K. Ungar

In recognition of engineering excellence in support of the SOFIA Project in developing a scientifically-based and practical methodology for the safe design of new science instruments

NESC Administrative Excellence Award

Wayne E. Branch

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

Loren J. Plante

In recognition of exceptional program analyst support to the NASA Engineering and Safety Center Management and Technical Support Office

NESC Group Achievement Award

Avcoat Non Destructive Evaluation Team

In recognition of outstanding contributions in the field of Non Destructive Evaluation for the NASA Engineering and Safety Center led bond verification plan for the Orion Avcoat thermal protection system

Launch Vehicle Buffet Verification Team

In recognition of excellence in defining, planning, and executing a test program to investigate innovative techniques for prediction of launch vehicle buffet environments

Multi-Stage Supersonic Target Missile Team

In recognition of outstanding contributions in the design, development, and successful flight test of the Taurion sounding rocket booster in support of the U.S. Navy multi-stage supersonic target missile

NASA Engineering and Safety Center Shell Buckling Knockdown Factor Assessment Team

In recognition of outstanding contributions in the highly successful test of the 8-foot diameter composite shell

Orion and Commercial Crew Window Wavefront Measurement Assessment Team

In recognition of outstanding contributions in the field of Non Destructive Evaluation for the Orion and Commercial Crew Window Wavefront Measurement Assessment

Spacecraft Occupant Protection Team

In recognition of development of tools and methods for crew injury prediction to ensure human-rated spacecraft are designed with the appropriate level of occupant protection



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NESC Technical Discipline Team Member Scholarly Papers, Conference Proceedings, and Technical Presentations

Aerosciences

1. Panda, J.; Roozeboom, N. H.; and Ross, J. C.: Wavenumber-Frequency Spectra of Pressure Fluctuations Measured via Fast-Response Pressure-Sensitive Paint, 22nd AIAA/CEAS Aeroacoustics Conference, AIAA Paper 2016-3007, May 30 - June 1, 2016, Lyon, France.
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3. Spisz, T. S.; Taylor, J. C.; Gibson, D. M.; Kennerly, S.; Osei-Wusu, Kwame; Horvath, T. J.; Schwartz, R. J.; Tack, S.; Bush, B. C.; and Oliver, B.: Processing Near-Infrared Imagery of the Orion Heatshield During EFT-1 Hypersonic Reentry, AIAA Aviation and Aeronautics Forum and Exposition 2016, AIAA Paper 2016-4286, June 13-17, 2016, Washington, DC.
4. Vander Kam, Jeremy: Orion Exploration Flight Test One (EFT-1) Spacecraft Recovery and Thermal Protection System (TPS) Assessment, 27th Annual Thermal and Fluids Analysis Workshop, August 1-4, 2016, NASA Ames Research Center, Moffett Field, CA.

Avionics

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2. Darcy, Eric and Keyser, Matthew: On Demand Internal Short Circuit Device Enables Verification of Safer, Higher Performing Battery Designs, 18th International Meeting on Lithium Batteries, June 19-24, 2016, Chicago, IL.
3. Finegan, Donal; Darcy, E.; Keyser, M.; Tjaden, B.; Robinson, J.; Taiwo, O. O.; Hunt, I.; Scheel, M.; Di Michiel, M.; Rack, A.; Offer, G. J.; Hinds, G.; Brett, D. J. L.; and Shearing, P.R.: Understanding Battery Failure: A Multi-Scale and High-Speed X-Ray CT Approach, 18th International Meeting on Lithium Batteries, June 19-24, 2016, Chicago, IL.
4. Keyser, M.; Darcy, E.; and Pesaran, A.: A Research Tool to Evaluate the Safety Response of Lithium Batteries to an Internal Short Circuit, 18th International Meeting on Lithium Batteries, June 19-24, 2016, Chicago, IL.
5. Walker, William Q.: Energy Distributions Exhibited during Thermal Runaway of Commercial Lithium Ion Batteries used for Human Spaceflight Applications, Interagency Advanced Power Group Meeting, February 17-18, 2016, Houston, TX.
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7. Walker, William: Energy Distributions Exhibited during Thermal Runaway of Commercial Lithium Ion Batteries used for Human Spaceflight Applications, Thermal Fluids and Analysis Workshop, August 1-5, 2016, NASA Ames Research Center, Moffett Field, CA.
8. Walker, William: New Understanding of Energy Distributions Exhibited during Thermal Runaway of Commercial Lithium-Ion Batteries Used for Human Spaceflight Applications, 7th Annual Battery 2016 Safety, November 3-4, 2016, Bethesda, MD.
9. Yayathi, Sandeep; Walker, William; Doughty, Daniel; and Ardebili, Haleh: Energy Distributions Exhibited during Thermal Runaway of Commercial Lithium Ion Batteries used for Human Spaceflight Applications, Journal of Power Sources 329 (2016), pp 197-206.

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1. Higgins, Stephen L.; Davis, Robert; and Brown, Andrew M.: Reduced-Order Modeling of Flow-Induced Vibrations in Bellows Joints of Rocket Propulsion Systems, 57th AIAA/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, AIAA Paper 2016-0466, January 4-8, 2016, San Diego, CA.
2. Irvine, Tom: A Comparison of PSD Enveloping Methods for Nonstationary Vibration, ESTECH 2016, May 2-5, 2016, Glendale, AZ.
3. Irvine, Tom: A Matlab GUI Package for Statistical Energy Analysis IV&V, Spacecraft and Launch Vehicle Dynamic Environments Workshop, June 21-23, 2016, El Segundo, CA.
4. Irvine, T.: Statistical Energy Analysis Software & Training Materials, Spacecraft and Launch Vehicle Dynamic Environments Workshop, June 21-23, 2016, El Segundo, CA.
5. Irvine, Tom: Multiaxis Rainflow Fatigue Methods for Nonstationary Vibration, MoVIC & RASD 2016, July 3-6, 2016, University of Southampton, United Kingdom.

Mechanical Systems

1. DellaCorte, C.; Howard, S. Adam; and Moore, Lewis E. III: Failure Analysis and Recovery of a 50-mm Highly Elastic Intermetallic NiTi Ball Bearing for an ISS Application, 43rd Aerospace Mechanisms Symposium, May 4, 2016, Santa Clara, CA.
2. DellaCorte, C.; Howard, S. A.; Thomas, F.; and Stanford, M. K.: Microstructural and Material Quality Effects on Rolling Contact Fatigue of Highly Elastic Intermetallic NiTi Ball Bearings,” 2016 STLE Annual Meeting, May 15-19, 2016, Las Vegas, NV.

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2. Kenderian, Shant: Bond Quality Inspection for Nonhomogeneous Highly Attenuating Heat Shield Blocks, 3rd IEEE International Workshop on Metrology for Aerospace, June 22-23, 2016, Florence, Italy.

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1. Wilmot, Jonathan; Fesq, Lorraine; and Dvorak, Dan: Quality Attributes for Mission Flight Software: A Reference for Architects, 2016 IEEE Aerospace Conference, March 5-12, 2016, Big Sky, MT.

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1. Goyal, V.; Rome, J.; Soltz, B.: Lessons Learned in Certifying Space Structures, American Society for Composites 31 Technical Conference and ASTM Committee D30 Meeting, September 19-22, 2016, Williamsburg, VA.

Systems Engineering

1. Clem, A. K.; Nelson, G. J.; Mesmer, B.; Watson, M.D.; and Perry, J. L.: Exergy Based Analysis for the Environmental Control and Life Support Systems of the International Space Station, AIAA Space 2016, September 13-15, 2016, Long Beach, CA.
2. Compton, P.; Schomberg, K.; Ferreira, S.; and Hansen, J.: Systems Engineering Processes in NASA and Commercial Projects, 14th Annual Conference on Systems Engineering Research, March 22-24, 2016, Huntsville, AL.
3. Gilbert, A. and Mesmer, B.: Uses of Exergy in Systems Engineering, 14th Annual Conference on Systems Engineering Research, March 22-24, 2016, Huntsville, AL.
4. Gilbert, A.; Mesmer, B.; and Watson, M.D.: Exergy Analysis of Rocket Systems, IEEE International Systems Conference, April 18-21, 2016, Orlando, FL.

5. Gilbert, A.; Mesmer, B.; and Watson, M. D.: Exergy Based Optimization of Rocket System Staging Times, IEEE International Systems Conference, April 18-21, 2016, Orlando, FL.
6. Greene, M. T. and Papalambros, P. Y.: A Cognitive Framework for Engineering Systems Thinking, 14th Annual Conference on Systems Engineering Research, March 22-24, 2016, Huntsville, AL.
7. Greene, M. T.; Papalambros, P. Y.; and McGowan, A.-M.: Position Paper: Designing Complex Systems to Support Interdisciplinary Cognitive Work, 14th International DESIGN Conference, May 16-19, 2016, Cavtat, Dubrovnik, Croatia.
8. Johnson, Stephen B. and Day, John C.: Theoretical Foundations for the Discipline of Systems Engineering, AIAA SciTech Conference, AIAA Paper 2016-0212, January 4-8, 2016, San Diego, CA.
9. Johnson, Stephen B.: The Representations and Practices of the Discipline of Systems Engineering, 14th Annual Conference on Systems Engineering Research, March 22-24, 2016, Huntsville, AL.
10. Kis, D.; Poetting M.; Wenger, C.; and Bloebaum, C. L.: A Multidisciplinary Coupling Analysis Method to Support Investigation of Ares 1 Thrust Oscillation, 14th Annual Conference on Systems Engineering Research, March 22-24, 2016, Huntsville, AL.

11. Marquart, S. and Szajnfarber, Z.: A Novel Approach to Measuring the Time-Impact of Oversight Activities on Engineering Work, 14th Annual Conference on Systems Engineering Research, March 22-24, 2016, Huntsville, AL.
12. Moreland, Rob; Phojanamongkolkij, Nipa; Knizhnik, Jessica; Mills, Ted; and Weiland, Karen: A Survey of Model-Based Programmatic Systems Methodology at NASA, NASA Cost Symposium, August 25, 2016, NASA Glenn Research Center, Cleveland, OH.
13. Price, R. M. and Malak, R. J.: A Capability-Based Framework for Supporting Value-Driven Design, 14th Annual Conference on Systems Engineering Research, March 22-24, 2016, Huntsville, AL.
14. Watson, M. and Farrington P.: NASA Systems Engineering Research Consortium: Defining the Path to Elegance in Systems, 14th Annual Conference on Systems Engineering Research, March 22-24, 2016, Huntsville, AL.

NESC Scholarly Papers, Conference Proceedings, and Technical Presentations

1. Barth, T.; Blankmann-Alexander, D.; Kanki, B.; Lilley, S.; and Parker, B.: Recurring Themes From Human Spaceflight Mishaps During Flight Tests and Early Operations, Eighth IAASS Conference, May 18-20, 2016, Melbourne, FL.
2. Brown, T.; Klem, M.; and McRight, P.: Foundational Methane Propulsion Related Technology Efforts and Challenges for Applications to Human Exploration Beyond Earth Orbit, 3AF Space Propulsion 2016, SP2016_3125381, 2016.
3. Currie-Gregg, N. J.: Managing Risk and Innovation in a High-Reliability Organization, 2016 Professional Engineers Conference, June 22-26, 2016, Dallas, TX.
4. Czech, M. T.; Groh-Hammond, M.; Henderson, G.; Miller, D.; Neal, A. J.; Parker, R.; Ruiz, J.; Stambolian, D.; Tran, D.; Kanki, B.; Ellenberger, S. R.; Boyer, J.; Reynolds, D. W.; Dischinger, C.; Null, C. H.; and Barth, T. S.: Ground Operations Human Factors Task Analysis Pathfinder, Eighth IAASS Conference, May 18-20, 2016, Melbourne, FL.
5. Ferguson, D. C. and Minow, J. I.: Status of Spacecraft Charging in the USA, 14th Spacecraft Charging Technology Conference, April 4-8, 2016, Noordwijk, Netherlands.
6. Gilbert, M. G.: Purpose, Principles, and Challenges of the NASA Engineering and Safety Center, 8th IAASS Conference “Safety First, Safety for All,” May 18-20, 2016, Melbourne, FL.
7. Horvath, T. J.; Rufer, S. J.; Schuster, D. M.; Mendeck, G. F.; Oliver, A. B.; Schwartz, R. J.; Verstynen, H. A.; Mercer, C. D.; Tack, S.; Ingram, B.; Spisz, T. S.; Taylor, J. C.; Gibson, D. M.; Osei-Wusu, Kwame; Kennerly S.; and Bush, B. C.: Infrared Observations of the Orion Capsule During EFT-1 Hypersonic Re-entry,” AIAA Paper 2016-4285, June 2016.
8. Irvine, T. and Larsen, C. E.: Modified Spectral Fatigue Methods for S-N Curves with MIL-HDBK-5J Coefficients, 14th European Conference on Spacecraft Structures, Materials and Environmental Testing (ECSSMET), September 27-30, 2016, Toulouse, France.
9. Johnson, K. L. and Tylka, J.: Burn Length: The 10k Test, Knowledge Exchange Workshop 2016, April 11-13, 2016, Crystal City, VA.
10. Larsen, C. E. and Raju, I. S.: Moving Aerospace Structural Design Practice to a Load and Resistance Factor Approach, SciTech Conference, January 4-8, 2016, AIAA Paper 2006-2030, San Diego, CA.

11. Mendenhall, M. R.; Lesieutre, D. J.; and Kelly, M. J.: Wake-induced Aerodynamics on a Trailing Aircraft, 2016 Applied Aerodynamics Conference, July 19-21, 2016, Bristol, United Kingdom.
12. Minow, J. I.: Space Environments and NASA's Engineering and Safety Center, 96th Annual AMS Meeting, January 10-14, 2016, New Orleans, LA.
13. Minow, J. I.: Tutorial: Science Weather Impacts on Space Assets, CCMC Space Weather School, Science of Space Weather Workshop, January 24, 2016, Goa, India.
14. Minow, J. I.: Spacecraft Charging and Auroral Boundary Predictions in Low Earth Orbit, Science for Space Weather Workshop, January 24-29, 2016, Goa, India.
15. Minow, J. I.: Space Weather Impacts on Satellites with Emphasis on Launch Vehicles, GSFC Weather Training Course, February 2-4, 2016, Cocoa Beach, FL.
16. Minow, J. I.: NASA Missions Space Weather Needs: Spacecraft (Surface) Charging at LEO Orbits, 8th CCMC Workshop 2016, April 10-15, 2016, Annapolis, MD.
17. Minow, J. I.: NASA Technical Fellow for Space Environments View of CCMC, 8th CCMC Workshop 2016, April 10-15, 2016, Annapolis, MD.
18. Minow, J. I.: CHANDRA Space Weather Vulnerabilities and Needs Update, 8th NASA Space Exploration & Space Weather Workshop, September 27-28, 2016, Greenbelt, MD.
19. Minow, J. I.: NASA Space Exploration and Space Weather Workshop, 8th NASA Space Exploration & Space Weather Workshop, September 27-28, 2016, Greenbelt, MD.
20. Minow, J. I. and Neergaard Parker, L.: Dual-Spacecraft Observations of Auroral Charging, 14th Spacecraft Charging Technology Conference, April 4-8, 2016, Noordwijk, Netherlands.
21. Prosser, W. H.: The NASA Engineering and Safety Center Nondestructive Evaluation Technical Discipline Team, 25th ASNT Research Symposium 2016, April 11-14, 2016, New Orleans, LA.
22. Prosser, W. H.: Applications of Advanced Nondestructive Measurement Techniques to Address Safety of Flight Issues on NASA Spacecraft, 3rd International Workshop on Metrology for Aerospace, June 21-23, 2016, Florence, Italy.

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NESC Scholarly Papers, Conference Proceedings, and Technical Presentations

Continued

23. Raju, I. S.: Real Life Problems are Multi-disciplinary, 2016 AIAA Science and Technology Forum and Exposition, January 4-8, 2016, San Diego, CA.
24. Raju, I. S.: Simple Test Functions in Meshless Local Petrov-Galerkin Methods, 2016 AIAA SciTech Conference, January 4-8, 2016, AIAA Paper 2006-1240, San Diego, CA.
25. Raju, I. S.: Design Process Using Factors of Safety, Margins of Safety, and Probabilistic Approaches, Seminars to Engineering Students, February 4-5, 2016, Kakinada And Hyderabad, India.
26. Raju, I. S.: Real Life Problems are Multidisciplinary, Seminar at the Department of Mechanical Engineering, September 23, 2016, Auburn, AL.
27. Rickman, S. L.: Form Factors, Grey Bodies and Radiation Conductances (Radks), Thermal and Fluids Analysis Workshop 2016, August 1-5, 2016, Moffett Field, CA.
28. Rickman, S. L.: Introduction to Numerical Methods in Heat Transfer, Thermal and Fluids Analysis Workshop 2016, August 1-5, 2016, Moffett Field, CA.
29. Rickman, S. L.; Christie, R. J.; White, R. E.; Drolen, B. L.; and Navarro, M.: Considerations for Thermal Modeling of Lithium-Ion Cells for Battery Analysis, 46th International Conference on Environmental Systems, July 10-14, 2016, Vienna, Austria.
30. Rickman, S. L. and Iannello, C. J.: Heat Transfer Analysis in Wire Bundles for Aerospace Vehicles, 14th International Conference on Simulation and Experiments in Heat Transfer and its Applications, September 7-9, 2016, Ancona, Italy.
31. Singh, U. N.: International Coordination-group for Laser Atmospheric Studies (ICLAS) Working Group Report for 2010-2015, The International Radiation Symposium 2016, April 16-22, 2016, Auckland, New Zealand.
32. Singh, U. N.; Petros, M.; Refaat, T. F.; and Yu, J.: 2-micron Triple-pulse Integrated Path Differential Absorption Lidar Development for Simultaneous Airborne Column Measurements of Carbon Dioxide and Water Vapor in the Atmosphere, SPIE Asia-Pacific Remote Sensing, April 4-7, 2016, New Delhi, India.
33. Singh, U. N.; Refaat, T. F.; Yu, J.; Petros, M.; and Kavaya, M. J.: High Energy Solid-state Pulsed 2-micron Lidar Development for Wind, Water Vapor and CO₂ Measurements From Ground and Airborne, The International Radiation Symposium 2016, April 16-22, 2016, Auckland, New Zealand.
34. Singh, U. N.; Petros, M.; Refaat, T. F.; Antill, C. W.; Remus, R. G.; and Yu, J.: Airborne Lidar for Simultaneous Measurement of Column CO₂ and Water Vapor in the Atmosphere, SPIE Remote Sensing 2016, September 26-29, 2016, Edinburgh, United Kingdom.
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NASA Technical Publications

1. The Making of SOFIA - The Stratospheric Observatory for Infrared Astronomy - 1985 to 2016 **NASA/NP-2016-09-842-LaRC**
2. Experimental Verification of Buffet Calculation Procedure Using Unsteady PSP **NASA/TM 2016-219069**
3. Space Launch System (SLS) Program Block IA Advanced Booster (AB) High-Performance Solid Propellant and Composite Case/Internal Polybenzimidazole (PBI) Nitrile Butadiene Rubber (NBR) Insulation Development **NASA/TM-2016-219006**
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6. Maxwell Technologies, Incorporated Single Board Computer (SBC) Printed Circuit Board (PCB) Panels Assessment (Lot 2 - Date Code (DC) 1401 Follow-on Task) **NASA/TM-2016-219187**
7. Carbon Fiber Strand Tensile Failure Dynamic Event Characterization **NASA/TM-2016-219188**
8. Computing Buffet Environments for Space Launch System (SLS) Configurations **NASA/TM-2016-219190**
9. Multi-Purpose Crew Vehicle (MPCV) Program Window Wavefront Measurement Capability Development **NASA/TM-2016-219207**
10. Human Vibration Modeling for Multi-Purpose Crew Vehicle (MPCV) Coupled Loads Analysis (CLA) **NASA/TM-2016-219208**
11. Review of Multi-Purpose Crew Vehicle (MPCV) Program Crew Module (CM) European Space Agency (ESA) Service Module (ESM) Interfaces **NASA/TM-2016-219212**
12. Remote Imaging of Exploration Flight Test-1 (EFT-1) Entry Heating Risk Reduction **NASA/TM-2016-219214**
13. NASA Engineering and Safety Center (NESC) Modeling of Crawler-Transporter (CT), Mobile Launcher (ML), and Forcing Functions **NASA/TM-2016-219333**
14. Crew Exploration Vehicle (CEV) (Orion) Occupant Protection **NASA/TM-2016-219337/Volume I**
15. Crew Exploration Vehicle (CEV) (Orion) Occupant Protection: Appendices Part 1 **NASA/TM-2016-219337/Volume II-Part 1**
16. Crew Exploration Vehicle (CEV) (Orion) Occupant Protection: Appendices Part 2 **NASA/TM-2016-219337/Volume II-Part 2**





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