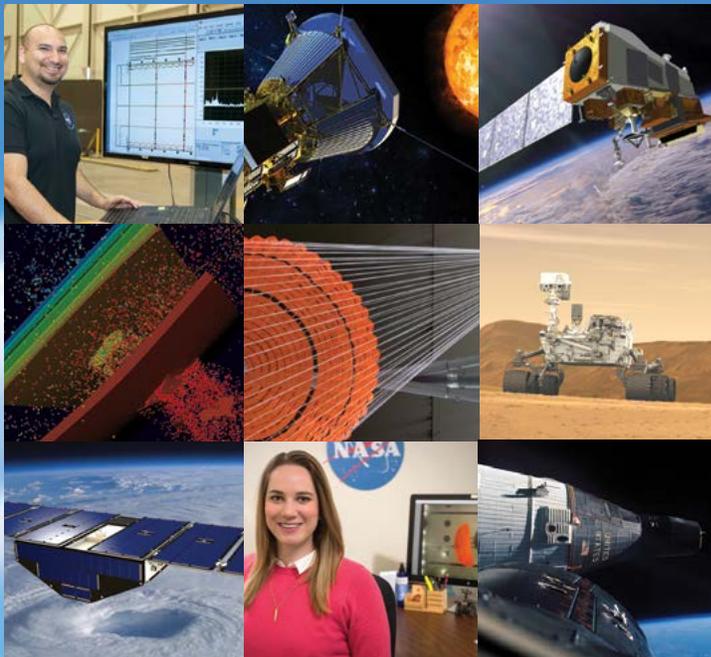




# NASA ENGINEERING & SAFETY CENTER TECHNICAL UPDATE



2015





NASA Engineering  
& Safety Center  
Technical Update  
2015

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

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The NESC is the “go to” technical resource for the Agency. This year the NESC continued to provide tremendous value to our ongoing programs — quickly addressing real-time issues, providing alternative designs for consideration when necessary, and taking the extra steps in testing and analysis for areas where the Agency needed further confidence around key technical risks.

The collection of experts in the NESC forms the foundation and leadership of not only NASA’s renowned technical capabilities, but also has extensive reach into industry and academia to help tackle the Agency’s technical challenges. Also this year, the NASA Technical Fellows took on the added responsibility of assessing the overall Agency capabilities in their discipline areas. The Technical Fellows and their discipline teams developed the first ever comprehensive look at these Agency technical capabilities. These efforts lead the Agency in developing a more efficient operating model with regard to investing in those critical capabilities we hold not only for the Agency, but also for the Nation.

**Robert Lightfoot, NASA Associate Administrator**



Over the past decade, many things have changed at the NESC: the leadership has evolved, the number of technical discipline teams has increased, and the scope of work and the responsibilities the NESC takes on has expanded to meet the Agency’s priorities. What has not changed, however, is the core purpose of the NESC: the commitment to successful programs and projects by providing independent technical analysis and testing, the open environment and focus on safety, and the dedication to NASA’s overall mission. The NESC reflects some of the NASA community’s best ideals by working together across Center boundaries toward a common vision. I am extremely proud of how the NESC has progressed over the past 13 years, and look forward to the NESC’s continued support toward the success of Agency programs.

**Ralph Roe, Jr., NASA Chief Engineer**

## Meeting the Agency's Technical Challenges



NASA has always risen to meet some of the great challenges in human history: from landing men on the Moon, to exploring the solar system, to the technological achievements of the Space Shuttle and International Space Station. But the path of exploration and discovery has been crossed by moments of tragedy — when members of the NASA family were lost in the pursuit of these accomplishments. Knowing that space travel is inherently both challenging and perilous doesn't make tragedies easier to accept. Nor should it. We owe it to those who have lost their lives to both continue the pursuit of space and to learn the lessons bought at such a high price to make space travel as safe as we can. This is a challenge as difficult, but as important, as anything NASA has achieved so far.

NASA established the NASA Engineering and Safety Center (NESC) after the Columbia accident to help address some of the aspects of NASA's culture that led to the tragedy. Too often, prior to the accident, tough technical discussions were missing an independent voice that was detached from and not beholden to the Space Shuttle Program. The NESC provides an independent voice. As a unit of the NASA Office of the Chief Engineer, it is separate from all of NASA's programs, projects, and mission directorates and is also distributed across the Agency to avoid influence from any one particular Center. The NESC is an organization that derives its strength and credibility from experts from across the country and by encouraging diverse points of view in an open and inclusive decision making process.

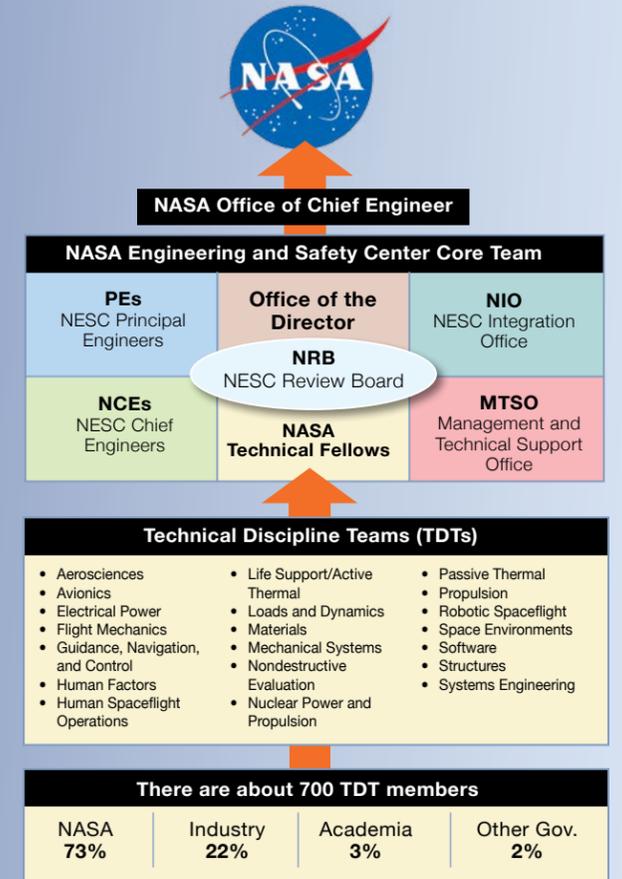
The formal activities that the NESC undertakes are called assessments. An assessment team is formed to pursue a specific technical issue and is patterned after the "tiger team" concept. An objective from the start of the NESC was to provide a capability to quickly bring in engineers and scientists — with the highest level of technical knowledge and experience available — to form teams to pursue the toughest technical problems. The NESC's Technical Discipline Teams (TDTs) serve as pools of engineering talent ready to feed into assessments as needed. Members of the TDTs come from throughout NASA and the federal government, as well as from academia and industry. There are a total of 20 TDTs: one for each of 18 engineering disciplines (see sidebar) plus one each for Robotics and Human Spaceflight Operations.

The 18 discipline-specific TDTs are led by the NASA Technical Fellows. The Technical Fellows are NASA's senior

technical experts and are the stewards of their respective disciplines. They are considered part of the NESC core team. Other members of the core team include the Principal Engineers, NESC Chief Engineers, the NESC Integration Office, the Management and Technical Support Office, and the NESC Director and the Director's Office. An NESC Chief Engineer is resident at each Center and is a convenient way to contact the NESC. The TDT members and others who are not badged to the NESC, but who participate in assessments, make up the extended team. The extended team has approximately 700 people compared to about 60 core team members.

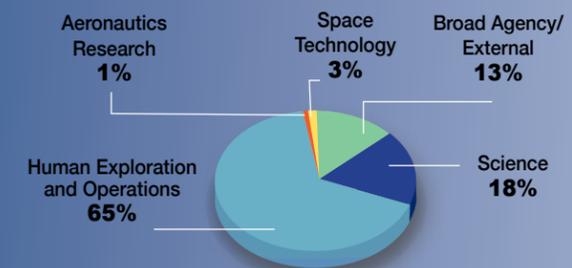
In 2015, the NESC accepted approximately 60 requests for either independent assessments or other support activities. As assessments are completed, the NESC provides findings and recommendations to the assessment stakeholders and also shares the results with NASA and the broader technical community through detailed engineering reports. The NESC also shares lessons learned and transfers knowledge from the TDT members through Technical Bulletins and the NESC Academy — a source of web-based, instructor-led courses covering a variety of technical discipline topics. The NESC Academy reached over 15,000 viewers in 2015. The NESC also led the Agency in a wide-ranging study of NASA's technical capabilities throughout the Agency. This activity represented a new dimension of the Technical Fellows' responsibilities, and the results are critical to understanding how the Agency can most effectively meet NASA's mission priorities in the future.

The NESC was created because of a tragedy. The NESC exists to prevent the next one. It is important to not lose sight of some of the cultural and systemic causes of the Columbia accident and to create an environment for a strong safety culture driven by the engineering excellence that is a foundation of NASA. The NESC is a resource for the entire Agency to make these goals possible.

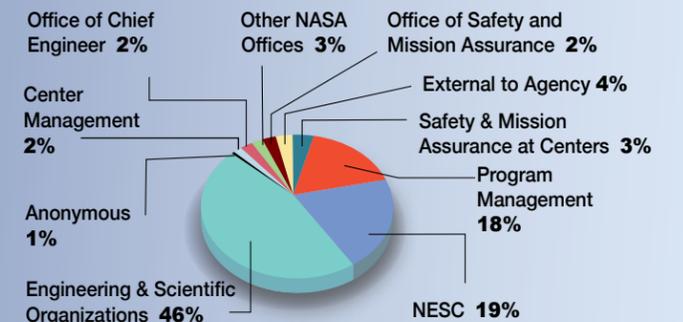


### Accepted Requests Since 2003: 669 total

#### Accepted Requests by Mission Directorate



#### Sources of Accepted Requests



Data as of December 31, 2015

## Setting Priorities

How the NESC keeps its focus on key technical risks



NESC Director Tim Wilson

In 2015, the NESC accepted almost 60 requests for assessments, bringing the total number of active assessments to nearly 100. That acceptance rate reflects a steady average of more than 50 requests per year since the organization began in 2003 in the wake of the Columbia accident. What the numbers do not show, however, is how the NESC decides, in a tough fiscal climate, which assessments to undertake.

NESC Director Tim Wilson discusses how the decision to take on an assessment requires a careful, calculated approach — not only to understand the potential risks and benefits to a program but also to recognize how it fits into the bigger NASA picture.

**As the Space Shuttle Program came to a close, did the NESC workload decrease at all?**

The workload hasn't decreased. In fact, it has gone up. In the early years we had two crewed programs running,

Shuttle and the International Space Station (ISS). Now we have six, with Orion Multi-Purpose Crew Vehicle (MPCV), Space Launch System (SLS), their supporting ground systems [Ground Systems Development and Operations — (GSDO)], two commercial partners, and ISS. Demand has certainly not gone down.

**How does the NESC prioritize assessment requests as they come in? And how did the priority structure come about?**

When our budget started to shrink and it became clear that we were going to have to do more with less, as most government agencies have, we had to prioritize the requests to make sure we focus on the ones most important to the Agency. So we developed priority levels from 1 to 5. We first focus on requests for in-flight programs. Those are always priority 1. Priority 2 focuses on programs in the design phase, or near flight. Priorities 3 - 5 focus on work to avoid potential future problems or system improvements. We had to do that in order to manage demands on our budget.

**Does the NESC only take on requests that meet level 1 and 2 priorities?**

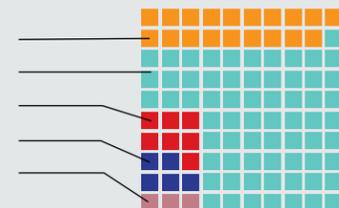
We're quickly getting to that point, but for now, we still have work underway in all of those categories. As requests come in, our normal process is to do initial evaluations. As part of that process, we look at the risk and the benefits to the program or project and the Agency as a whole, then decide what work to take on. But certainly, programs that are in flight, or about to fly, get the focus and consume the bulk of our resources.

**As an organization under the Office of the Chief Engineer (OCE), how do you support them in terms of mitigating engineering/technical risks faced by Agency programs?**

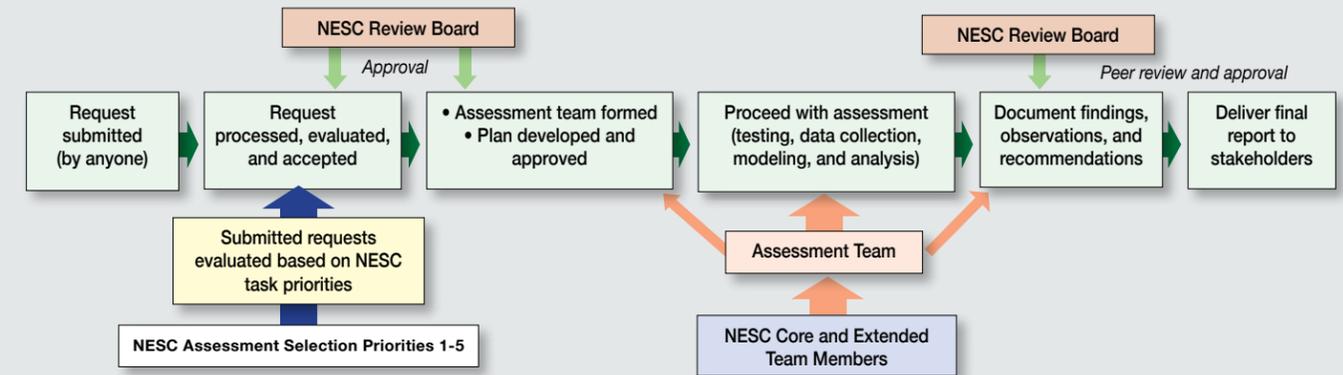
The NASA Chief Engineer keeps a list of what he considers the Agency's top technical risks. And as it turns out, the work we do maps very well to that list. Part of it is a natural by-product of our selection process, which uses risk matrices and asks tough questions during our initial evaluations. We're also concerned about the same things he is — like new programs coming online and keeping the station flying.

### 2015 In-Progress Requests by NESC Assessment Selection Priorities

Priority 1. Technical support of projects in the flight phase	19%
Priority 2. Technical support of projects in the design phase	66%
Priority 3. Known problems not being addressed by any project	7%
Priority 4. Work to avoid potential future problems	5%
Priority 5. Work to improve a system	3%



### Performing NESC Assessments



**Can you provide examples of where NESC work supports mitigating the OCE's Agency technical risks?**

One of the NASA Chief Engineer's concerns is integration of the new exploration programs. With SLS, Orion MPCV, and GSDO, he's concerned about how you ultimately pull those together into one operating program. So, one of our tasks is independent modeling and simulation for Exploration Systems Development (ESD) to develop tools that will give us insight on how they do integration and modeling, and will give them independent answers, or checks and balances, against work that they are doing internally. It is a good example of an assessment that specifically attacks an OCE key risk. And almost any assessment for Orion or SLS directly attacks what he calls "closing the gap," or ensuring the new exploration programs have the technical support they need to accomplish their goals. Those are big pieces of the pie for us.

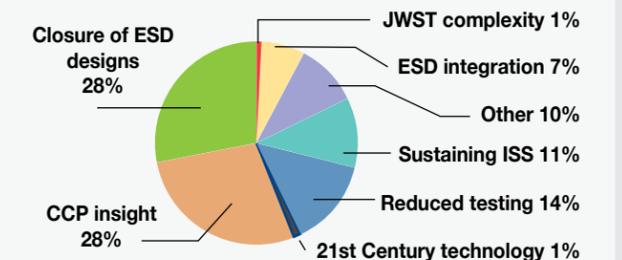
**When you look back over the NESC's 600+ assessment portfolio, what stands out to you?**

That we've made a positive impact on the Agency. We get good feedback — unsolicited feedback — that the work that we've done has added value and helped programs and projects be successful. Our work is spread well across NASA programs, from human exploration to the Science Mission Directorate, aeronautics, and technology, and has expanded over the years. The demand for our work comes from program managers and engineering organizations, which has grown as folks have come to learn about our capabilities and appreciate the products we provide. I don't see any of that changing.

**Where do you see the NESC in the next 10 years?**

I think the pattern of moving from operational to developmental work is going to shift back in the other direction. We're all counting on having two commercial partners flying within the next couple of years. And we're going to have NASA exploration vehicles flying. So we'll be back into an operational mode. We'll still be supporting development work with science programs, but the big hitters will be in-flight programs at that point. I don't see any slow-down, however. I think the demand will keep coming.

### Percent of NESC FY 2015 Assessments Supporting OCE Agency Technical Risks



### OCE Agency Technical Risks Currently Supported by the NESC

- **Commercial Crew Partner (CCP) Insight** into partner designs to enable their success and certify vehicles for human spaceflight
- **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
- **Reduced testing** and heavy reliance on models and analysis, driven by constrained budgets, with limited anchoring to ground or flight tests
- **21st century technology** tools and methods successfully incorporated into NASA programs and projects

## Professional Launchpad

Engineers draw experience from the NESC as they begin their careers

“Hands-on” experience is one of the most valuable assets an engineer can have, and also one of the most difficult to obtain. To assist in preparing the next generation of engineers who will take us to Mars and beyond, the NESC includes an early-career engineer, who typically has fewer than 10 years in the NASA workforce, on most NESC assessments. Following are discussions with three such engineers who reflect on their experiences as team members on NESC assessments.

### Dr. Alan Schwing – Computational Aerodynamics

Launching small, scaled models of an entry capsule at speeds of up to Mach 3.0 is going to help the NESC collect important flight data. It is part of an NESC assessment to measure backshell pressures the Mars 2020 capsule may experience during its descent to the red planet. The results will help guide the best placement for certain instrumentation on the vehicle.

For JSC engineer Dr. Alan Schwing, this NESC assessment is a chance to put his new doctorate in computational aerodynamic analysis to the test. A former co-op student with JSC, Dr. Schwing has been with NASA for just a few years, launching what will likely be a successful profession in aerospace engineering.

Drawing from the previously successful resident engineer program, the NESC strives to add early-career engineers to assessments that can offer opportunities to absorb as much knowledge as they can by working alongside some of the best and brightest in the Agency. It is a chance to be part of multi-discipline and multi-Center teams, build a network of contacts, and engage in important NASA missions.

Dr. Schwing has already seen the advantages of working on the NESC’s backshell pressure field assessment. “It’s very different from things I’ve worked on in the past,” he says. “But whenever you step outside your comfort zone and work with senior engineers, I think you have the opportunity to grow. It builds confidence and competency. I’ve learned a lot already, and it’s made me more self-sufficient.”

Used to working with a small group on Orion crew module flight testing, Dr. Schwing says the NESC assessment is broadening his horizons. “We have weekly meetings with several people across the Agency. In terms of collaboration, everyone is open and sharing. These people are some of the best at what they do. At some point this project will end, but I’ll have connections with these people who are much more seasoned and have been around the block with test programs,” he says. “It may not be quantifiable today, but will hopefully provide dividends in the future.”



*“Whenever you step outside your comfort zone and work with senior engineers, I think you have the opportunity to grow”*

— Dr. Alan Schwing

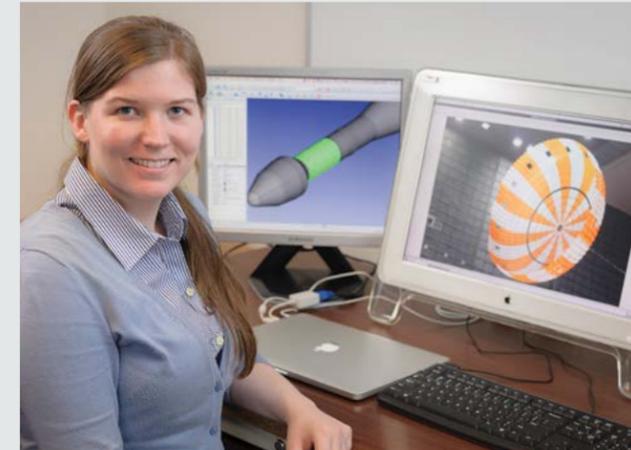
### Jessica Powell – Computational Mathematical Engineering

Jessica Powell combines her work at NASA with her studies at Stanford University, where she is getting her master’s degree in computational mathematical engineering. On rotation to ARC from JSC, Ms. Powell is another early-career engineer working with the NESC on an assessment involving the application of system identification to parachute modeling.

She is hoping that by improving current modeling and simulation techniques for parachutes, she’ll have knowledge she can take back to her work on Orion crew module aerodynamics. Though brand new to the assessment team,

NESC Director Tim Wilson on early-career engineers

*“It’s an opportunity we can’t afford to miss,” says NESC Director Tim Wilson. “There won’t be a NASA 20 years from now if those folks aren’t well trained and well versed in what we do and how we do it.”*



*“It’s good to know whom to contact if you have questions and need expertise to handle problems as they come up” — Jessica Powell*

she already has an idea of what she will take away from the experience as this is not her first time working with the NESC. She is also part of an assessment on launch vehicle buffet verification testing that started last year.

“It’s a role outside my expertise so it’s been a huge learning experience,” she says. “It was my first time working with folks at other Centers. I’ve made great contacts that have helped on my core work with Orion.” The assessments offer her a “wider field of experience,” she says. “And it’s good to know whom to contact if you have questions and need expertise to handle problems as they come up.”

### Dr. Rafael Lugo – Flight Dynamics and Flight Mechanics

Dr. Rafael Lugo was a graduate student until early 2014. Through his position at Analytical Mechanics Associates, Inc., he has worked with NASA on the Mars Atmosphere and Volatile Evolution (MAVEN) Mission. More recently however, he was asked to join the NESC assessment on Exploration Systems Independent Modeling and Simulation. “My background is flight dynamics and flight mechanics,” Dr. Lugo says. “I work heavily with figuring out how spacecraft will move through space,” which is what brought him to this assessment, where he is analyzing the possible trajectories of the Orion service module panels once they are jettisoned after liftoff to check for possible



*“It’s been a lot of hard work, but rewarding” — Dr. Rafael Lugo*

re-contact with the Space Launch System (SLS) core stage.

“Working with a large group of people is very interesting,” he notes, which is different from his days as a student, working by and for himself. He has since worked as a technical lead on the NESC assessment, coordinated meetings, and done multiple presentations. “This was a big responsibility. I hadn’t done anything like that up until then. But I think I rose to the challenge. It’s been a lot of hard work, but rewarding.”

Dr. Lugo never anticipated working on a project of this size right after finishing his dissertation. “But it’s been a lot of fun and I’d love to continue being a part of it,” he says.

“They are the future,” says NESC Director Tim Wilson of engineers just beginning their careers at NASA. That is why he adds an early-career engineer to NESC assessments whenever the opportunity arises. “We have some of the most mature, seasoned engineers at NASA work on our assessments. And this is an opportunity for those new engineers to work directly with them, to talk to them, and understand how they work. It’s not every day they get that kind of opportunity to interact with engineers of that caliber. It’s an opportunity we can’t afford to miss,” says Mr. Wilson. “There won’t be a NASA 20 years from now if these folks aren’t well-trained and well-versed in what we do and how we do it.”

## Ames Research Center

In 2015, Ames Research Center (ARC) personnel supported a diverse set of NESC assessments. A major area of contribution included providing key aerosciences expertise in support of investigations into the buffet environment of the Space Launch System (SLS). Of special interest was the interface between the SLS core stage and solid rocket booster. Another significant area of support was providing entry, descent, and landing expertise necessary to develop independent modeling and simulation of Commercial Crew Provider mission profiles. This effort will support NASA's insight to the provider's designs and will ultimately support independent analysis during mission operations. ARC personnel also supported investigations and independent reviews of Li-Ion battery thermal runaway risk reduction efforts for the International Space Station and also of fault detection, isolation, and recovery algorithms to be implemented in the Orion crew module guidance, navigation, and control system. The NASA Technical Fellow for Human Factors is resident at ARC.



**Nans Kunz**  
NESC Chief Engineer

**27** ARC employees supported NESC work in FY15

"It was good training, reviewing tons of analysis and drawings to see what might be missing, what could be done differently, and how to validate that analysis."

Working with the NESC, says Mr. Lam, offers him the chance to work with multi-Center teams and to learn from senior members. "Usually they are looking at the broader picture, while I'm down in the details, but that's okay. I've learned to listen to presentations, quickly assess large amounts of data, and decide on what to review in the time I have available. I've learned how to make the most effective use of my time and gain some good insight."

### Applying Aeroacoustics

This year Nathan Burnside brought his expertise in aeroacoustics to bear on a key NESC assessment on buffet environments, fluctuating pressures that can generate loads on a vehicle. For this assessment, Mr. Burnside spent a large amount of time in the Ames 11-foot wind tunnel calibrating more than 200 unsteady pressure transducers and verifying that each was accurately positioned on a vehicle model. "There were a lot of new measurement techniques involved and many of them would be verified and validated by the measurements we were making. And there were many groups interested in the data that would result from these tests," he says.

This assessment is not Mr. Burnside's first with the NESC. In past years he has helped conduct wind tunnel tests on a model that would help determine the shape of the MPCV and tests on backshell pressures for reentry capsules. He says he is happy to answer when the NESC calls. "I look forward to working with the NESC. Their projects are interesting and they are always looking to solve a problem," which he finds challenging.

He also sees the work having a positive impact on his discipline. "I see a changing landscape of wind tunnel testing for aeroacoustics," he says. "The measurements we took are very promising. I can see how they will be used a lot more in the future."

### Scrutinizing Stress

ARC Structures Engineer Paul Lam specializes in stress analysis of flight vehicles and has worked with the NESC on several assessments. He has provided a crucial independent look at countless stress analysis reports for the SLS and the Multi-Purpose Crew Vehicle (MPCV) during critical design reviews, as well as commercial partner vehicles, providing valuable feedback to the NESC.

"I typically review thousands of pages of stress analysis," says Mr. Lam. "It may not be everyone's idea of fun, but I enjoy it." While he finds being mired in the details appealing, he also finds the overall work very rewarding. "It's exciting to see the future of space exploration being developed right now. I imagine this could be similar to the dawn of aviation as we're developing all new vehicles for spaceflight."

Mr. Lam says the work harkens back to his early days at NASA reviewing structural analyses for SOPHIA, NASA's Stratospheric Observatory for Infrared Astronomy.



Paul Lam, structures expert.



Nathan Burnside, aeroacoustics expert.

## Armstrong Flight Research Center

The Armstrong Flight Research Center (AFRC) provided engineering technical support and expertise to the NESC for numerous assessment activities including the Frangible Joints Design Testing, Shell Buckling Knockdown Factors (SBKF), the Vehicle Integrated Propulsion Research (VIPR) Experiment Impacts on the Test Aircraft Airframe, and commercial partners electrical power system review. AFRC collaborated with JSC to lead an assessment requested by the Stratospheric Observatory for Infrared Astronomy (SOFIA) Project to develop a technique called the Simplified Methodology to Estimate the Maximum LHe Cryostat Pressure from a Vacuum Jacket Failure. AFRC engineers were also invited by NASA Technical Fellows to give presentations to their Technical Discipline Teams (TDTs).



**Dr. W. Lance Richards**  
NESC Chief Engineer

**10** AFRC employees supported NESC work in FY15

instrumentation layout of fiber optic sensors to be installed onto an 8-foot diameter composite barrel structure. The SBKF activity is a multi-Center assessment focused on designing leaner and more efficient rocket shell structures through new designs, simulations, and advanced test technologies. The use of nearly 16,000 fiber optic sensors, located on the inner and outer surfaces of the barrel, will help the engineers verify their buckling prediction models for large-scale shell structures with the goal of reducing mass and increasing payload. Through this activity, Mr. Peña has gained greater insight into the process of coordinating multiple sensor suites onto a large-scale space structure. He has enjoyed participating on the SBKF team and has grown significantly from working with expert structural engineers from multiple NASA Centers.

### Frangible Joint Testing

Because of his expertise in instrumentation and testing, Christopher Kostyk was requested to serve as the Data Team Lead on the Assessing Risks of Frangible Joint Designs Assessment. Mr. Kostyk enjoyed this role because it allowed him to contribute at a high level in helping to design the test series that would enable critical data collection, as well as leading the design of the high-speed instrumentation suite that would capture the ephemeral activity associated with the detonation event. Mr. Kostyk had the opportunity to learn various analytical tools, including how to use specialized software for extracting quantitative data from the high-speed video footage that greatly helped inform the team on various aspects of the short life of a frangible joint. In November, he received the NESC Engineering Excellence Award for his support of the frangible joint assessment.

### Composite Shell Buckling Knockdown Factor

Francisco Peña, an aerospace engineer at AFRC, contributed to the SBKF activity by developing the

### Passive Thermal Support

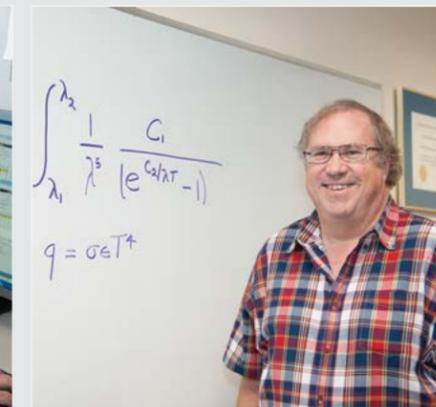
In 2015, Timothy Risch supported the NESC in a variety of activities. As AFRC's continuing representative on the Passive Thermal TDT, Mr. Risch led an assessment of the Agency's ablation modeling capability to help define NASA's future direction for this work. He also worked cooperatively with NESC to help analyze and provide a solution to mitigate convective engine heating on a C-17 pylon. This activity supported ground testing for the Aeronautics Research Mission Directorate's VIPR Program conducted jointly with the Air Force Test Center and AFRC. Mr. Risch also authored an NESC Academy lesson on radiative temperature measurement that outlined various methods and strategies for performing non-contact temperature measurements on heated objects commonly found in reentry, propulsion, and other high-temperature environments. Mr. Risch has appreciated the opportunity to contribute to NESC's and the Agency's missions by applying his skills and knowledge in heat transfer and thermal protection systems design and testing.



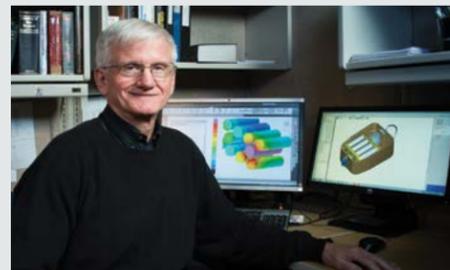
Francisco Peña developed SBKF instrumentation.



Christopher Kostyk analyzed high-speed video of frangible joint design tests.



Timothy Risch provided expertise in thermal protection system design and testing.



Brianne DeMattia, left, in front of environmental test chambers in one of GRC's battery characterization laboratories. Robert Christie, above, modeling Li-Ion battery pack. Dr. Robert Bruckner, right, in the lab with the Extreme Environment Tribometer.



## 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 20 NESC assessments and 17 of the NESC TDTs with 60 engineers. These activities supported all mission directorates as well as some crosscutting discipline activities. Significant contributions this year were in support of Li-Ion battery assessments as well as bearing and tribology related assessments. The Discipline Deputies for both the Propulsion and Electrical Power TDTs are resident at GRC.



**Robert S. Jankovsky**  
NESC Chief Engineer

**60** GRC employees supported NESC work in FY15

### Providing Battery Expertise

Robert Christie is an aerospace engineer with 50 years of technical experience in the aerospace industry. Mr. Christie has a very diverse multiphysics background in mechanical engineering, mechanics of materials, aviation electronics, and system modeling. For the Li-Ion Battery Thermal Runaway Assessment, he performed thermal analyses of different battery pack configurations as well as reduction of experimental data from dozens of calorimeter tests. The analysis task generated several best practice design guides describing the benefit of a properly designed heat spreader in mitigating thermal runaway propagation and the serendipitous thermal benefit that insulating sleeves, added to prevent electrical shorting, had in impeding heat rejection to adjacent cells. Mr. Christie creatively used the calorimeter test data to determine the bounds of energy released and the magnitude of the uncertainty in the data. He also provided insight into how calorimetric testing can be improved, and these recommendations were implemented on subsequent testing.

Brianne DeMattia is an energy storage specialist who works on battery components and systems. Under the NESC's International Space Station (ISS) Large Cell Thermal Runaway activities, Ms. DeMattia served as the task lead for large cell accelerated rate calorimetry (ARC) testing of Li-Ion cells. While the ARC testing did produce some useful data,

further assessment showed that the standard ARC test setup historically used for smaller cells does not adequately translate to use with much larger, higher energy cells. The NESC team will investigate new test setups that will be unique to NASA's test needs and hopefully provide the data that is lacking due to current test limitations. "My knowledge base has really broadened after leading this task and will continue to grow as I apply what I've learned to my other projects. One of the best parts of this job was collaborating with NESC team members across the Centers, all with different areas of expertise. I always came away from a meeting learning something new."

### Providing Bearing and Tribology Expertise

Dr. Robert Bruckner is an aerospace engineer at GRC with over 26 years of experience. His expertise ranges from aircraft engine systems to hydrodynamic bearings and tribology. In 2015, Dr. Bruckner contributed to two assessments for the NESC. He was the deputy assessment lead for the Vehicle Integrated Propulsion Research Experiments Impacts on the C-17 engine-pylon interface where he coordinated the engine environment simulations, and he was the lead and principal investigator for the assessment of Minimum Wear Life for the ISS pump control valve package rotor-bearing system. In the latter assessment, Dr. Bruckner developed an analytic methodology to calculate the remaining wear life of the ISS ammonia pumps given only the pump current draw as an input. For this assessment he also developed a new tribometer, the Extreme Environment Tribometer, which is capable of simulating the exact conditions of the ammonia pump bearings and was critical in generating the experimental database that grounds the new methodology. According to Dr. Bruckner, "Being involved with NESC assessments are the high points in my career. They provide the opportunity to apply my expertise to unique applications important to NASA missions, gain valuable experience across the Agency, and work with talented individuals."

## Goddard Space Flight Center

The Goddard Space Flight Center (GSFC) supported 15 assessments and investigations in 2015, leading the assessments for Modeling and Simulation of System Behavior at Space Launch System/Multi-Purpose Crew Vehicle to Ground Systems Development and Operation Interfaces; Spacecraft Guidance, Navigation, and Control (GNC) Component Open Source Benchmarking; Exploration Systems Development Integrated Avionics and Software Verification and Validation Plan; and Effects of Storage and Humidity on Dry Film Lubricant (DFL) Performance. GSFC provided expertise to 14 Technical Discipline Teams in 2015 with 77 engineers, technicians, and scientists. GSFC is the resident Center for the NASA Technical Fellows for Software, GNC, Mechanical Systems, and Avionics.



**George L. Jackson**  
NESC Chief Engineer

**77** GSFC employees supported NESC work in FY15

### Effects of Storage and Humidity on Dry Film Lubricant Performance for the James Webb Space Telescope

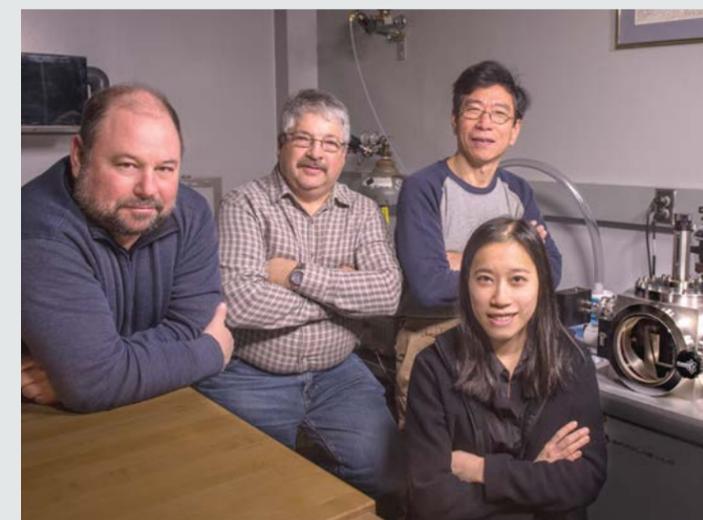
The NESC is conducting an assessment aimed at evaluating the effects of humidity on the performance of cryogenic mechanisms that have sliding/rolling mechanical surfaces. The James Webb Space Telescope (JWST) has numerous mechanisms with DFLs to minimize wear, reduce friction, and extend the usable life of the mechanisms. This assessment, led by Claef Hakun, will meet the request by the JWST Project to test substrates lubricated with flight Molybdenum Disulfide (MoS<sub>2</sub>) coatings in order to predict the performance and life impacts that humidity exposure has on these critical mechanisms during flight.

GSFC has the capabilities and expertise in mechanisms, materials, and tribology to fully assess the long-term impact that humidity has on the degradation of DFLs. The joint GSFC and GRC team will leverage experience and knowledge of tribology and material science experts and the capabilities of the spiral orbiting tribometer (SOT) to determine the performance of the MoS<sub>2</sub> substrates. In addition, the assessment utilizes an x-ray photoelectron spectrometer (XPS) and scanning electron microscope to characterize the reaction kinetics behind oxide formation over exposure time to humidity. In addition to the assessment lead, Mr. Hakun, core GSFC participants in the assessment included Calinda Yew, Liqin Wang, and Bruno Muñoz.

Ms. Yew is an aerospace engineer with a chemical engineering background. For the assessment, she executed sample tests using the SOT and XPS equipment. Ms. Yew stated that on this assessment, "I learned how to work in a diverse group of individuals from different technical backgrounds and experiences. I enjoyed the exposure this assessment has given me to collaborate with individuals from other disciplines and other Centers, and to be able to tackle the challenges together."

Mr. Wang is a staff consultant with an expertise in metallic materials and microanalysis. Mr. Wang studied the humidity and temperature effect on the MoS<sub>2</sub> coating and assessed the risk of long-term storage of the hardware with such coatings under ambient conditions. Mr. Wang stated that this assessment "would greatly enrich our knowledge base on the coatings and improve our capability to perform future analysis and quantitative assessment of long-term storage risk on flight hardware."

Mr. Muñoz is a senior engineer with an expertise in vacuum systems and test integration. On this assessment, he modified the SOT to enhance its capabilities to provide and maintain humidification levels inside the SOT. Mr. Muñoz stated that, "I'm always extremely pleased to be able to help the NESC perform their critical work."



Left to right, Claef Hakun, Bruno Muñoz, Liqin Wang and Calinda Yew, front.

Mr. Hakun is the Associate Branch Head of the Electromechanical Systems Branch. He has expertise in cryogenic mechanism development and tribology. As the assessment lead, he organized the team, devised test methodology, reviewed mechanism designs, and assessed the critical interfaces. Mr. Hakun said that as a result of this work, "we will have a much better understanding of the effects of humidity and perhaps other factors like repeated exposure from humid to vacuum

environments on the performance of MoS<sub>2</sub> films." As for the benefits of participating on an NESC activity, Mr. Hakun said, "I think working on this assessment with multiple-Center interaction shows how a team can work together for their mutual benefit. Also, it has been a pleasure to work with early-career engineers and to see their dedication and enthusiasm at NASA is alive and well."

## Jet Propulsion Laboratory

The Jet Propulsion Laboratory (JPL) has provided engineering support for 20 assessments and actively supports the NESC Technical Discipline Teams (TDTs). Several of the JPL staff have served as deputy TDT leads supporting the NASA Technical Fellows in their respective disciplines. The investigations supported modeling and simulation, Exploration Systems Development Verification and Validation, Orion Multi-Purpose Crew Vehicle (MPCV) Environmental Control and Life Support, several Commercial Crew Program (CCP) assessments, vibroacoustic environments, and others. JPL leads the Composite Overwrapped Pressure Vessel (COPV) working group and related COPV assessments, the Robotic Spaceflight TDT, and the RAD750 qualification testing effort. The Soil Moisture Active Passive (SMAP) Project was supported by NESC in the study of the deployment of its mesh antenna. The NESC Chief Scientist is resident at JPL.



**R. Lloyd Keith**  
NESC Chief Engineer

**104** JPL employees supported NESC work in FY15

emerging composite pressure vessel technology. It is also tasked with the development of appropriate strategies, approaches, and methodologies to minimize technical risk associated with composite pressure vessels and create/revise technical requirements to mitigate this risk for future human and robotic space missions.

The CPVWG coordinates with programs and projects throughout NASA, and has been working proactively to address COPV mechanical modeling concerns, nondestructive testing, lifetime assessment issues, and standards development. In particular, the CPVWG has been supporting the CCP and the Orion MPCV Program in the past year. The CPVWG has been helping those programs interpret COPV requirements and lessons learned from prior NASA programs.

Dr. Grimes-Ledesma says, "Working with the NESC has allowed me to collaborate with experts at other Centers so we can all improve the Agency's knowledge base to enable better understanding of COPV risk."

### Loads and Dynamics

Ali Kolaini has been at JPL for 11 years and is an expert in the loads and dynamics area. Mr. Kolaini and his team are developing nonlinear dynamic models for the Applied Physics Laboratory's Solar Probe Plus configuration/restraint options. He is also reviewing and assessing the development of the nonlinear slosh dynamics models for the Space Launch System (SLS) flight control design. Mr. Kolaini was part of the NESC independent team to review the SLS, Ground Systems Development and Operations, and Orion MPCV Programs' plans for modal testing, development flight instrumentation, and dynamic model correlation.

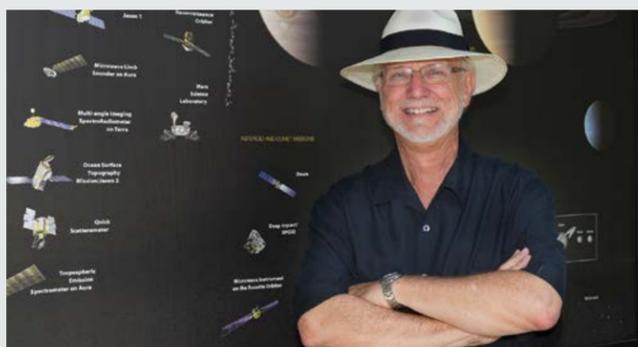
Mr. Kolaini and his team have been developing a new and novel method to reduce shock levels (by more than 10 dB) at shock sources, which can easily be implemented into the existing separation devices. This method is currently being implemented into the Surface Water and Ocean Topography Project to help reduce environments. Also, a different shock attenuation mechanism was developed for the path from separation devices to critical flight components. Such a system was designed, qualified for launch environments, and included in the SMAP observatory.

### Providing COPV Expertise

Dr. Lorie Grimes-Ledesma has worked at JPL for 15 years and is an expert in COPVs. She leads related assessments and the NESC Composite Pressure Vessel Working Group (CPVWG), which is responsible for understanding and communicating issues and risks associated with the current state of the art as well as



Dr. Lorie Grimes-Ledesma.



Dr. Daniel Roscoe provided leadership in telecommunications.

### Telecommunications Community of Practice Leadership

Dr. Daniel Roscoe acts as the Chief Engineer for Telecommunications at JPL, and has been supporting the NASA Technical Fellow for Avionics as one of his community of practice (CoP) leaders. The Telecommunications CoP discusses a broad range of telecom-related topics, with several sessions devoted to the proliferation of CubeSat missions, which are now poised to go beyond low Earth orbit.

According to Dr. Roscoe, "I find that the associations being made with others via e-mail and WebEx are especially helpful to me when I need to find expertise for specialized topics, like multipaction and ionization inside high power radio frequency hardware."

Annually, the team assesses the state-of-the-telecommunications discipline and NASA's ability to meet the needs of future missions. He also says, "I continue to enjoy the professional and personal relationships that come from our community gatherings and look forward to more in 2016."

## 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 (ISS), development of the Orion Multi-Purpose Crew Vehicle (MPCV), and consultation for commercial crew vehicles. The NESC Deputy Director for Safety; an NESC Principal Engineer; NASA Technical Fellows for Life Support/Active Thermal, Loads and Dynamics, and Passive Thermal; and an NESC Integration Office Engineer are resident at JSC. JSC personnel provided expertise and leadership to numerous assessments within the Agency such as Orion MPCV Avcoat studies and ISS Li-Ion Battery Thermal Runaway analyses and tests. 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 Thermal and Fluids Analysis Workshop, Capability Leadership Teams to help define the future of NASA technical disciplines, and a joint NASA/Department of Defense thermal protection system familiarization technical interchange meeting. Finally, JSC personnel engaged in standing review boards for the Stratospheric Aerosol and Gas Experiment III on ISS, the Human Research Program, Tropospheric Emissions: Monitoring of Pollution, Cyclone Global Navigation Satellite System, and the Asteroid Redirect Mission.



**T. Scott West**  
NESC Chief Engineer

**61** JSC employees supported NESC work in FY15

he developed an internal short circuit device to induce a battery cell failure for testing thermal runaway resistant battery designs. This device has garnered worldwide attention. Dr. Darcy credits his involvement with the NESC battery effort for making this possible.

### WSTF Frangible Joint Testing

Larry Starritt is a project leader with Jacobs Technology at WSTF and supports NESC's efforts to assess the risks of commercial crew vehicle frangible joints. With over 20 years of experience working with propellants, high energy explosives, and pyrotechnics, Mr. Starritt has been responsible for supervising over 85 successful frangible joint tests that are providing invaluable data on the function of these devices for the safety of future NASA crewmembers flying on commercially provided spacecraft.

### MPCV Avcoat Assessments

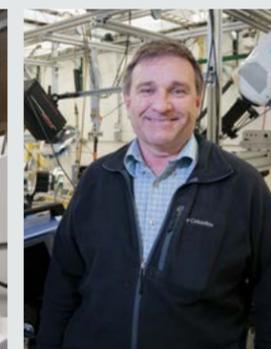
Stan Bouslog, Dr. Michael Fowler, Dr. James Smith, and Thomas Modlin, all from the JSC Structures Division, have provided a wide range of technical expertise to the Orion MPCV Avcoat assessments. Mr. Bouslog is the Entry, Descent, and Landing/Thermal Protection Systems Technical Discipline Lead; Dr. Fowler is a materials engineer; Dr. Smith is the Structures Design & Analysis Technical Discipline Lead; and Mr. Modlin is a structural engineer with over 50 years of experience in spacecraft design and analysis. Together they performed root cause analysis of the Orion MPCV Exploration Flight Test-1 (EFT-1) heat shield Avcoat strength discrepancies and enabled the successful flight of EFT-1 and now support follow-on assessments to ensure the safety of the upcoming Orion MPCV Exploration Mission-1 (EM-1) and EM-2 missions. All agreed that their participation in these NESC assessments yielded better corporate knowledge in this area for the Structures Division, and Dr. Smith noted, "Despite having several decades of analysis experience, the various Avcoat-related assessments have allowed me to stretch my knowledge in the field."

### ISS/EVA Li-Ion Battery Thermal Severity Runaway Reduction Measures

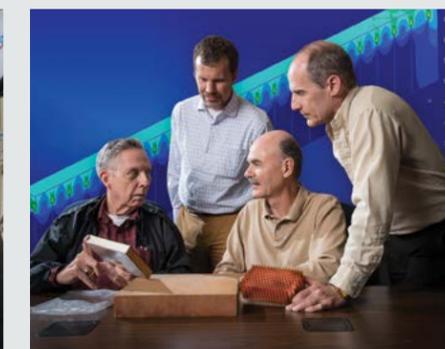
Dr. Eric Darcy is the Battery Technical Discipline Lead in the JSC Propulsion and Power Division and has over 30 years of experience working with battery technologies. Dr. Darcy has supported several NESC assessments of the thermal runaway hazard of Li-Ion batteries, and was a singular voice in the NASA battery community postulating that these high energy batteries could be designed to safely support missions and maintain viable energy density. Dr. Darcy has provided visionary guidance in the redesign of ISS Extravehicular Activity (EVA) and Orion MPCV Li-Ion batteries to resist thermal runaway. As part of this effort,



Dr. Eric Darcy, left, and Kandler Smith of the National Renewable Energy Laboratory prepare to test Li-Ion batteries.



Larry Starritt with the frangible joint test rig at WSTF.



From left, Avcoat team members Thomas Modlin, Dr. James Smith, Stan Bouslog, and Dr. Mike Fowler.

Photo: Pat Corkery

## Kennedy Space Center

The NESC was involved in multiple activities and projects at the Kennedy Space Center (KSC). Likewise, KSC continues to provide expertise to a wide variety of NESC assessments and testing across the Agency and membership on 15 different NESC Technical Discipline Teams (TDTs). The NASA Technical Fellow for Electrical Power and a Deputy for the Materials TDT reside at KSC. KSC expertise plays a role in resolving many of the Agency's difficult problems and was engaged in a variety of NESC assessments this past year. Some of those assessments include: Commercial Crew Program (CCP) frangible joint sensitivity testing; CCP avionics system reviews and parts testing; Exploration Systems Development (ESD) independent flight modeling; International Space Station Plasma Contactor Assessment; Orion crew module heat shield independent analysis and testing; The Cyclone Global Navigation Satellite System electrical power board consultation; and ESD Integrated Avionics Software Verification Assessment.

### Providing Frangible Joint Expertise

Kevin Vega is the CCP Integrated Performance Lead Engineer and a consulting member of NESC's assessment of the risks of frangible joint designs. The assessment is an empirical test to determine the effects that various design parameters and environmental factors have on frangible joint separation. The NESC is using high-rate cameras and instrumentation to get an unprecedented look at what happens during the microseconds of time before, during, and after a frangible joint separation in an attempt to understand design sensitivities. Mr. Vega has prior experience with pyrotechnic separation system design, development, and testing. He is helping the NESC define and evaluate technical requirements necessary to alleviate engineering and program concerns. Mr. Vega is inspired by the level of detail he and the NESC team encounter during testing to get answers. "Three million frames per second says a lot — when you look at the number and fidelity of the cameras, instrumentation, data storage, communication protocols, cabling, interfaces, test fixtures, test configurations, processes, and safety procedures to get



**Stephen A. Minute**  
NESC Chief Engineer

**41** KSC employees supported NESC work in FY15

three-tenths of a second of data" says Mr. Vega.

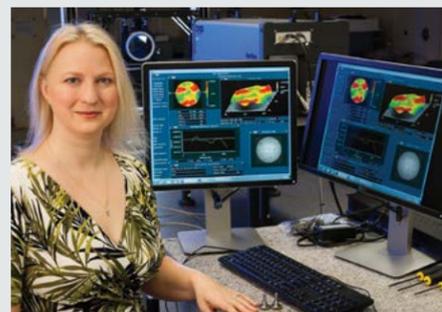
### Ensuring a Clear View

The Orion Multi-Purpose Crew Vehicle (MPCV) Program has particular requirements that flight windows have minimal distortion and flaws. KSC's Susan Danley and the NESC have taken a wavefront measurement technique developed at LaRC and applied it to a system capable of measuring distortion in the Orion crew module flight windows. Ms. Danley is a mechanical systems engineer and has been the lead window engineer at KSC for 11 years on Space Shuttle, Orion MPCV, and commercial crew programs. She believes that multiple programs could benefit from this window wavefront measurement technique. Ms. Danley honed her technical and project management skills as the project manager and lead engineer for

this project. "I learned more about project management. I learned how to document and design a system that can serve the needs of multiple programs." This NASA-developed capability is available to support other programs and projects.

### A Passion for Figuring Out How Things Work, or Why They Don't

The KSC engineering development and failure analysis laboratories play important roles in NESC assessments. Thad Johnson, an electrical engineer and failure analysis investigator, and Lawrence Ludwig, KSC Engineering Development Lab Manager, applied their expertise and lab facilities in support of the Electrical Power TDT on several NESC activities. Comprehensive testing of wire sizing and overcurrent protective features for CCP and investigative testing for the ARC arc jet mishap investigation are some examples. Combined, they have over 50 years experience in electrical failure analysis, including: digital microscopy, digital radiography, programmable microcontrollers, and computed tomography. Both Mr. Johnson and Mr. Ludwig agree that their NESC work helped them understand the scope of large-scale investigations and the importance of valuable expertise available across the Agency.



Susan Danley is KSC's lead window engineer and Project Manager for the Wavefront Measurement System.

Kevin Vega is the CCP Integrated Performance Lead Engineer in KSC's Engineering Directorate.



Lawrence Ludwig, left, is KSC's Engineering Development Lab Manager. Thad Johnson is an electrical engineer and failure analysis investigator.

## 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, 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. LaRC is also home to the NASA Technical Fellows for Aerosciences, Flight Mechanics, Materials, Nondestructive Evaluation, and Structures.

### Promoting Statistical Engineering

As the Statistical Engineering Team Lead in LaRC's Engineering Directorate, Dr. Peter Parker brought his expertise in the strategic application of statistical methods to several NESC assessments. He developed a test strategy and analysis methodology to support sizing requirements of the roll torque reaction control system for an NESC assessment on the Crew Launch Vehicle Project. He also assessed the adequacy of existing reliability predictions and guided recommendations on experimental drop test program strategies for the Capsule Parachute Assembly System. On another NESC assessment, Dr. Parker co-lead the development of an independent, statistically based analysis of lidar sensor systems performance. "I gained an in-depth appreciation of several NASA systems and technologies that I would have not been exposed to without my NESC experience," says Dr. Parker. "It was amazing to see how we collectively developed the assessment results, truly integrating input from each team member's expertise, that we could not have achieved individually."

### Commercial Crew Program Entry, Descent, and Landing

Flight dynamics engineer Carlie Zumwalt brought her knowledge of simulation-based parachute performance



**Jill L. Prince**  
NESC Chief Engineer (Through Aug. 2015)

**126** LaRC employees supported NESC work in FY15

to the NESC's wind tunnel testing of subscale ringsail and disk-gap-band parachutes. She played an integral role in test design, test article fabrication, wind tunnel testing, and post-processing of data to develop aerodynamic models. "I now understand the steps to go from a full-scale parachute, to a sub-scale wind tunnel model, to a parachute aerodynamic model ready for use in simulation. It was a fantastic opportunity to move a little outside of my comfort zone and learn about parachutes from some of the best in the world," says Ms. Zumwalt.

Her understanding of computer-based simulation and how vehicles perform during entry, descent, and landing (EDL) also aided the NESC in developing EDL simulations of commercial partner vehicles. "This project not only provided me with a better understanding of how our commercial

crew partners are designing their spacecraft, but also the invaluable experience of interacting with engineers and leaders from most of the NASA Centers, as well as the partners themselves."

### Assessing Frangible Joints

Research materials engineer Paul Leser is analyzing scans and producing a 3D model of frangible joints as part of an NESC assessment to evaluate any potential risks in their designs. Using a model that he built, along with inputs from the NESC team, Mr. Leser is running 3D finite element models of frangible joints and conducting post-test dimensional analysis of the test articles. He has run finite element models using NASA's high performance computing assets before, but this assessment was Mr. Leser's first experience with modeling shock physics. This work on flight hardware is also a departure from his primarily research-driven background. "Modeling the operation of a frangible joint has expanded my knowledge on modeling fracture," he says. "I have made a lot of great contacts with people from diverse fields working on this assessment from around NASA and outside the Agency, while getting first-hand experience with the important work that the NESC is doing."



Materials engineer Paul Leser developed models of frangible joints to better understand their reliability.



Carlie Zumwalt has supported NESC-sponsored wind tunnel testing of aerodynamic decelerators and currently provides EDL expertise.



Dr. Peter Parker provides expertise in statistical engineering to NESC assessments.

## Marshall Space Flight Center

In 2015, the Marshall Space Flight Center (MSFC) provided engineers, scientists, and technicians to over 30 ongoing and completed NESC investigations. These activities involved exploration systems development, space operations and environmental effects, science, and crosscutting discipline activities. Some of the more significant efforts included: advanced chemical propulsion, shock loading characterization in composites, additive manufacturing, environmentally friendly solvents, launch vehicle to spacecraft interface modeling and simulation, and human factors task analyses. The NASA Technical Fellows for Propulsion, Space Environments, and Systems Engineering, and Discipline Deputies for Human Factors, Propulsion, Software, and Space Environments Technical Discipline Teams (TDTs) are resident at MSFC. MSFC provided critical support to 16 of 20 NESC TDTs.



**Steven J. Gentz**  
NESC Chief Engineer

**79** MSFC employees supported NESC work in FY15

materials supporting Space Shuttle, Ares, and Space Launch System (SLS) Program Solid Rocket Motors (SRM). Ms. Howse was the materials and processes lead for the SLS Program Block I Booster Element Polybenzimidazole Insulation Performance Characterization Assessment, which investigated concerns on insulation/propellant slag interactions. This experience increased her understanding of alternate internal motor insulation and nozzle liner materials for future SRM development and analysis validation of nozzle liner erosion. Ms. Howse indicated, "Working with the NESC has allowed us to be able to address risks or concerns of the engineering community by co-funding the efforts with the SLS Program, in an environment where funding is limited. In addition to answering

the risk concerns, we have been able to improve instrumentation capabilities; advance analytic models supporting the full-scale motor for propellant, insulation, and nozzle materials; and partner with the Army and other NASA Centers for mutual benefit."

### Predicting Shock Response on Composite Materials Subjected to Pyroshock Loading

Prior to joining NASA 8 years ago, David Ordway worked for more than 23 years in industry developing expertise in pyrotechnic components and systems for the Department of Defense, expendable launch vehicles, and NASA crewed space applications. Mr. Ordway was the NESC technical lead studying the effects of pyroshocks on composite structures. Mr. Ordway feels, "this project was successful in establishing a methodology for evaluating the quality of acceleration time history data including developing algorithms for post-processing the data, which may be used for future higher-fidelity pyroshock testing of composites." Mission programs using this information include the SLS and CCP partners. In addition to the pyroshock of composites investigation, Mr. Ordway has been a critical member of a number of NESC assessments that included the MPCV Docking Mechanism Jettison System Cheater Cut Testing, Launch Services Program Launch Vehicle Fairing Instrumentation, and Assessing Risks of Frangible Joint Designs.

### Propulsion TDT Support

Christopher Popp is a propulsion engineer with over 18 years experience with NASA. He provided critical support to the Propulsion TDT through activities including independent subject matter expert reviewer for the Orion Multi-Purpose Crew Vehicle (MPCV) propulsion system critical design review (CDR), and the Commercial Crew Program (CCP) SpaceX and Boeing delta CDRs, as well as related propulsion system and component variance reviews. Involvement in these reviews and their corresponding preliminary design reviews provided Mr. Popp with broad perspectives for a diverse variation in propulsion system design, analysis, test, and verification approaches. This involvement provided the opportunity to mentor and challenge early-career and senior engineers at multiple NASA Centers on propulsion system and component-level design and lessons learned. Mr. Popp said he "gained invaluable insight in a greater scope of activities being performed by the Agency involving new spacecraft propulsion system development, which would not have been provided without involvement with the NESC."

### SRM Insulation and Nozzle Liner Characterization

Sarah Howse is a materials engineer with 14 years of NASA experience in the areas of high temperature ablative



Sarah Howse in NASA's National Center for Advanced Manufacturing.



Christopher Popp, propulsion system subject matter expert and TDT member.



David Ordway in the MSFC Pyrotechnic Shock Facility Control Room.



Richard Ross analyzes solvent test samples.



Dr. Danny Allgood of the SSC Design and Analysis Group.

## Stennis Space Center

The Stennis Space Center (SSC) provided expert technical support to the NESC, including laboratory facilities for the evaluation, testing, and qualification of a propulsion oxygen system cleaning solvent. SSC has members on several NESC Technical Discipline Teams and on the Propulsion Capability Leadership Team. The NESC utilized the unique capabilities and expertise from SSC's Engineering and Safety and Mission Assurance Directorates on assessments including the Exploration Systems Development Integrated Hazard Development Process, Assessing Risks of Frangible Joint Designs, and Glenn Extreme Environments Rig Independent Review.

### Rocket Test Detonation Modeling

As a follow-on effort to a recent NESC investigation, a Center Innovation Fund Project was conducted at SSC by Dr. Danny Allgood to enhance current capabilities in predicting rocket propellant detonations during test and launch activities. The goal of the project was to systematically demonstrate valid computational fluid dynamics (CFD) methodologies for predicting cryo-vapor cloud detonations. The ability to predict the probability of detonation and their blast environments is critical for the safety of the facility and project success. All model development was conducted within the framework of the Loci/CHEM CFD tool, which has a demonstrated robustness and accuracy in predicting high-speed combusting flows associated with rocket engines and plumes. Verification and validation studies were completed for hydrogen-fueled detonation phenomena such as shock-induced combustion, confined detonation waves, vapor cloud explosions, and deflagration-to-detonation transition (DDT) processes. The DDT validation cases included predicting flame acceleration mechanisms associated with turbulent flame-jets and flow-obstacles. The CFD methodology was then applied to a relevant problem in which a detonation event had occurred during rocket testing at SSC. The favorable results demonstrated the code's capability in predicting a rocket test detonation event and its associated blast environment. Dr. Allgood stated, "It



**Michael D. Smiles**  
NESC Chief Engineer

**13** SSC employees supported NESC work in FY15

was a great opportunity to continue the work our NESC team had begun on developing modeling techniques for rocket propellant detonations. I believe this program enabled critical research to be performed in the area of vapor cloud detonations that will be helpful in ensuring safe rocket testing and launch programs for NASA. Additionally, the general scientific and engineering communities should benefit by the further development of robust and validated methodologies for predicting DDT phenomena."

### Solvent Replacement Evaluation

NASA's rocket propulsion test facilities at MSFC and SSC have relied upon hydrochlorofluorocarbon-225 (HCFC-225) to safely clean and verify the cleanliness of large propulsion oxygen systems. The purchase of HCFC-225 was prohibited starting in 2015. A

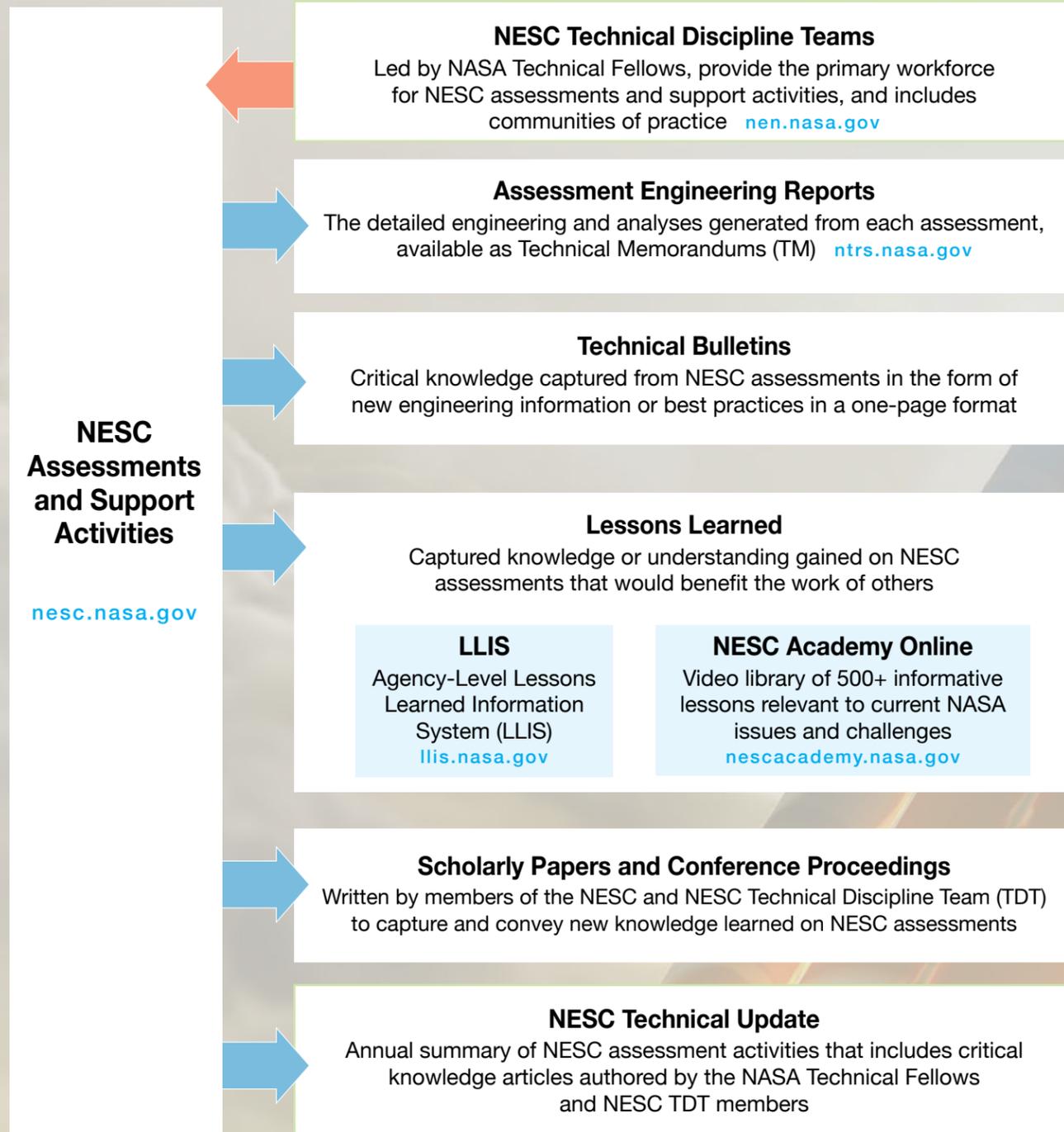
team of engineers, laboratory personnel, and end users from MSFC, SSC, WSTF, and the NESC collaborated to identify, test, and qualify a safe, effective replacement cleaner. Two solvents were downselected for comprehensive testing from an initial list of eight. The results of the study recommended Solstice Performance Fluid for applications at NASA propulsion test facilities where HCFC-225 is currently used.

Richard Ross, an SSC gas and materials science expert, stated, "Working on the project with the team was a very challenging and rewarding experience. Without providing a replacement solvent for precision cleaning, it would not be possible to test rockets that use LOX [liquid oxygen] and to clean propulsion hardware for engine testing and flight. Everyone on the team had a different discipline or perspective, which produced several eclectic ideas. The opportunity to help create something useful, tackling important elements for a critical process for the aerospace community, and seeing progress by working with extraordinary folks across the Agency was very satisfying. I feel privileged to represent SSC and the NESC and to present the LOX compatibility findings to the international community."

## NESC Knowledge Products

### Capturing and preserving knowledge for the future

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



### NESC Academy Online

The NESC Academy is an innovative video library featuring nearly 500 informative lessons on topics relevant to current NASA issues and challenges. In 2015, more than 150 new video lessons were released with such varied topics as the JSC U.S. Spacesuit Knowledge Capture Series to the most viewed webcast, Autonomous Deep Space Navigation.



The NESC Academy offers the audience a virtual 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.

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.

Significant enhancements this year include the ability to perform keyword searches across the entire video library. A keyword search will result in links to the location within a video where the keyword appears in the audio (based on the closed captioning) and in the presentation materials. Further, the NESC Academy now supports playback on most popular mobile devices.

The NESC Academy videos have received more than 35,000 views since inception, with more than 15,000 views in 2015 alone, illustrating the popularity of this approach among NESC Academy users. The NESC Academy video catalog is available at [nescacademy.nasa.gov](http://nescacademy.nasa.gov).

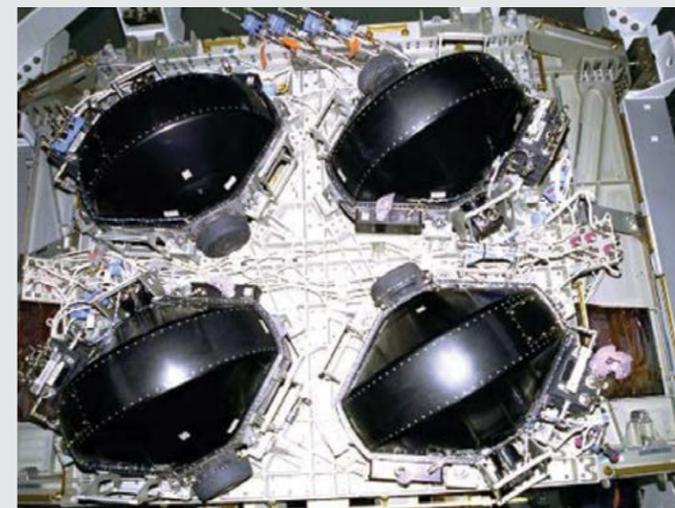
### Most Viewed Videos by Discipline

1. Aerosciences ..... Ares Launch Vehicle Transonic Buffet
2. Avionics ..... Electromagnetic Compatibility (EMC): Antennas, Part 1
3. Electrical Power ..... High Voltage Engineering Techniques for Space Applications: Part 1, Background Engineering Discussion
4. Flight Mechanics ..... Standard Check-Cases for Six-Degree-of-Freedom Flight Vehicle Simulations
5. Guidance, Navigation, and Control ..... Autonomous Deep Space Navigation
6. Human Factors ..... Human Error in Maintenance, Part 1 of 3
7. Life Support/Active Thermal ..... EVA Development and Verification Testing at NASA's Neutral Buoyancy Laboratory
8. Loads and Dynamics ..... Force Limited Vibration Testing: A Review of Existing and New Methods
9. Materials ..... Apollo 13 Pressure Vessel Failure
10. Mechanical Systems ..... An Overview of Fastener Requirements in the new NASA-STD-5020
11. Nondestructive Evaluation ..... Introduction to Probability of Detection (POD) for Nondestructive Evaluation (NDE)
12. Passive Thermal ..... Rationale for Selected MIL-STD-1540E Thermal Test Requirements
13. Propulsion ..... Saturn Launch Vehicles: Engine Restart and Propellant Control in Zero-g
14. Structures ..... Buckling, Shells, Knockdown Factors, and Validation Testing
15. Systems Engineering ..... Model-Centric Engineering, Part 1: Introduction to Model-Based Systems Engineering

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

**Priority 1: completed work in 2015**

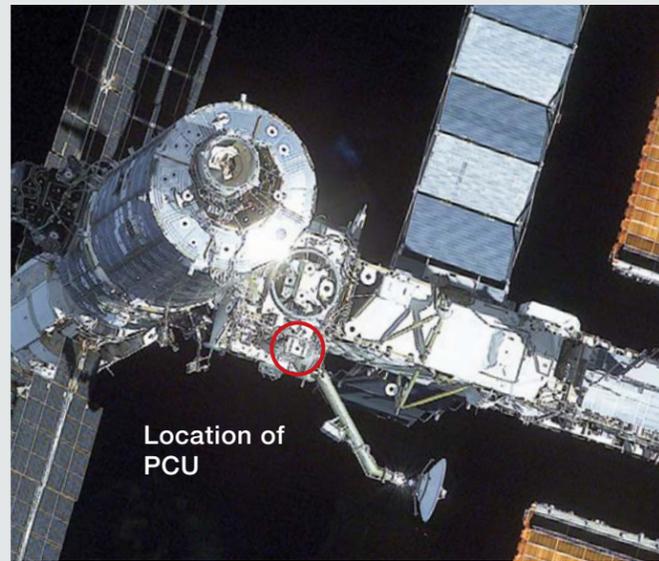
**ISS CMG Bearing Contaminant Assessment:** Given the history of issues with the International Space Station (ISS) control moment gyroscopes (CMG), the NESC identified the need to test CMG flight bearings to evaluate the hypothesis that a dewetting event could produce a telemetry signature similar to a lubricant dewetting event on an ISS CMG bearing in October 2006. The NESC also evaluated the results obtained from previous tests that supported lubricant dewetting as a possible root cause for the CMG-1 and CMG-3 anomalies. *This work was performed by GRC, GSFC, and JSC.*



Four double-gimbal CMGs for the ISS.

**Portable Fire Extinguisher Evaluation:** The NESC was anonymously requested to provide an independent assessment of burst-tested portable fire extinguisher (PFE) qualification hardware to determine the fatigue/burst test failure mode and provide recommendations, if necessary, for additional testing and/or analyses. PFEs are used onboard the ISS. The primary objectives of this assessment were to independently determine the failure progression from fatigue and burst testing and, if necessary, perform sensitivity studies to the structural analysis and provide recommendations for additional testing and/or analyses. *This work was performed by MSFC.*

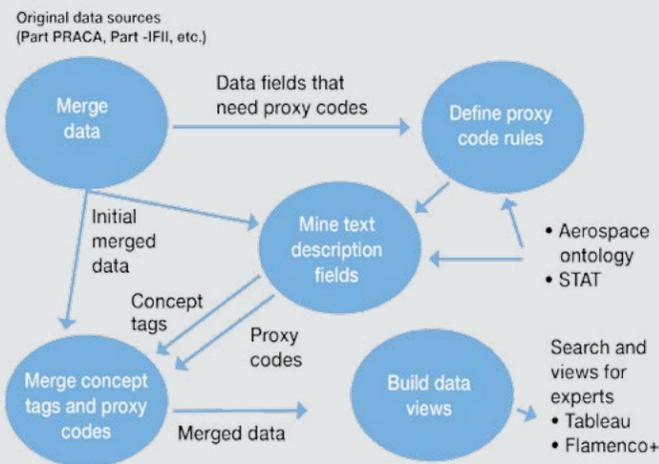
**ISS Plasma Contactor Unit Utilization Plan Assessment Follow-on:** The ISS Space Environments Group requested the NESC revisit and increase fidelity of a calculation included in an NESC report, "ISS Plasma Contactor Unit Utilization



Location of the plasma contactor unit on the ISS.

Plan Assessment Update." The calculation addressed the possible amount of current the extravehicular activity (EVA) crewmembers can accumulate while outside the ISS. The current collection drives the severity of the positive charging hazard to EVA crewmembers while outside of the ISS. *This work was performed by KSC, GSFC, and JPL.*

**ISS Anomalies Trending Study:** The NESC proactively addressed the need to identify trends and significant issues from ISS problem data (e.g., problem reporting databases and the Problem Analysis Resolution Tool) to enable NESC Technical Discipline Teams to investigate and document any areas of concern. *This work was performed by KSC, JSC, and LaRC.* NASA/TM-2015-218991



Approach to enhancing ISS nonconformance reports.

**Simplified Methodology to Estimate the Maximum LHe Cryostat Pressure from a Vacuum Jacket Failure:** The NESC was requested to provide an alternative simplified methodology or tool to estimate the maximum pressure in a



The SOFIA aircraft carries sensors cooled by liquid helium.

liquid helium dewar after the loss of vacuum insulation. The method is intended to enable the university-based science instrument development teams to conservatively determine the cryostat's vent neck sizing during preliminary design of new Stratospheric Observatory for Infrared Astronomy science instruments. *This work was performed by AFRC and JSC.* NASA/TM-2015-218810

**Mars Curiosity Rover Wheel Consultation:** After a lengthy period of successful operation on the rough Martian surface, the Mars Curiosity rover began to show signs of wheel damage. The NESC provided consultation to the JPL tiger team for the Mars Curiosity wheel by contributing expertise relative to wheel damage testing and predictive modeling. Analysis was performed to develop wheel damage mitigation strategies and wheel life predictions relative to materials durability and damage tolerance issues. *This work was performed by LaRC.*



Wheel damage on Mars Curiosity rover.

NASA/JPL-Caltech/MSSS

**Priority 1: ongoing work in 2016**

- ISS Solar Boom Array Thermal Issues
- Hubble Space Telescope Attitude Observer Anomaly Follow-On Technical Support
- Human Spaceflight-1 Mishap Recurring Factor Study
- Minimum Wear Life for the ISS Pump Control Valve Package Rotor Bearing System
- Kepler Spacecraft Hybrid Attitude Control Concepts Evaluation
- Materials, Structures, and Nondestructive Evaluation Consulting Support for ISS Micrometeoroid and Orbital Debris
- Ground Testing to Assess the ISS Ultrasonic Leak Location Concept
- Assessment of ISS/ Extravehicular Activity Li-Ion Battery Thermal Runaway Severity Reduction Measures
- Multi-Purpose Oxygen Generators Swelling
- Evaluation of Solar Array Batten Micrometeoroid and Orbital Debris Damage
- Composite Overwrapped Pressure Vessel Liner Inspection Capability
- Simplified Aid for Extravehicular Activity Rescue Battery Assessment
- ISS Columbus Interface Heat Exchanger Thermal Response
- ORB-3 Independent Review Team Support
- Mars Organic Molecule Analyzer Wide Range Pump Qualification Module Failure Review Board Support Activity
- Robonaut Battery Safety
- Extravehicular Mobility Unit Water Pump Redesign
- Support to Soil Moisture Active and Passive Anomaly Circuit Investigation
- ISS Carbon Dioxide Removal Assembly Blower Speed Range Extension

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

**Priority 2: completed work in 2015**



CPAS drop test of one-main-parachute-out configuration.

**Technical Support to the MPCV CPAS Pendulum Assessment Team:**

In certain conditions, the Orion crew module can experience an unexpected vehicle pendulum motion during one-main-parachute-out operation, which under certain circumstances, could produce unacceptably high loads on the crew module at splashdown. The Chief Engineer for the Orion MPCV Capsule Parachute Assembly System (CPAS) requested the NESC participate on a tiger team to address this issue. The NESC provided technical support to the CPAS Project to investigate parachute pendulum motions through theory, ground test, and flight test. *This work was performed by LaRC.*



Conceptual illustration of JPSS on-orbit.

**JPSS MMOD Assessment:** The Joint Polar Satellite System (JPSS) Project requested the NESC perform an independent evaluation of Orbital Debris Environment Model 3.0, the Micrometeoroid and Orbital Debris (MMOD) model used in the latest JPSS MMOD risk assessment, and compare it to other models used by the European Space Agency (ESA) and the Aerospace Corporation's Center for Orbital and Reentry Debris Studies. As part of this review, the NESC team provided recommendations concerning current JPSS MMOD protection. *This work was performed by LaRC, GSFC, JPL, JSC, and MSFC. NASA/TM-2015-218780*

**Modeling and Simulation of System Behavior at SLS/MPCV/GSDO Interfaces:**

The Exploration Systems Development (ESD) Standing Review Board requested the NESC provide a model of the Space Launch System (SLS), Multi-Purpose Crew Vehicle (MPCV), and Ground Systems Development and Operations (GSDO) system interfaces to provide critical detail of the systems behavior in nominal and off-nominal scenarios. The model was used to identify gaps and completeness of system interfaces. The NESC also performed systems architecture analysis for the GSDO Program to ensure the communications, command, and control range design met vehicle ground processing/prelaunch requirements within an appropriate level of architectural complexity. As a proactive objective, lessons learned in the use of the modeling tools were identified along with any requirements issues due to using model-based system engineering on this assessment. *This work was performed by GSFC, JPL, KSC, LaRC, and MSFC.*

**ESD Integration Independent Review:**

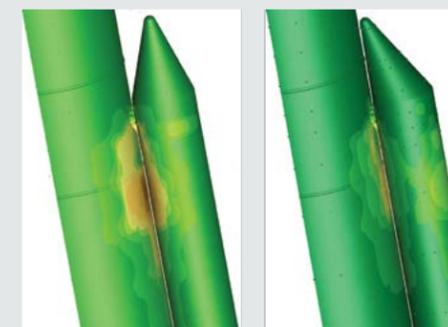
The ESD Division Chief Engineer requested the NESC perform an independent review of the ESD cross-program integration construct as currently baselined and to identify any integration functions potentially missing. The assessment's scope for Exploration Mission-1 (EM-1) and EM-2 included: independently developing a list of critical integration functions for a large launch vehicle, launch complex, and crewed cislunar space capsule, then comparing these functions with current ESD cross-program integration functions to identify potential gaps; reviewing additional integration functions such as integrated scheduling and system safety; and highlighting any potential gaps. *This work was performed by LaRC, KSC, and MSFC.*

**Review of Fatigue Cycle-Counting/Fatigue Spectra Cycle-Counting Methodology:**

The NESC augmented an MSFC team with fatigue spectra counting expertise to evaluate the rainflow and spectrum methodologies and document the inherent assumptions, limitations, and best practices to determine if one or multiple methods should be used on the SLS Program. Results and lessons learned will be incorporated in the next update to NASA-HNBK-7005 Dynamic Environmental Criteria. *This work was performed by MSFC and JSC.*

**Computing Buffet Environments for SLS Configurations:**

The SLS Chief Technologist requested independent assessment by the NESC of the capability of advanced computational fluid dynamics (CFD) tools to characterize the unsteady flow caused by booster-to-core attach hardware and the resultant buffet loads. The assessment's scope included numerically assessing unsteady aerodynamic loading effects of SLS booster geometric variations; conducting wind tunnel validation experiments leveraging SLS models; and considering nose cone variations. The NESC team applied advanced hybrid Reynolds Averaged Navier-Stokes/Large Eddy Simulation (RANS/LES) CFD techniques to the problem of predicting highly unsteady launch vehicle buffet environments. The hybrid CFD was used to design and evaluate several new SLS booster nose cone shapes, which demonstrated varying levels of reduction in the buffet environments. The hybrid RANS/LES technique and new nose cone designs were validated through wind tunnel tests performed in cooperation with the SLS Program. *This work was performed by LaRC.*



CFD results for sharp on-axis, far left, and canted solid rocket booster nose cones, left.

**SLS Program Booster Element Qualification Motor-1 Aft Segment Unplanned/Unintended Event or Condition Investigation:**

The SLS booster element experienced aft segment propellant issues adjacent to the liner/insulation. The NESC provided input from subject matter experts from NASA Technical Fellows and/or their Technical Discipline Teams. Support included review of engineering reports, test and inspection results, and presentation material related to the investigation and process development activities. *This work was performed by MSFC.*

**Peer Review of the SLS, GSDO, and MPCV Programs' Modal Test, DFI, and Dynamic Model Correlation Plans:**

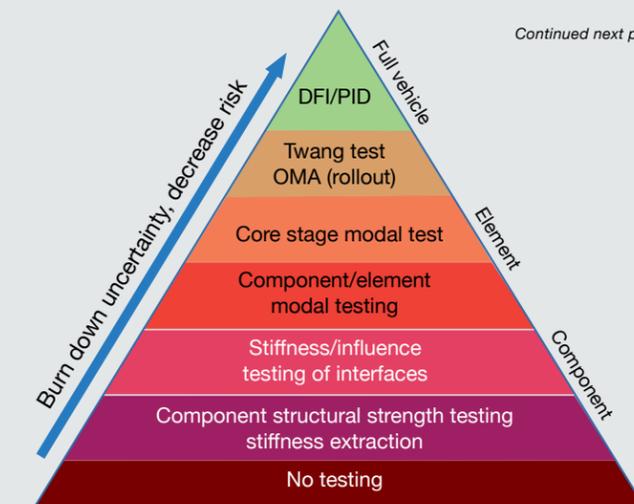
As a proactive measure, the NESC assembled an independent team to review the SLS, GSDO, and MPCV Programs' modal test, development flight instrumentation (DFI), and dynamic model correlation plans. The scope of this assessment included peer review of program test planning for structural dynamic model verification, structural dynamic model correlation planning, and structural DFI planning; identification of concerns and gaps within these plans and schedules that affect program ability to support an integrated system verification loads analyses for EM-1, EM-2, and subsequent missions; and proposal of mitigations by test or analysis that address the concerns or gaps identified. *This work was performed by JSC, GSFC, JPL, KSC, and MSFC.*



Saturn V F-1 engine

**Advancing the State-of-the-Practice for Liquid Rocket Engine Combustion Stability Assessment:**

The SLS Advanced Development Program Manager requested the NESC advance the predictive capability of state-of-the-practice combustion stability methodologies and tools for SLS using higher-fidelity, physics-based models from state-of-the-art CFD simulations. *This work was performed by MSFC. NASA/TM-2015-218771*



SLS test validation philosophy.

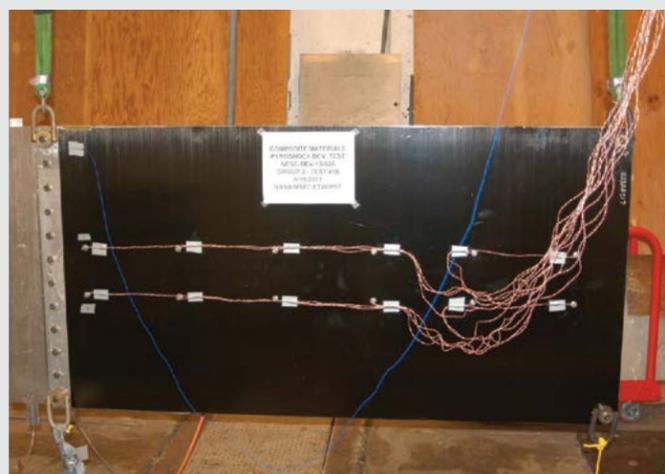
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Practice recovery of the Orion crew module.

**Technical Support to GSDO Landing and Recovery Trade Study for Crew Module Recovery:** The NESC defined and assessed trades for the concept of operations for nominal end-of-mission crew module recovery for the EM-2 flight crew as soon as possible after splashdown. *This work was performed by KSC.*

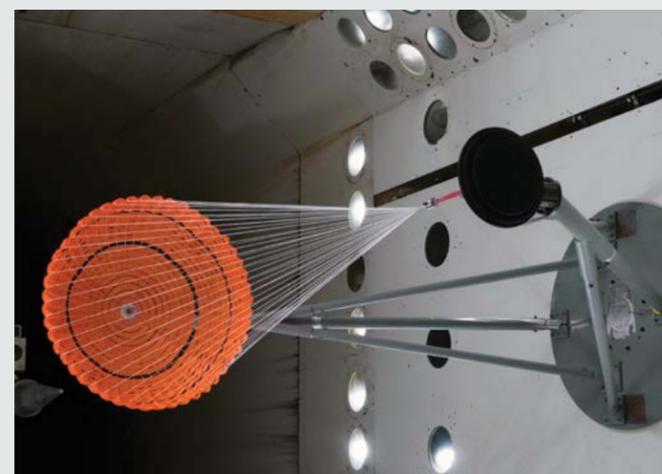
**Empirical Model Development for Predicting Shock Response on Composite Materials Subjected to Pyroshock Loading:** The SLS Chief Technologist requested the NESC develop an analysis model based on both the frequency response and wave propagation analysis for predicting shock response spectrum on composite materials subjected to pyroshock loading. The model would account for the near-field environment dominated by direct



Composite panel instrumented for measurement of pyroshock loading.

wave propagation, mid-field environment characterized by wave propagation and structural resonances, and far-field environment dominated by lower frequency bending waves in the structure. The assessment's scope included the development of an analytical tool to accurately predict the maximum expected flight environment for pyroshock induced into a composite material. *This work was performed by MSFC and LaRC. NASA/TM-2015-218781*

**Wind Tunnel Testing of Subscale SSRS and DGB Parachutes:** Larger parachutes with improved capabilities will be needed to land larger payloads on Mars. The Low Density Supersonic Decelerator (LDSD) Project is developing a new, large-diameter supersonic parachute and performing necessary supersonic testing to qualify it for use at Mars.



Supersonic ringsail parachute in LaRC's Transonic Dynamics Tunnel.

The LDSD Project requested the NESC perform comparison subscale wind tunnel tests of the proposed Supersonic Ringsail (SSRS) and the flight proven disk-gap-band (DGB) to measure the static aerodynamic coefficients of these two designs at subsonic speeds. The assessment's scope included obtaining SSRS and DGB parachute aerodynamic data to create models to simulate the dynamics of payloads descending at subsonic speeds on Mars, as well as data that will allow performance comparisons between the two parachutes. *This work was performed by LaRC and JPL.*

**Solar Probe Plus Water-Cooled Solar Array Peer Review:** The Solar Probe Plus mission uses photovoltaic technology to produce electrical power during all mission phases and presents unique design challenges. The NESC provided subject matter expertise, chaired a preliminary design-level peer review, and supported critical design reviews of the solar array cooling system. *This work was performed by JSC.*

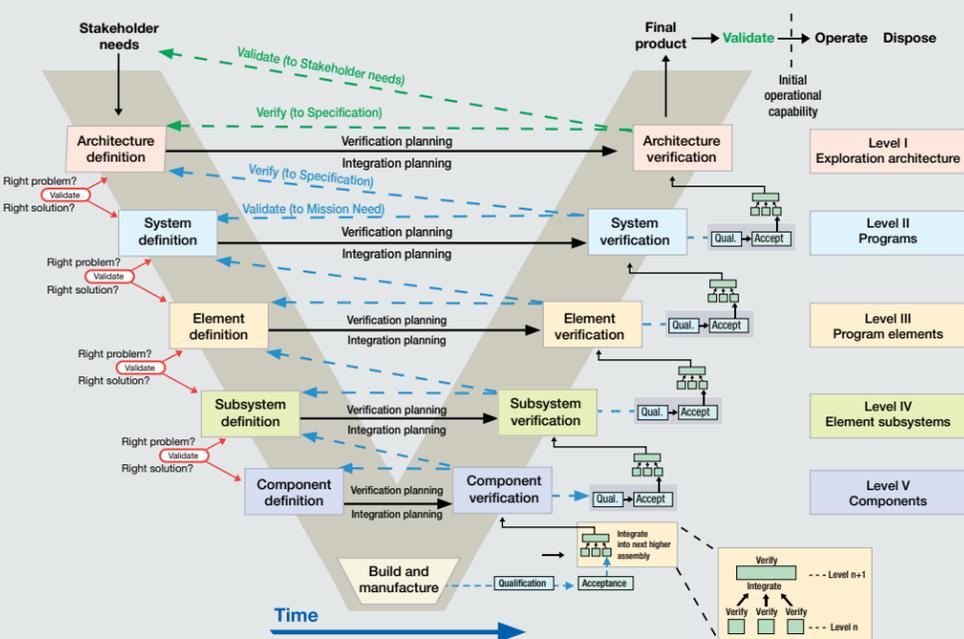


Task analysis of Orion crew module launch abort system integration.

**Ground Operations Human Factors Task Analysis:** An NESC request for technical support was submitted by the GSDO Chief Engineer, after the GSDO Preliminary Design Review, to investigate a gap identified by the NESC in-ground operations task design and analysis methodologies. *This work was performed by KSC, ARC, JSC, and MSFC.*

**MSFC Additive Manufacturing Specification Review:** The NESC formed a team of materials experts who completed a detailed review and provided comments on the MSFC draft additive manufacturing specification entitled "Engineering and Quality Standard for Additively Manufactured Spaceflight Hardware." *This work was performed by LaRC, GRC, GSFC, KSC, JPL, JSC, and MSFC.*

**Flight Test Support for an Engineering Test Article:** The Commercial Crew Program Integration Team Guidance, Navigation, and Control Lead requested flight test expertise support for an independent review team for a commercial partner drop test. NESC members participated in reviews, reviewed plans and documentation, and provided flight test expertise. *This work was performed by AFRC.*



Systems engineering life-cycle "V" model.

**ESD Integrated Avionics and Software V&V Plan Assessment:** The ESD Chief Engineer requested the NESC perform an independent assessment of the ESD's integrated avionics and software verification and validation (V&V) plan to include level of risk incurred by the existing approach and its level of completeness. The assessment's scope focused on how ESD's cross-program plans were defined by what means and methods various simulators, emulators, and test beds were scheduled, delivered, and integrated in support of EM-1 system V&V. The level of risk being assumed from widely distributed integrated testing avionics and software systems was also assessed. *This work was performed by GSFC, GRC, JPL, JSC, KSC, and MSFC.*



Illustration of Solar Probe Plus on orbit. NASA/Johns Hopkins University Applied Physics Laboratory



Sierra Nevada Corp. Dream Chaser during ground testing.

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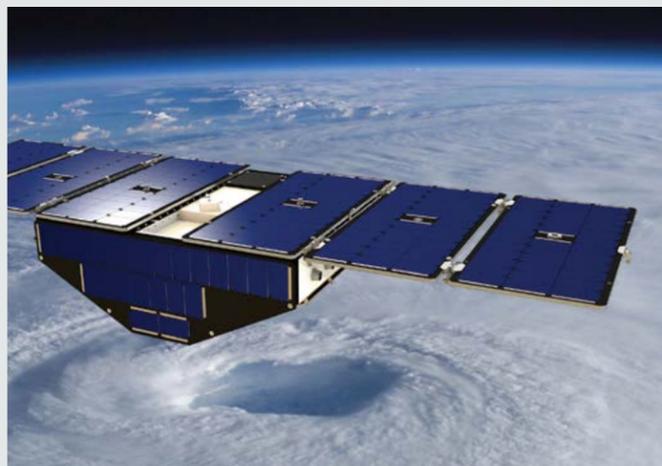


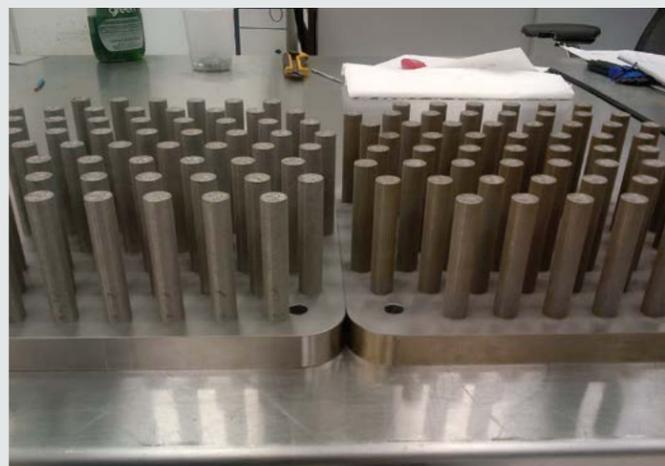
Illustration of a CYGNSS microsatellite on orbit.

**CYGNSS Peak Power Tracker Board Consultation:** The Cyclone Global Navigation Satellite System (CYGNSS) consists of a constellation of eight microsatellites scheduled to launch in October 2016, which will use Global Positioning Satellites to measure ocean surface wind speed. When a problem developed with a system component, the CYGNSS team formed a group of outside experts, including the NESC, to work the problem. NASA's Earth System Science Pathfinder Program Office Mission Manager for CYGNSS also requested NESC expertise with power supply, peak power tracking, and analog circuitry background to improve performance of the existing design. *This work was performed by KSC.*

**Support to ARM Robotic Concept Integration Team:** The NESC was requested to provide technical support to the Asteroid Redirect Mission (ARM) Robotic Concepts Integration Team and Independent Review Team to help determine the mission concept and configuration of the robotic portion of the ARM, as well as integrate the robotic and crewed mission segments. The NESC team worked with ARM project teams, performed a comprehensive risk assessment, and made recommendations for risk mitigation to the project teams. *This work was performed by JSC, GSFC, JPL, KSC, and MSFC.*



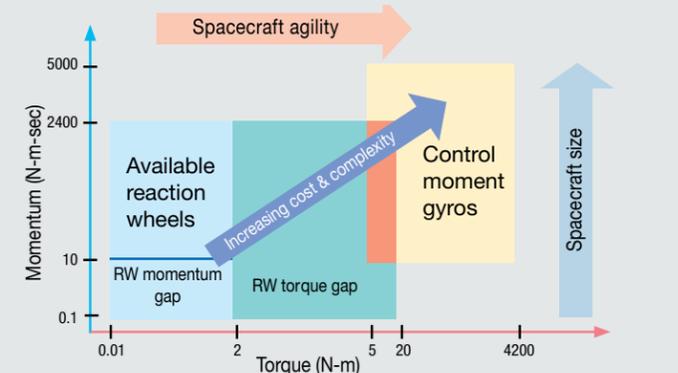
Conceptual illustration of potential capture mechanism for the ARM.



Test specimens developed by additive manufacturing with unique identifiers included on ends.

**Inconel 718 Additive Manufacturing Mechanical Property Investigation:** An NESC team provided independent oversight and technical expertise in the investigation of apparent anomalous ambient temperature tensile test data from Inconel 718 test specimens. The investigation team provided a comprehensive summary of the most probable cause of the anomalous tensile test results. Metallurgical analysis of supplemental test specimens generated during the investigation provided conclusive data on the cause and lessons learned from this investigation and will be incorporated in the draft Agency additive manufacturing certification requirements document. *This work was performed by MSFC and GRC.*

**Spacecraft GNC Component Open Source Benchmarking:** Using open-source data, an industry-wide survey of globally available guidance, navigation, and control (GNC) sensors, namely star trackers, gyros, and sun sensors, was undertaken jointly by NASA and the ESA GNC teams. Data on reaction wheels (RW) and control moment gyros (CMG) were also collected. The survey intent was to identify gaps in the available capabilities. Mission types that are not currently well-served by the available components were considered, as well as some missions that would be enabled by filling gaps



Momentum-torque space chart showing available values for RWs and CMGs.



Demonstration of Solstice PF Solvent use at the SSC Component Processing Facility (CPT) with Jon Herdlein, left, a Honeywell chemist, and Darrin Spansel, Lockheed Martin, CPT technician.

in the component space. This collaborative activity was in support of the independent NASA and ESA GNC technology roadmapping activities. *This work was performed by GSFC.*

**AK-225 Solvent Replacement Evaluation:** The Rocket Propulsion Test Program Manager requested NESC technical support in identifying a replacement for the hydrochlorofluorocarbon solvent (AK-225) used for precision cleaning of large liquid and gaseous oxygen system components and field service at SSC and MSFC. The activity's scope included testing of selected chemicals to verify cleaning capability and compatibility with materials used in rocket propulsion and testing facility systems. *This work was performed by MSFC, SSC, and LaRC.*

**MPCV Heat Shield Carrier Structure Alternate Design:** The Orion MPCV Chief Engineer requested the NESC develop alternate MPCV heat shield carrier structural designs with the goal of reducing the structural system mass by 25% from the existing baseline. The final NESC design was estimated



GEER stainless steel pressure vessel.

to have achieved double the original goal. Even though the NESC's alternative design was not selected by the Orion MPCV Program, it promoted the aggressive redesign of the current baseline and the net result was a significant reduction of overall mass. *This work was performed by LaRC, AFRC, GRC, GSFC, JSC, and MSFC. NASA/TM-2015-218683*

**GEER Independent Review:** The Glenn Extreme Environments Rig (GEER) is designed to simulate the temperature, pressure, and atmospheric compositions of bodies in the solar system, including those with acidic and hazardous elements. The Science Mission Directorate Associate Administrator requested the NESC provide an independent review of the GEER hazards assessment, sufficiency of the design, and operational controls to mitigate hazards. The assessment's scope included a review of existing GEER documentation, on-site inspection of the rig/facility, and a tabletop review with the project/facility engineering team who designed and built the GEER. *This work was performed by GRC, JPL, and SSC. NASA/TM-2015-218809*

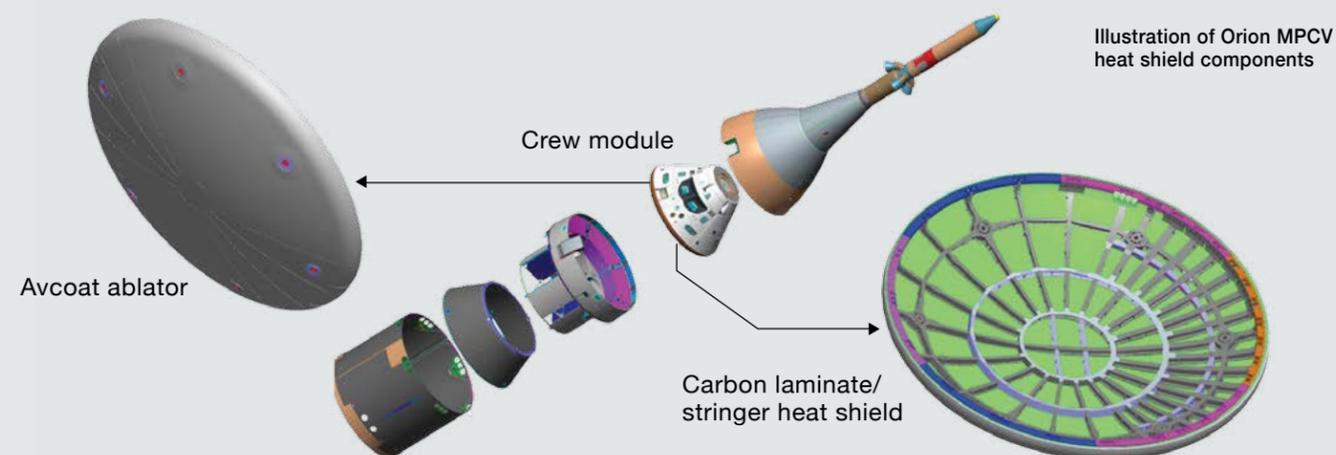


Illustration of Orion MPCV heat shield components

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**Priority 2: ongoing work in 2016**

- Independent Modeling and Simulation for Commercial Crew Program Entry, Descent, and Landing
- Assessing Risks of Frangible Joint Designs
- SpaceX Electrical Power System Review
- Development of a Manned Vehicle Reentry Thermal Protection System Damage Assessment and Decision Plan
- Engine Hot Fire Acceptance Test Procedure Requirements
- Electrical, Electronic, and Electromechanical Parts Testing for Commercial Crew Program
- Support to Commercial Crew Program Crew Orientation Tiger Team
- Commercial Crew Program Avionics Architecture Review
- Commercial Crew Program Aerodynamics Peer Review
- Materials and Processes Requirements for SpaceX Orbital Tube Weld Acceptance of Class A Welds
- Electrical, Electronic, and Electromechanical Parts Statistical Analysis Support
- Exploration Systems Independent Modeling and Simulation
- Model of Space Launch System/ Multi-Purpose Crew Vehicle/ Ground Systems Development and Operations Stack on the Pad
- Exploration Systems Development Verification and Validation Plan
- Independent Verification of Abort Loads
- European Service Module Hyper System Valve Bellows Peer Review
- Support for Plumbrook 6-Degree of Freedom Shaker Table
- Effects of Humidity on Dry Film Lubricant Storage and Performance
- James Webb Space Telescope Space Environment Launch Constraints
- Peer Review of the Multi-Purpose Crew Vehicle Aerodynamic/Aerothermal Database Models and Methods
- Remote Imaging for Exploration Flight Test-1 Entry Heating Risk Reduction
- Space Launch System Aerosciences Independent Consultation and Review
- Space Launch System Advanced Booster Composite Case/Internal Polybenzimidazole N-butyl Rubber Insulation Development
- Space Launch System RS-25D Main Engine Ignition Acoustics and Initial Overpressurization Design Load Determination
- Analysis of Anthropomorphic Test Dummy Response for Proposed Orion Crew Impact Attenuation System
- Orion Multi-Purpose Crew Vehicle Tube Weld Digital Radiography Assessment
- Multi-Purpose Crew Vehicle Avcoat Study
- Ascent Abort Loads Tool Development
- Attitude Control Motor Carbon/Carbon-Silicon Carbide Component Performance Testing Approach for Certification
- Human Vibration Modeling for Orion Multi-Purpose Crew Vehicle Coupled Loads Analysis
- Orion Multi-Purpose Crew Vehicle Program Window Wavefront Measurement Assessment
- Launch Vehicle Buffet Verification Testing
- Stability and Flight Readiness of the Space Launch System Flight Control System with Adaptive Augmentation
- Orion Crew Module Environmental Control and Life Support System Assessment
- Nonlinear Slosh Damping Analysis for Launch Vehicles
- Evaluation of Micrometeoroid and Orbital Debris Risk Predictions with Available On-orbit Assets
- Risk Reduction of Orion Crew Module Government-Furnished Environmental Control and Life Support
- Review of Space Launch System Flight Software
- Technical Support for Space Launch System Vibroacoustics Plans and Analysis (Follow-On)
- Orion Multi-Purpose Crew Vehicle Organizational Safety Assessment Technical Support
- Assessment of Ascent Abort-2 Downgrade
- Alternative Orion Multi-Purpose Crew Vehicle Small Cell Battery Design Support
- Application of System Identification to Parachute Modeling
- Bond Verification Plan for the Orion Crew Module Molded Avcoat Block Heat Shield Design
- Orion Multi-Purpose Crew Vehicle Titanium Hydrazine Tank Weld - Sustain Load Cracking Issue
- Space Launch System Program Block I Booster Element Alternate Internal Insulation Risk Reduction Assessment
- Review of the Orion Multi-Purpose Crew Vehicle-European Service Module Interfaces
- Analyze Variable Effects on Oxygen Impact Reaction Sensitivity of Aerosol Solstice Performance Fluid
- Orion Multi-Purpose Crew Module Guidance, Navigation, and Control Fault Detection, Identification, and Recovery Independent Review
- Space Launch System Interim Cryogenic Propulsion Stage Frangible Joint Assembly Integral Manifold Attachment Preliminary Design Review Evaluation
- Launch Abort System Risk Mitigation
- Reaction Wheel Performance on NASA Missions
- Modal Mass Acceleration Curve Loads Analysis Methodology
- Carbon Fiber Strand Failure Dynamic Event Characterization
- Stress Ruptures Composite Overwrapped Pressure Vessel
- Composite Pressure Vessel Working Group
- Modeling of Crawler/ Transporter, Mobile Launcher, and Forcing Functions
- Soil Moisture Active and Passive Reflector Boom Assembly Deployment Risk Assessment
- Independent Assessment of the Backshell Pressure Field for Mars Science Laboratory Entry, Descent, and Landing Instrumentation 2 (Mars 2020)
- Maxwell Single Board Computer Panels Assessment (Lot 2 - follow-on task)
- Helium Composite Overwrapped Pressure Vessel Qualification Review
- Infrared Laser Sensor Technology Readiness and Maturation
- Global Ecosystem Dynamics Investigation Laser Side-Lobes Review Team Chair
- Independent Review of Additive Manufacturing Development Plans
- Evaluation/Validation of Range Safety Blast Distance Focusing Overpressure Model
- United States Navy Multi-Stage Supersonic Target
- Human Factors Review of Space Network Ground System Sustainment Project
- Vehicle Integrated Propulsion Research Experiment Impacts on the C-17 Engine-Pylon Interface
- Stratospheric Aerosol and Gas Experiment-III Interface Adapter Module Subsystem Anomaly Support
- Solar Probe Plus Fields Whip Antenna Assessment
- Review Committee Support: Radiation Exposure Testing of Europa Clipper Composites

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

**Priority 3: completed work in 2015**

**Technical Support to STMD Brazing Tiger Team:** The NESC provided metallic materials and manufacturing subject matter expertise to the Space Technology Mission Directorate (STMD) Brazing Tiger Team. This effort was the impetus behind the creation of an Agency brazing team to provide review and guidance to future programs/projects utilizing this joining method. Investigation results of team activity is documented in the Agency's Lessons Learned Information System Entry: 14001. *This work was performed by MSFC, GRC, GSFC, JPL, JSC, KSC, and LaRC.*

**Shell Buckling Knockdown Factors (SBKF) Update: Composite Structures**

The SBKF assessment was chartered to develop and experimentally validate new analysis-based buckling knockdown factors for stability-critical metallic and composite launch vehicle structures. The assessment team has provided new metallic structure knockdown factors for the Space



SBKF's 8-foot diameter composite shell test article.

Launch System (SLS) core stage, which resulted in documented mass, cost, and schedule savings. In order to make similar gains for composite structures, the SBKF Team is planning to perform five large-scale validation tests by partnering with additional Agency, industry, and international organizations. The first large-scale validation test—the buckling failure and subsequent test and analysis correlation of an 8-foot diameter composite cylindrical test article—is scheduled for May 2016. The test article is a honeycomb-core sandwich composite with an out-of-autoclave, single-piece construction that was provided by Northrop Grumman. The test article will be extensively instrumented and tested to failure under axial compression. The test article construction is typical of most dry launch vehicle structures, and the test article will be the first large-scale composite structure tested as part of this effort.

The test is being jointly funded by the NESC, MSFC, SLS, and the LaRC Space Technology and Exploration Directorate. In addition to this test, in FY16 the remaining four test articles will be designed and a joint NASA-industry technical interchange meeting will be held on shell buckling.

**Priority 3: ongoing work in 2016**

- Micrometeoroid and Orbital Debris Pressure Vessel Failure Criteria
- Shell Buckling Knockdown Factor Proposal
- Implementation of JR-A Methodology into the NASGRO/Fracture Analysis by Distributed Dislocations Codes to Improve Crack Instability Analysis
- Rad750 Qualification Testing
- Layered Pressure Vessel Technical Consultation
- Space Technology Mission Directorate Formulation of Extreme Environments Power Semiconductor Project
- Support for Development of Softgoods Design Factors of Safety

**NESC Priority 4**  
Work to avoid potential future problems

**Priority 4: ongoing work in 2016**

- Review of Ultem 9085 Material Properties Characterization Document
- Support to NASA In-Space Manufacturing Project
- Support to Additively Manufactured Metals in Oxygen Systems Project
- Support to NASA Standard 5009 Development

**NESC Priority 5**  
Work to improve a system

**Priority 5: completed work in 2015**

**Support to NASA MagicDraw Cloud License Project:**  
An NESC team provided expertise to an Agency-wide initiative to license MagicDraw, a systems engineering software tool currently in use by NASA Centers as a cloud-based application. *This work was performed by GSFC, JPL, and JSC.*

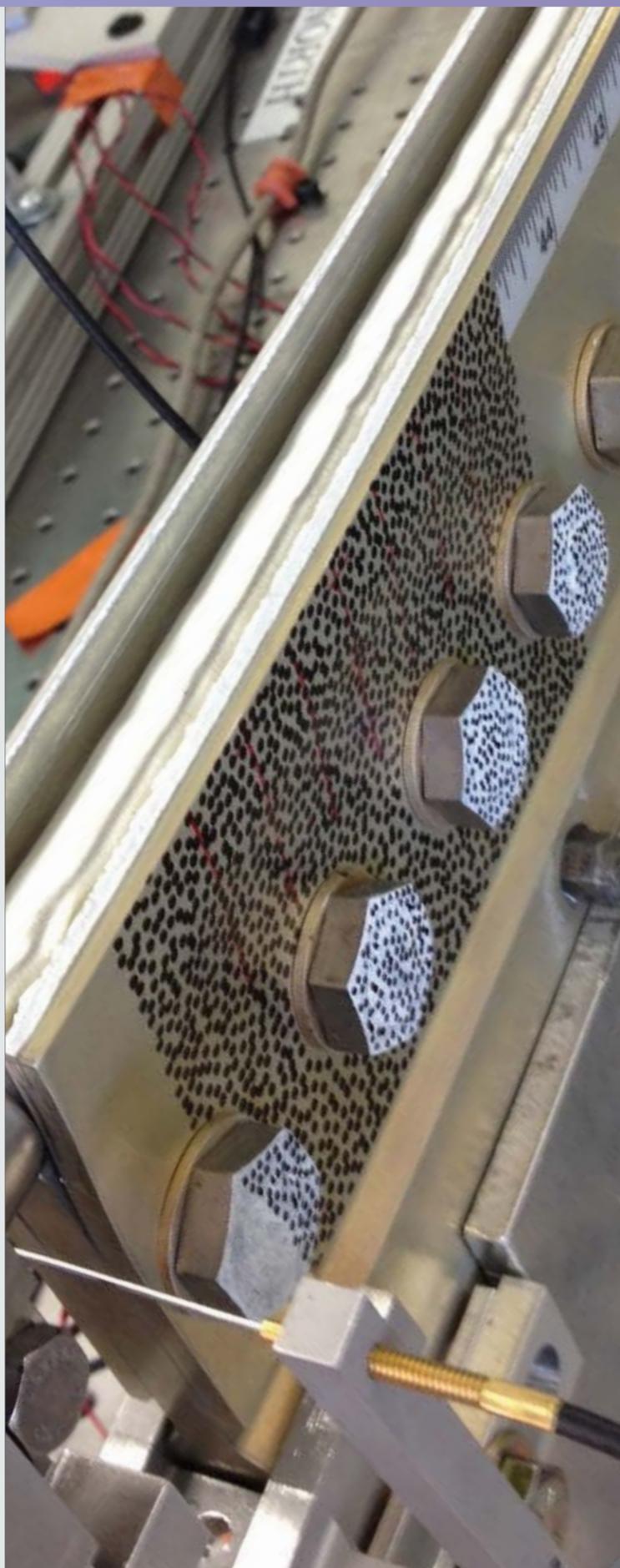
**Assessing Risks of Frangible Joint Designs Update:**  
The NESC Frangible Joint Design Assessment is an empirical test program undertaken at the request of the Commercial Crew Program (CCP) to determine the effects that various design parameters and environmental factors have on single mild detonating fuse joint separation capability. The objective is to characterize the interactions and sensitivities of the key design parameters, which could provide design guidance for safe and reliable frangible joints supporting human spaceflight. There have been 79 tests to date of different frangible joint designs representative of the CCP configurations. Two- and three-dimensional LS-DYNA models are being developed and correlated to the test data. Testing, data analysis, and model development is expected to conclude in the fall of 2016.



George Quezada of Jacobs Technology measures a frangible joint.

**Priority 5: ongoing work in 2016**

- Empirical Launch Vehicle Explosion Model Evaluation
- Support for Orion Alternate Heat Shield Study
- Fracture Control Standard and Handbook



**TB 15-01: Preventing Incorrect Installation of Polarized Capacitors**

Concerns that the incorrect installation of polarized capacitors has continued, despite lessons learned from past installation issues, Dr. Christopher Iannello, NASA Technical Fellow for Electrical Power, and Andrew Ging, an industry partner on the NESC Electrical Power Technical Discipline Team, initiated this technical bulletin to shed new light on a timeworn problem. Using an NESC assessment of an anomaly on board the International Space Station as an example, Dr. Iannello and Mr. Ging highlight the ways in which reverse installation can occur, and provide a short list of best practices — from procedure review to the correct use of symbols on schematics — to help eliminate any future issues with reverse installation.



**TB 15-02: Best Practices for Use of Sine Burst Testing**

For more than two decades, sine burst testing has provided a method of strength testing for aerospace hardware that not only minimizes potential for damage to the test item, but can be performed on a shaker table along with other tests to maximize efficiency. But with all testing comes potential risk. In this Technical Bulletin, Mr. Daniel Kaufman, NESC Discipline Deputy for Loads and Dynamics, identifies top risks such as unintended over-test or erroneous calculations, and provides best practices to help mitigate those risks and take full advantage of what sine burst testing provides.



**TB 15-03: Best Practices for Use of Sine Vibration Testing**

Sine vibration testing replicates the low-frequency launch environment. This test method is used mainly on flight articles to determine if they can survive the harsh launch environment. Testing involves accepting calculated risk, but failure to follow best practices for sine vibration testing has resulted in avoidable damage to flight hardware. Dr. Curtis Larsen, NASA Technical Fellow for Loads and Dynamics; Mr. Daniel Kaufman, NESC Discipline Deputy for Loads and Dynamics; and their Technical Discipline Team identified top risks and documented best practices to help mitigate those risks and take full advantage of what sine vibration testing has to offer.

NESC Technical Bulletins can be found at [nesc.nasa.gov](http://nesc.nasa.gov)

# New Approaches to Refining the Launch Vehicle Buffet Environment

There is a very short window of time, about 30 seconds, between launch and a rocket's transition from subsonic to supersonic flight, when the airflow around the vehicle begins a chaotic dance of sorts. It is called buffet, and it likes to occur in the so-called transonic flight regime. NASA engineers and the aerospace industry have been wrestling with the unpredictability of transonic flight for over half a century, since before Chuck Yeager successfully piloted the Bell X-1 beyond the sound barrier and launched us into the space age.

Today, as the design of the Orion Multi-Purpose Crew Vehicle and the Space Launch System (SLS) takes shape, the challenge persists. Orion/SLS is a larger, more geometrically complex spacecraft than those flown during the Apollo era, and engineers are facing new challenges as they navigate Orion's journey through the transonic flight regime (see box next page).

Through NESC assessments, Dr. David Schuster, NASA Technical Fellow for Aerosciences, has been tackling some of these challenges, most recently with buffet environments, which can occur during transonic flight.

"The buffet environment is the fluctuating pressure that generates an oscillating load on the vehicle,"

says Dr. Schuster. That fluctuating pressure can cause shock waves, which interact with the boundary layer or the flow of air closest to the vehicle. "The shock wave can cause that flow to detach or separate," he explains. "And when it does, it becomes very chaotic and generates this fluctuating pressure that can affect the structure and other systems on the vehicle."

Besides shock waves, buffet environments can also be triggered by abrupt changes in vehicle geometry, for example, where support hardware is located or where there are changes in the vehicle's



SLS model with canted ogive booster nose configuration in LaRC's Transonic Dynamics Tunnel.

## Effects of canting booster nose on unsteady pressures.



(A) Sharp on-axis booster nose.

(B) Sharp canted booster nose.

(C) Canted ogive booster nose.

CFD was used to investigate the contribution of buffet to booster interface loads on core/booster launch vehicle configurations. From left: (A) Sharp on-axis booster nose — pressure on core stage and solid rocket booster is the base line configuration; (B) Sharp canted nose configuration indicates reduced pressure on core stage but increased pressure on booster, and (C) Canted ogive indicates reduced pressure on both booster and core stage. These data were verified by wind tunnel tests.

diameter. "Air flow accelerates around these corners, can't make the turn, and then separates and starts rolling off," Dr. Schuster states.

Whatever their cause, buffet environments can elicit a buffet response in the spacecraft, causing things to shake. And for critical systems, like avionics, that shaking can cause these systems to fail.

"And if they fail, then the vehicle fails," he notes. In addition, spacecraft tend to enter the transonic range at the same time they reach their maximum dynamic pressure, or the maximum loads the vehicle will encounter during its flight. "So these buffet fluctuations are hitting the vehicle right at the worst time. That's why the whole buffet problem is so important."

## New Computational Approaches

When the SLS Program requested an assessment to help determine the potential for high buffet environments on specific areas of the spacecraft, Dr. Schuster's NESC team needed to investigate both old and new techniques for acquiring buffet data. "We haven't designed a new launch vehicle in quite a while," says Dr. Schuster, and because the Orion/SLS will carry astronauts to the Moon and beyond, "there are more stringent requirements when we put humans in the loop."

Existing data from Apollo was a starting point, but ultimately, "a lot of what we had at our disposal from the Apollo era isn't applicable to SLS," he explains. "It has to do with the Orion/SLS shape. The problem is very geometry dependent. SLS has boosters strapped on the outside. And we've added the new Alternate Launch Abort System. It looks very different from what we sent up with Apollo, so it generates a very different buffet environment."

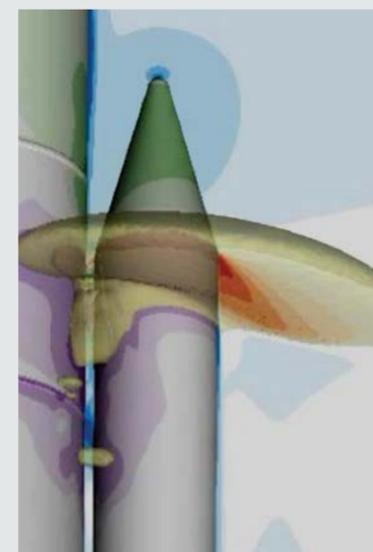
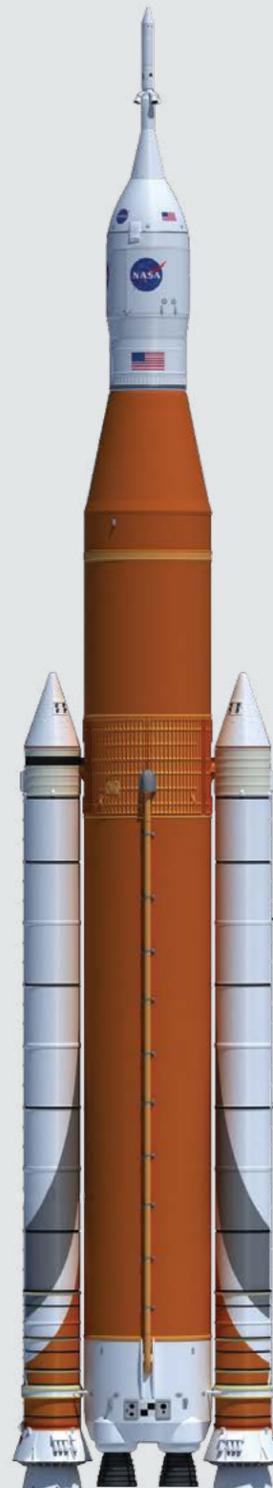
Because computational methods used in the past were not always successful in predicting these environments, NASA needed a new approach. The NESC team worked with an engineering team at LaRC who had developed a hybrid computational fluid dynamics (CFD) method using Reynolds Average Navier Stokes and Large Eddy Simulation. The NESC team used that hybrid method to predict the buffet environment on a specific area of the SLS. Then they compared those results with data gathered from recent NESC wind tunnel tests to confirm whether the CFD code was accurate in its predictions. "We found out this was doing a better job than we had ever experienced before," Dr. Schuster says. "It was looking like that hybrid scheme was a real possibility."

Excited with the preliminary results, the team wanted to take it a step further. "Since we knew we had a high buffet environment in a specific region," Dr. Schuster says, "could we use that CFD code to change certain design parameters on the vehicle and lessen the buffet problem?"

The answer was yes. "We started focusing on the shape of the booster nose cones," he says. Currently, the SLS nose cones resemble those flown on Shuttle, a conical shape with a spherical nose cap. The team examined different designs with more aerodynamically streamlined shapes. "The CFD code was telling us that we could affect the buffet environment pretty significantly by changing the nose cone shape. We could easily cut the buffet environment in half."

But the proof would come from testing these new designs in a wind tunnel, which they did by taking the most promising designs, building them, and attaching them to an SLS model. "We were able to demonstrate that the wind tunnel predicted the same buffet environment drops as the CFD code." That was big news, Dr. Schuster adds. "Now we

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## Transonic Flight

In transonic flight, a spacecraft is transitioning from subsonic to supersonic flight, but portions of the vehicle can generate supersonic flow before it actually goes supersonic. The ring structure in the CFD run pictured at left is a region of supersonic flow embedded in subsonic flow. Likewise, even after the vehicle has gone supersonic, portions of the flow can decelerate into subsonic. It is that mix of subsonic and supersonic that causes the chaotic air flow around the spacecraft.

## Who Benefits from Improved Buffet Environment Prediction?

NASA's commercial partners, the aeronautics industry, the launch vehicle community, and the spacecraft community could benefit from new prediction methods, says Schuster. "For a long time we focused our computations on steady flows. Now we're pushing those codes to try and predict unsteady flow, which helps with maneuvering aircraft, buffet, and many other things, so understanding these techniques for unsteady flow has a wide range of application across the industry. We spent about 20 years perfecting steady flow," he says. "I see us spending another 20 getting our capability up to speed on unsteady flow as well."

New Approaches to Refining the Launch Vehicle Buffet Environment, *continued*

have a computational tool that we can use, outside of the wind tunnel, to cycle through numerous designs before we actually go and commit to building hardware.”

For now, there are limits to using this new CFD tool. It is expensive to run as it ties up computer resources for weeks at a time. “But for specific problems where we want to look at the detailed physics of what’s going on,” Dr. Schuster says, “this tool gives us a capability that we never had before.”

To make this new CFD tool an accessible, functioning engineering tool will take time. “What we really want is to get this into the hands of the engineers so they can use it. But first we have to reduce the time it takes to generate data so it doesn’t bog down computer resources. There’s a lot of work to do, but it really shows a lot of promise.”

**Validating CFD Approaches with New Wind Tunnel Measurement Technology**

In the meantime, wind tunnels are still the main resource for gathering buffet environment data, so work continues to make them better at that job. “The wind tunnel tests to measure this buffet issue require that we measure the pressure at a large number of locations on the surface of the vehicle,” says Dr. Schuster. To do that, engineers employ unsteady pressure transducers, up to 400 of them on a single SLS model. But the transducers are expensive and add significant costs to the wind tunnel testing process. And even with 400 transducers, engineers are limited in how closely together they can be applied, which leaves gaps in the data measurement.

“It’s just not enough to get the resolution we need to accurately predict what is happening on the vehicle. So we’re always doing a lot of interpolation and trying to use engineering judgment to account for these gaps.”

But a new technology has recently emerged to fill these gaps. Late in 2015, the NESC team assisted in testing unsteady pressure sensitive paint (uPSP). When painted on a model, the uPSP can respond to pressure on the model at such a fast rate that engineers can measure the buffet frequencies. “The model is bombarded with light so that we can see every nook and cranny on the vehicle. Then we videotape the model with high resolution cameras.”

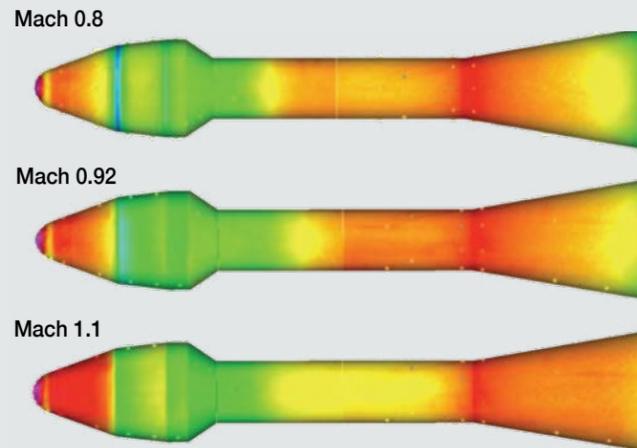
The result is hundreds of thousands of pixels, each denoting a pressure point. Instead of being limited to four or eight transducers placed around a circumference of the model, uPSP leaves no gaps. “It allows us to get a much more comprehensive view point of the fluctuating pressure field on the vehicle, without having to worry if some phenomenon occurred between our sensors that we didn’t pick up.”

**Weighing the Benefits of Buffet Prediction**

This is an exciting time for Dr. Schuster and the Aerosciences community. Adapting new CFD codes and pressure sensitive paint to the process of predicting buffet environments is shaping up to be a tangible advancement



Generic launch vehicle configuration of Coe and Nute in the ARC Unitary Plan Wind Tunnel. The model is covered with pressure sensitive paint to investigate new means of measuring fluctuating pressures (see below).

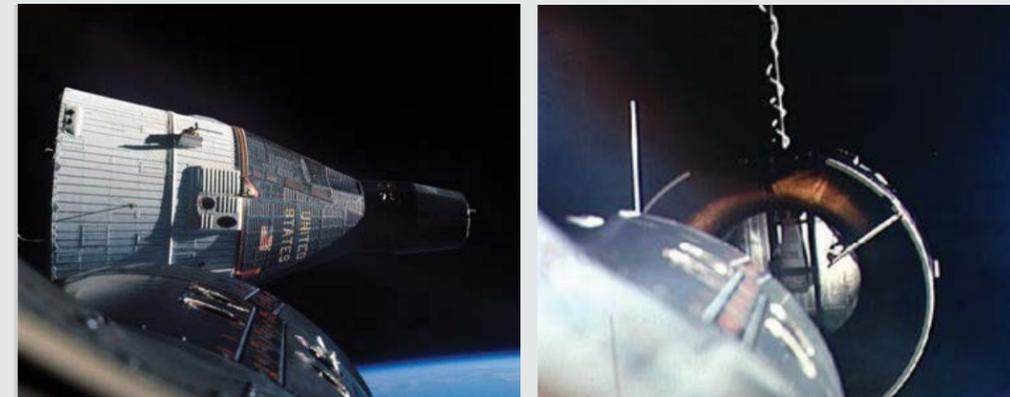


Pressure loads on the generic launch vehicle wind tunnel model were determined by time-averaged pressure sensitive paint measurements.

in the discipline. But he sees the benefits taking an even further leap forward.

“If we want to go to Mars,” he says, “we could just build margin into our vehicles so they’ll be robust to this buffet problem. But we’d likely build a vehicle that’s three times stronger than it needs to be, just to be sure it can survive the buffet, and make up for any uncertainties we might have in our ability to predict it.”

But that makes the vehicle a lot heavier than it needs to be, when weight would already be at a premium on long-term missions. “Being able to predict buffet environments more accurately will allow us to reduce the margin, reduce the weight, and give us a more efficient vehicle. Then we can use that weight to actually execute the mission,” says Dr. Schuster. “That’s the real benefit.”



Far left, Gemini 7 seen from Gemini 6A during the first U.S. rendezvous and station-keeping between two crewed spacecraft.

Left, Gemini 8 rendezvous with the Gemini Agena Target Vehicle to perform the first U.S. docking between two spacecraft.

# Space Rendezvous

Tomorrow’s technology will build on historical breakthroughs

Propelling technology forward normally involves building on past accomplishments. That is what prompted Cornelius (Neil) Dennehy, NASA Technical Fellow for Guidance, Navigation, and Control (GNC), to take a look back at NASA’s first space rendezvous. A half-century ago, two crewed Gemini spacecraft, Gemini 6A and Gemini 7, conquered the technological milestone of meeting up with one another while orbiting 160 nautical miles above the planet.

Though engaged in the study of space rendezvous for more than 20 years, Mr. Dennehy was struck by the enormity of the task that lay before those early astronauts and engineers. “They had to start with a clean sheet of paper,” he says. “They had to work out the question of relative motion, the radar sensors, the modeling and simulation, the training. They had to create it all. Back then, they didn’t know what they didn’t know, so they were unencumbered and creative. They were excited about breaking new technical ground.”

A fresh look at this first proximity flight in low Earth orbit inspired Mr. Dennehy, bringing a renewed vigor to his current work on rendezvous and capture capabilities. And it reminded him that today’s state-of-the-art sensors, which are guiding unmanned resupply spacecraft to their docking ports at the International Space Station (ISS), and the plans that are underway for a rendezvous mission with an asteroid, were built on that earlier Gemini success and the subsequent refinement of rendezvous with Apollo and Shuttle. And it cemented his conclusion that continued evolution in rendezvous technology will be the key to getting humans to Mars.

“The fundamental physics have already been flight proven,” explains Mr. Dennehy. Following that first space rendezvous in 1965, NASA refined its capabilities in later Gemini missions, achieving the first docking of two spacecraft. From there, Apollo missions honed NASA’s

Earth orbit rendezvous skills. Apollo 10 saw the first lunar-orbit rendezvous. Then the Shuttle Program saw more than 50 rendezvous and docking missions, with satellites in need of upgrades or repairs, with Mir, the Hubble Space Telescope, and in-space assembly and docking of the ISS.

“Our rendezvous operations became a very polished, well-orchestrated process,” he says. “We know how to do it. Now we need to focus on increasing the performance of these technologies, driving costs down, and finding ways to do rendezvous more autonomously. There are still challenges out there for us.”

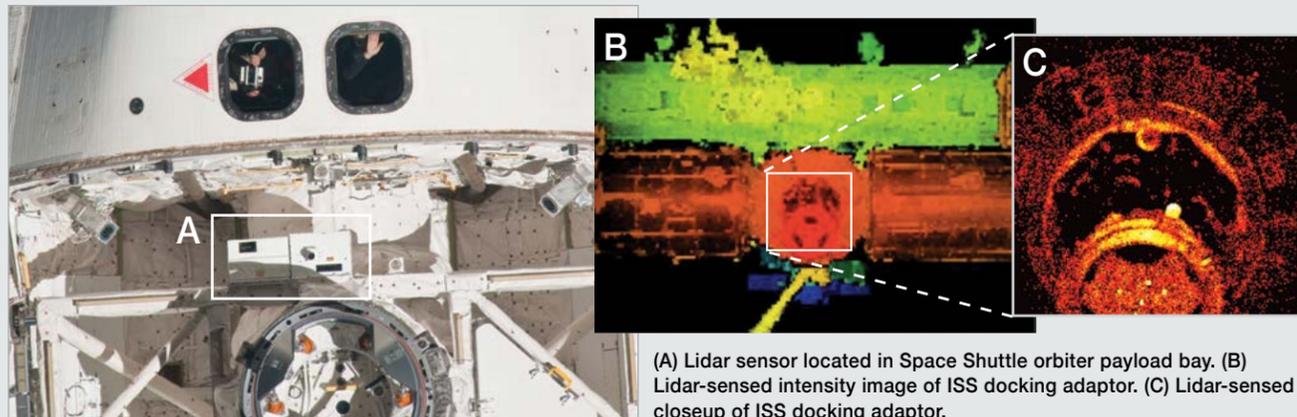
To that end, Mr. Dennehy is leading a system-level capability leadership team for the Agency focused on rendezvous and capture, and for the past 5 years has also been running a grass roots autonomous rendezvous and docking community of practice. Last summer he gave a lecture in Europe on the numerous lessons learned over the years from relative motion missions. “It’s an active area of study right now,” he says. “We’re working hard to make sure we have the right capabilities for the future needs of rendezvous and capture — workforce, facilities, tools, testbeds — all of the ingredients we’ll need on a journey to Mars.”

**Advancing Existing Technology**

Mr. Dennehy describes rendezvous and capture as more than just a single-discipline endeavor. “It is a true systems capability — it’s GNC, software, mechanical systems, avionics, sensors, vision processing — a true multi-disciplinary feat.” A unique combination of planning tools on the ground, onboard processing, control algorithms, navigation algorithms, docking mechanisms, and capture hardware are required for a successful meet-up in space.

But the area where Mr. Dennehy has focused much attention is lidar, also known as Light Detection and

*Continued next page*



(A) Lidar sensor located in Space Shuttle orbiter payload bay. (B) Lidar-sensed intensity image of ISS docking adaptor. (C) Lidar-sensed closeup of ISS docking adaptor.

Ranging. “Lidar has become one of the basic relative navigation sensors we use on missions,” he says. “Lidar sensors are most useful when there are mission requirements for obtaining lighting-independent relative navigation information or when there is a direct ranging requirement. It comes down to the sensors. If you can’t get data about where the target is relative to your position, you won’t have the data needed to accomplish a rendezvous. It won’t occur without the right sensor technology.”

There’s an art to selecting the appropriate relative navigation sensor suite for each rendezvous mission application. Typically, a combination of wide-angle and narrow-angle visible cameras, infrared cameras, laser range finders, and more recently flash or scanning lidar relative navigation sensors are used, all of which are optical-based sensors. The shift from radar-based to optical-based sensors for rendezvous, which occurred over the decades since the first radar-guided Gemini rendezvous, was driven by the desire to develop a fully autonomous rendezvous, proximity operations, and docking functional capability.

“Over the past few years, optical relative navigation sensors have successfully been used on the European Space Agency’s Automated Transfer Vehicle, the Japan Aerospace Exploration Agency’s H-II Transfer Vehicle, as well as the U.S. commercial Cygnus and Dragon spacecraft, to rendezvous with ISS for cargo resupply. The one noteworthy exception is with Russian spacecraft that rendezvous with the ISS. They employ radar-based relative navigation sensing, which has been their legacy approach since the 1960’s.”

Radars will continue to have a role as a GNC relative navigation sensor, particularly for planetary landing mission applications where they are used for altimetry and velocity measurement, Mr. Dennehy says. “In fact, every single spacecraft, robotic or manned, that landed on the Moon or Mars, has used radar. With continued investments in lidar technology development, I can foresee the day when planetary landings will be accomplished with relatively small, low power, high-performance lidar sensors, potentially replacing radars. There is also the possibility of multi-functional lidar sensors for future mission applications that will perform direct relative range and range rate

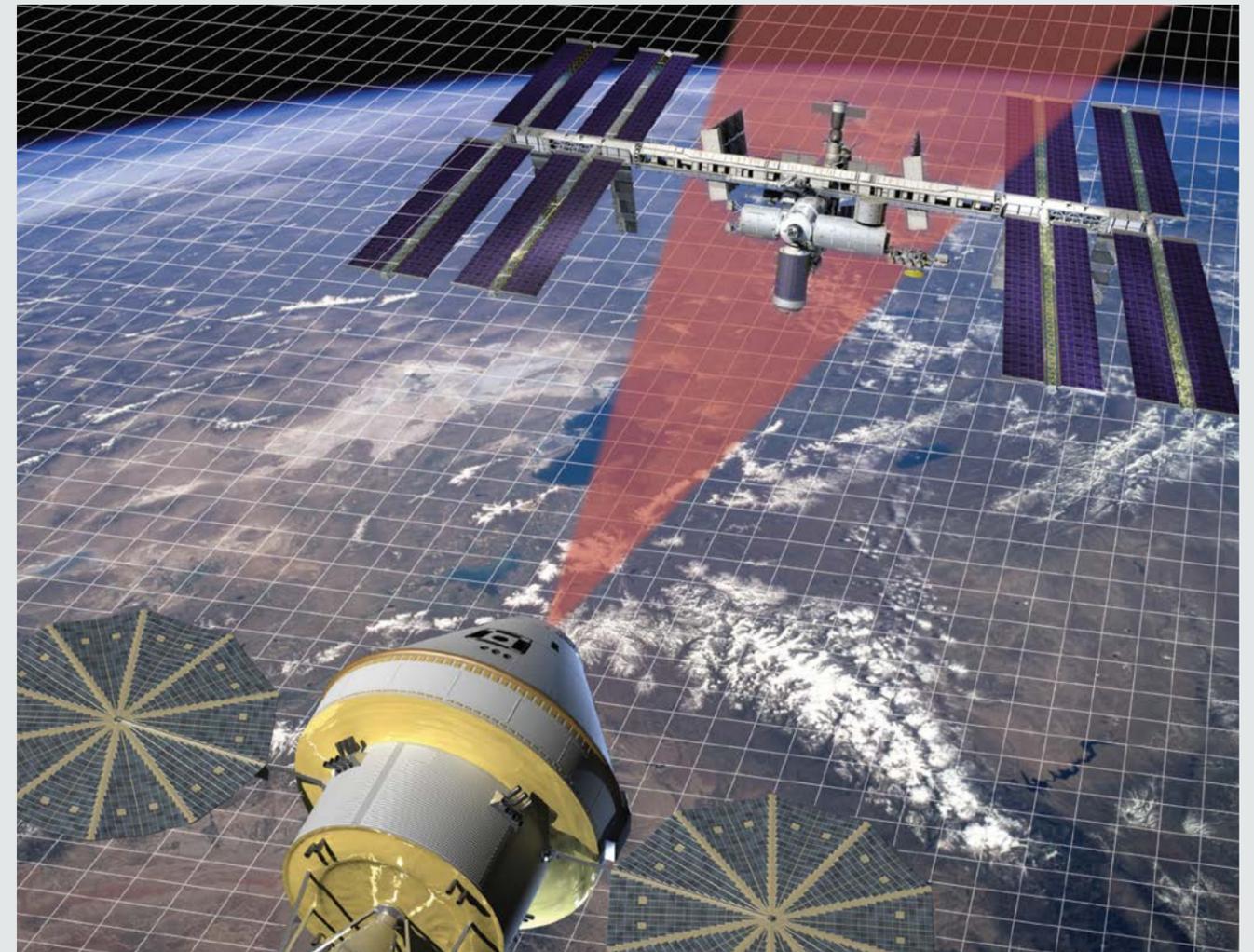
measurements as well as providing the raw data needed for target attitude pose estimation and hazard detection.”

Over the past decade, lidar sensors have become an increasingly intriguing relative navigation option for GNC engineers designing rendezvous missions. Lidar works similarly to radar, but uses laser light pulses instead of radio-frequency electromagnetic pulses to measure the distance from and bearing to a target object, like another spacecraft. The laser return data collected must then be processed in order to reach a relative navigation state. Lidar sensors cannot only provide the range and bearing to the target but can also provide the attitude orientation (or “pose”) of the target relative to the chase spacecraft. Several NESC assessments, led by Mr. Dennehy, have focused on lidar technology. “We want to help characterize

*“Autonomous rendezvous and capture will be an integral element of going to Mars”*

their performance and the flight software algorithms that process the data.” It is a step forward toward improving the reliability and lifecycle length needed for prolonged missions in space.

Mr. Dennehy recently led an NESC assessment to evaluate the lidar-based natural feature tracking technology planned for OSIRIS-REx (Origins-Spectral Interpretation-Resource Identification-Security-Regolith Explorer). “It’s an asteroid sample return mission set to launch in September 2016. The spacecraft will rendezvous with an asteroid and through a controlled touch-and-go (TAG) maneuver, will collect a sample and bring it home.” What complicates this mission is the rendezvous target. The motion of small, distant bodies is often not well-known or characterized. It is not another known cooperative spacecraft. It is not engaging with a well-defined docking port on ISS. “It’s a rendezvous between a spacecraft and a natural object, a primitive body,” he says.



Notional representation of the Vision Navigation System flash lidar illuminating the ISS to determine range and bearing relative navigation information.

Aside from advances in lidar, “we’ll also need higher degrees of autonomy and operational flexibility,” states Mr. Dennehy, for managing a rendezvous that could be happening millions of miles away from Earth. In a mission like OSIRIS-REx, ground operations will be doing navigation and flight dynamics, but only up to a point. “The time it will take a signal to travel to the spacecraft and back for processing on the ground will be on the order of minutes,” Mr. Dennehy says. “When OSIRIS-REx is doing its TAG maneuver, it will have to do it autonomously since the ground can’t realistically be in the loop.”

What is learned from OSIRIS-REx can then be applied to another mission – a Mars sample return. “A lander will go down to the surface, gather samples of soil, and launch itself back to orbit and rendezvous with an orbiting craft.” This could mean in-space assembly of assets that would involve rendezvous and docking with platforms and other spacecraft – even further out into the solar system. “Autonomous rendezvous and capture will be an integral element of going to Mars,” he says.

Autonomous rendezvous could also lead to lower operational costs. More autonomy may eventually reduce the workload for on-ground crews or the pilots and crews in the spacecraft itself. “But we’ll have to work up to that very carefully, by advancing this system capability in a careful and well-thought-out manner.”

“We’ve certainly come a long way, but we have a long way to go,” says Mr. Dennehy. That is why building on what has already been accomplished is so important. “The environment has changed and we have to find more affordable ways to do this. We can’t afford the development of entirely new spacecraft-unique rendezvous solutions each time a future mission application arises. As creative engineers, we’d all like to start with that clean sheet of paper and show how innovative we are, but we need to both leverage our existing rendezvous architecture for our future missions and increase the levels of autonomous operations,” he says. “That will get both implementation and operations costs down so that we can fly even more missions, and that’s what we all want to do here at NASA.”

## Digital Exposure

### Shining a light on x-ray film's successor

Transitioning from familiar and trusted technology to new, more advanced technologies isn't always a choice; it is a necessity.

For NASA, x-ray film radiography has been the go-to inspection method for decades. Right now, NASA is using this technique to inspect tube welds on the Orion Multi-Purpose Crew Vehicle (MPCV) that will one day take astronauts to destinations beyond our Moon. But film production is declining, and decisions on what technology will take its place must be made before film costs become unaffordable or production ceases all together.

During the Orion Tube Weld Digital Radiography Assessment, the NESC evaluated technologies that may soon replace film radiography, not just for the Orion MPCV, but for the Agency's nondestructive evaluation (NDE) community as a whole.

Film radiography works by finding hidden flaws in materials using x-ray photons to capture those flaws on film. "It's very common around the Agency and it's used for many different things, everything from solid rocket booster aft skirt welds to small tube welds, tanks, seams, and for part certification," says Eric Burke, Technical Lead for the NESC assessment. "It's the first technique we use to get a quick look inside, and it was one of the first techniques added to our NASA Standard 5009 (NDE Requirements for Fracture Critical Metallic Components). It's been around for a long time."

Most people are familiar with film radiography's use in the medical community. "It's exactly the same as a medical x-ray," Mr. Burke says, with a slightly different application. While a doctor uses the technology to see through the human body, NASA is looking through composites and metals. "The medical world and the NDE world are very parallel when it comes to using ultrasound and x-rays. However, doctors are looking for things that are millimeters in size, while we're looking at things down to the micron level," Mr. Burke says.

"And typically, higher energy sources are used in NDE in order to penetrate denser, thicker materials," adds

Dr. William Prosser, NASA Technical Fellow for NDE.

Aside from having to set up a safety zone prior to use, x-ray radiography is simple to operate and gives a clear image of complex parts, even more so than ultrasonic techniques, which can lose focus the farther it penetrates a material. "x-rays go straight through," notes Mr. Burke.

But the film needed for x-ray radiography is nearing extinction. "We don't consume as much film as the medical community, but the medical community has moved to digital technology, so film is harder to get," says Mr. Burke. Kodak, one of the primary manufacturers of x-ray film, has all but stopped production, leaving only one primary supplier left—Fuji. "It's getting prohibitively expensive to get it," he says.

#### Advantages of Digital

The NESC assessment took a closer look at a newer technology called computed radiography (CR) (see box next page). It has been around for a few years, but only recently reached a level to be comparable to, and in many ways better than, film.

The advantages of CR are akin to the benefits digital cameras offer over film photography. "To develop x-ray film requires chemicals," says Mr. Burke. "With digital, you don't have to deal with chemicals and their disposal, which is a big deal from an environmental and cost aspect. Digital gets away from all of that." And film, which must be stored properly and can deteriorate over time, is replaced by plates that can be reused.

In addition, time is required to get the processing done, adds Dr. Prosser. "You shoot film, process it, and if you didn't get the shot right, you do it again. Today, there's a big driver to reduce costs and get results much quicker." With CR, images can simply be erased and taken again.

Finding defects is easier with digital as well. "In the past you would take x-ray film and put it under a back light while using a magnifying glass to find defects," Mr. Burke states. "Now, with CR, images are automatically digitized into the

computer. There are a lot of enhancements you can do to the images, using digital filters within the software, which make it easier to find defects. Then you can print your report and you are ready to go."

During the assessment, the NESC team used commercially available CR equipment to put the technology to the test. They used tube weld samples of various diameters, thicknesses, and materials, such as stainless steel and titanium. The team looked at good welds, as well as those where lack of fusion and porosity defects were manufactured into the samples. Overall, they evaluated examples of some of the hardest and easiest scans currently being done on the Orion crew module, looking at more than 100 defects. After careful study of the results, what they ultimately found was that for finding the flaws in tube welds, CR was doing a better job than film.

"Until recently, the pixel size on CR detectors wasn't nearly as fine as the grain size of the film," says Dr. Prosser. "Historically we could get better results with film because we had better media to record the images. But now CR plates and scanners have gotten much better."

#### Opening the Door for Digital

Results from the NESC assessment have opened the door for production use of CR, states Dr. Prosser. Proving the technology will work for the Orion MPCV Program in certain applications will hopefully stimulate more in depth probability of detection studies. "It also opens the door to trying CR on other problems where we typically use film."

The transition will not be a fast one, though. Baselines for radiography in NASA Standard 5009 are based on film. "But now that we've had some success, it will pave the way to doing the work required to get into the NASA standard and applying the technology on a wider scale. It will help us transition from film and bring significant advantages in capabilities and cost savings," to NASA as well as its commercial crew partners, Dr. Prosser adds. "There's still more work to be done, but this is an important step. To include CR in the NASA standard will be a big change across the Agency and for every program."



Tube weld sample specimens, similar to that used on the Orion MPCV (left), were developed with deliberate flaws (pores and lack of fusion) to compare radiography techniques. Stainless steel, Inconel, and titanium tubes were used in testing. Computed radiography image of welded seam is shown below.

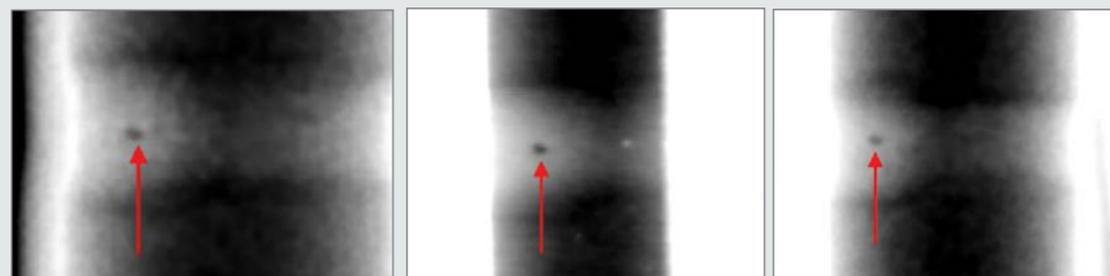
#### How Computed Radiography Works

CR uses similar equipment to conventional radiography, except that in place of a film to create the image, an imaging plate made of photostimulable phosphor is used. The plate is housed in a special cassette and placed under the body part or object to be examined, and the x-ray exposure is made. Then, instead of taking an exposed film into a darkroom for developing in chemical tanks or an automatic film processor, the plate is run through a special laser scanner, or CR reader, that reads and digitizes the image. CR can then leverage powerful software to enhance the digital images through functions such as contrast, brightness, filtration, and zoom.

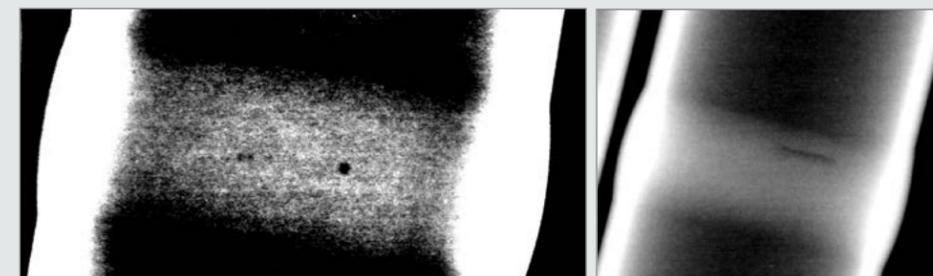
X-ray film

Computed radiography

Digital radiography



Detection of a pore in a tube weld using x-ray film, computed radiography, and digital radiography. NASA is pursuing the use of computed radiography.



Tube weld sample specimens with small dual-pore and large single-pore defects, far left, and lack-of-fusion defects, left, were used to evaluate x-ray NDE techniques. The ability of inspectors to detect the defects using film and computed radiography were examined. Computed radiography proved to be superior to film in these tests.

## From Launch to Splashdown

### Using modeling and simulation to preview the Orion spacecraft's journey

For NASA to embark on missions to asteroids, Mars, and beyond, three extremely complex systems must work together in an exceptionally intricate harmony: the new heavy-lift rocket that will launch the astronauts beyond Earth's orbit – the Space Launch System (SLS); the crew vehicle that will carry those astronauts – Orion Multi-Purpose Crew Vehicle (MPCV); and the infrastructure and personnel who will facilitate that launch – Ground Systems Development and Operations (GSDO).

Today, each of these systems is being designed, built, and tested individually. But NASA needs to fully understand how these three systems will work together once they are integrated, long before lift-off from a launch pad. That means visualizing how these systems will interact, anticipating any potential issues, and finding ways to resolve them.

To aid in that effort, the NESC put together a multi-Center team, who since early 2012 has been developing independent models and simulations of the Orion spacecraft's end-to-end journey from launch to splashdown, and the critical events that must happen along the way. Jill Prince, Manager of the NESC Integration Office, has been leading this assessment and explains the work required to undertake this modeling and simulation effort and what the team has accomplished so far.

**Why is independent modeling and simulation (M&S) so important when it comes to integrating complex flight systems?**

The key word here is complex. With a complex flight system, sometimes you can identify issues, or failure modes, once systems are integrated that you wouldn't necessarily catch on a subsystem level or during individual component testing. One way to identify those issues is with modeling and simulation – putting everything into one simulation to find things you wouldn't find otherwise. There, we look for areas of risk and try to reduce or mitigate those risks where we can.



Jill Prince, NESC Integration Office Manager.

**What were the major steps the NESC had to take to bring all of these independent systems together into one M&S tool?**

We already had an M&S framework to get started – the Program to Optimize Simulated Trajectories (POST), which has been used for other flight projects across all mission directorates. But because this complex system incorporates elements from across the Agency and industry, we had to find simulation experts from relevant Centers and bring them on board. Modeling and simulation is my background, so I knew some great people to get us started. But who wasn't as familiar to me were the experts doing the in-line work within Exploration Systems Development

(ESD). Developing those relationships was really important before we could move forward.

**What will independent M&S do for the SLS/Orion MPCV/GSDO Program? What do we ultimately hope to gain from this effort?**

We're hoping to have an independent simulation, and the experts to use it, at the ready. That way, if a technical risk comes up within the life span of SLS, Orion MPCV, and GSDO, we can corroborate, verify, or mitigate that risk with a mature, verified, and validated independent model. Also, by working independently, we can look for additional risks that may not have been identified or characterized yet. That way we can stay ahead of the game.

**Are there key areas where we are focusing our M&S efforts? What have we learned?**

We've developed a nominal, high fidelity simulation that's allowed us to provide an independent assessment of several key events in the SLS timeline. And we've run the nominal simulation against the SLS simulation and verified those results.

Building on that, we've looked at several clearance events on the timeline. We've delivered a lift-off proximity analysis of SLS and its separation from the GSDO systems, an SLS booster separation analysis to determine if the boosters would come close to recontacting the core vehicle as it ascends, and we also simulated the separation of the service module panels to look for potential recontact. And we've looked at separation of the ICPS, the interim cryogenic propulsion stage, from the core, and separation of the launch abort system. Those are the events we've focused on so far, but we're continually adding events to take a closer look at their details.

We've also put together an end-to-end, 3 degree-of-freedom capability that allows us to model the entire trajectory from SLS lift-off to splashdown of the Orion crew module. This lets us find potential efficiencies that we might not have found in a piece-meal look. We were able to run

several trade studies, for example, optimizing the day of launch and time of day for best mass performance. As we build the capability, we learn more about our framework, what it is capable of, and the limits to its flexibility.

**How important is it to see an animated visual of these simulations?**

We're using EVE, Exploration Visualization Environment, which is critical to getting everyone on the same page. The animation makes more sense to the many different people working on this program. That animation is critical to my understanding, the engineers, and the stakeholders. It's easier to understand where something can go wrong if you can see it.

**What's the next step for the M&S team?**

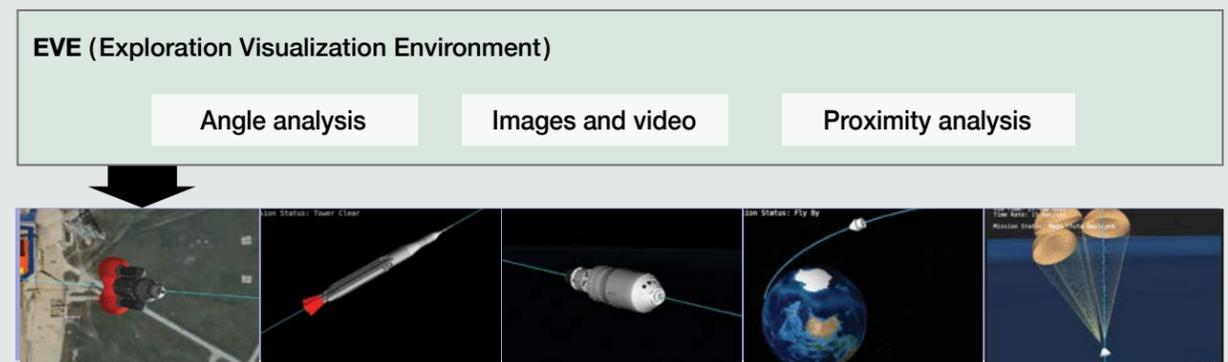
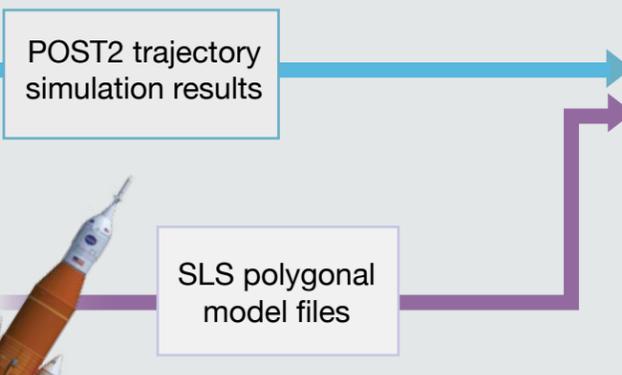
We'll continue to update the simulation to be current with the program's simulations. Soon we'll be switching out a component of the vehicle as missions change and seeing what effects that will have, and doing some additional trade studies as we look at Exploration Mission-2 and beyond. There's no shortage of work.

Because our analysis has been helpful for ESD, they've continued to ask for more, and we're so appreciative of the easy transfer of data between the programs and the NESC. I think the relationship we've built is strong and we'll continue to work on that relationship because we all know there's a great return on investment here.

**What will you take away from this assessment?**

Respecting the complexity of this program while figuring out how to reduce it to a simpler form for easier understanding has been really interesting. It's a whole new knowledge pool that I didn't have. And there's always a new challenge, and we're always adding new people to the skill mix and growing the expertise across the Agency. That's been very exciting for me.

### POST2 Trajectory Analysis



EVE combines trajectory data from POST with graphics models in a virtual environment to produce animations, proximity analysis, and angle analysis that provide insight into multi-body dynamics.

## Space Debris

### Understanding the risks to NASA spacecraft

Getting to space requires speed. A lot of speed. So, for NASA to send an object, like a satellite, into orbit, that object must reach velocities of several kilometers per second. And if it hits anything while in orbit, like debris, the damage can be substantial if not catastrophic.

This is why NASA has invested much into investigating the potential risk of damage to its spaceflight programs from orbital debris—those manmade objects in Earth orbit that no longer serve a useful purpose, from a derelict satellite to a flake of paint. Natural objects like meteoroids are also a threat, traveling even faster than orbital debris. Typically comprising particles originating from comets or asteroids, the vast majority of them are very small micrometeoroids.

Micrometeoroids and orbital debris (MMOD) is the number one risk for NASA's human spaceflight programs. Many orbital debris objects—approximately 20,000—are large enough to be tracked and catalogued by the U.S. Space Surveillance Network and can be avoided by spacecraft maneuvering. But it is the unseen population of MMOD that poses the biggest risk to spacecraft: the orbital debris large enough to cause damage, but too small to track, and the micrometeoroids, which cannot be tracked regardless of their size.

To help mitigate the risk of MMOD, NASA uses a variety of computer models and applications to perform MMOD risk assessments. The primary MMOD risk assessment tool is a computer application called Bumper. Bumper helps NASA determine the probability of a spacecraft being damaged by MMOD during its operational lifetime. Working with NASA's primary MMOD organizations—the Orbital Debris Program Office, the Meteoroid Environment Office, and the Hypervelocity Impact Technology (HVIT) Office—the NESC has performed several assessments in pursuit of improving the understanding of MMOD risk, refining the risk assessment processes, and reducing the actual risk.

For example, in 2014, an NESC team compared NASA's newest and most advanced orbital debris model, ORDEM 3.0, to other orbital debris models to analyze how it models the orbital debris population. ORDEM 3.0, key to predicting the orbital debris environment, uses the largest database of MMOD impact data taken from analyzing damage sites on the Space Shuttle after each return to Earth. As a result, there is a relatively high level of confidence in the results the model gives for the orbital altitude where the Shuttle flew. However, no sources of impact data are available for higher altitudes, so the model has to make certain assumptions on the sources of the debris, which results in more uncertainty in orbital debris predictions. The NESC review represented the most extensive independent review of ORDEM 3.0 since its release. The team concluded that ORDEM 3.0 is the best model available and appropriate for use in NASA's MMOD risk assessments, while still

making several recommendations that may reduce the uncertainties and improve the model.

MMOD environment model uncertainty affects the fidelity of predictions in MMOD risk assessments. But this is not the only source of uncertainty. Damage prediction is another area where uncertainties can be introduced into risk values. In order to predict the risk from MMOD, a clear understanding of the spacecraft's susceptibility to MMOD is needed. This includes looking at each exposed component and how it will behave when hit by a hypervelocity particle. This is damage prediction. By combining hypervelocity impact testing with simulations, ballistic limit equations (BLEs) are produced, which define the minimum size of a

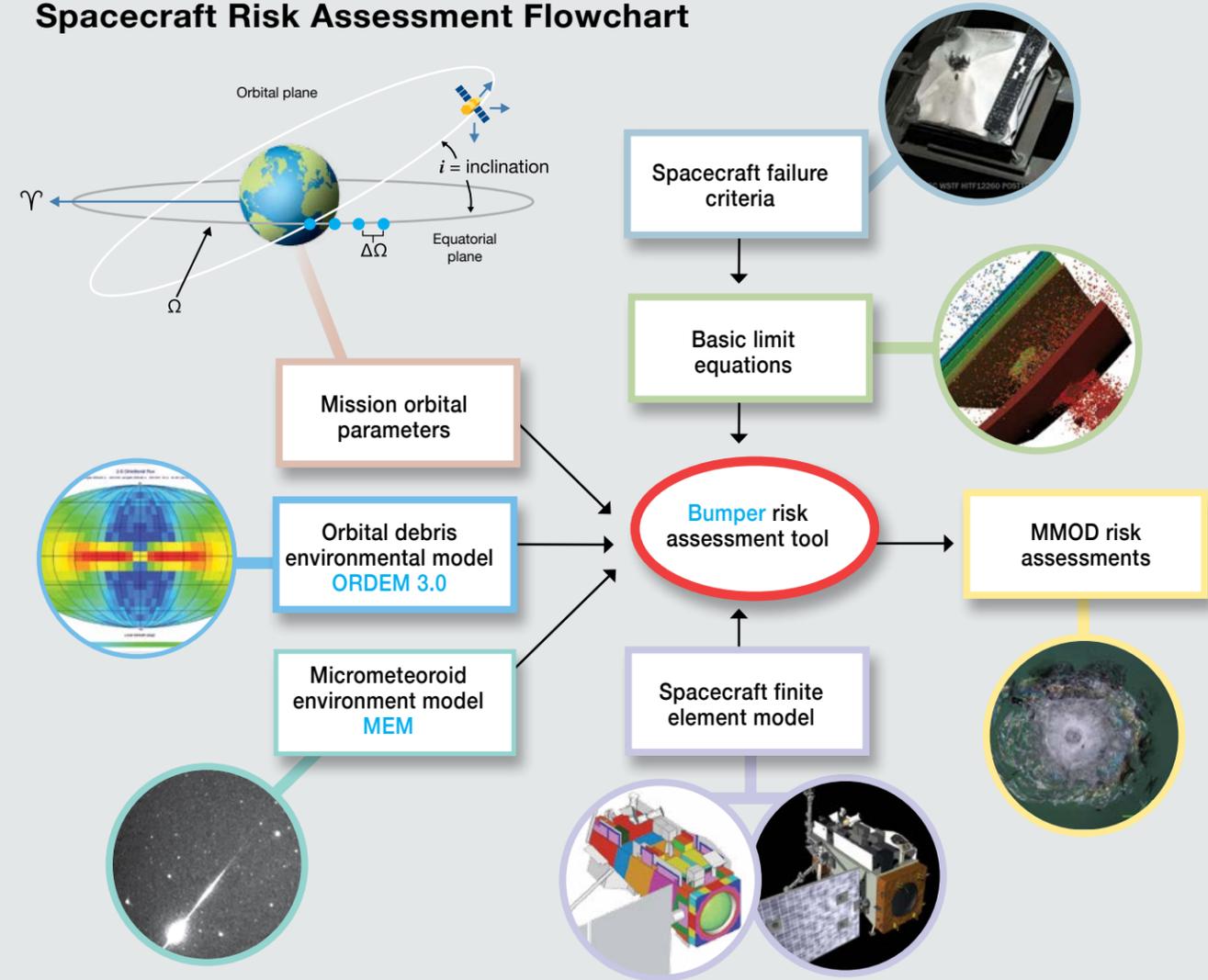
*... it is the unseen population of MMOD that poses the biggest risk to spacecraft: the orbital debris large enough to cause damage, but too small to track*

particle that will cause a failure as a function of velocity. BLEs are generated for particles of different material densities (e.g., lighter aluminum will cause less damage than heavier steel) and impact angles. The NESC has worked with HVIT to conduct testing and simulations to refine existing BLEs and to create new ones for advanced shield materials and configurations. The NESC/HVIT Team also worked together to test and evaluate multifunctional shields that would protect from the radiation as well as the MMOD environment, and they evaluated self-sealing materials for use in pressurized volumes.

The NESC is also working to gauge how well NASA does on assessing MMOD risk overall. The concept is to compare MMOD-caused anomalies and failures on active satellites to what their predicted risk would be. This work is challenging as failure data are not always readily shared by satellite operators, and it is often difficult to pinpoint the cause of a failure as MMOD. On the other hand, few MMOD risk assessments have been performed on robotic satellites so predicted risk is, for the majority, unknown.

The MMOD risk assessment process is time and labor intensive and requires a detailed knowledge of the configuration, materials, and failure criteria for the spacecraft. To achieve a good statistical comparison, the NESC is targeting a limited number of satellites for which anomaly data and configuration information are available. The goal is to determine how close NASA is to accurately predicting this top-priority risk and to learn how to improve our risk predictions.

### Spacecraft Risk Assessment Flowchart



#### Orbital Debris Model ORDEM 3.0

ORDEM 3.0 is appropriate for those engineering solutions requiring knowledge and estimates of the orbital debris environment (debris spatial density, flux, etc.) and is primarily used by spacecraft designers to understand the long-term risks of debris collisions. ORDEM 3.0 can also be used as a benchmark for ground-based debris measurements and observations.

ORDEM 3.0 includes flux estimates for several material density classes. It has also been extended to describe the orbital debris environment from low Earth orbit past geosynchronous orbit (100 to 40,000 km altitude).

A large set of observational data (both in situ and ground-based) incorporated into ORDEM 3.0 reflects the current debris environment and is NASA's best estimate of the current and near future orbital debris environment. These data cover the object size range from 10  $\mu\text{m}$  to 1 m. Analytical techniques (such as maximum likelihood estimation and Bayesian statistics) are employed to determine the orbit populations used to calculate population fluxes and their uncertainties.

ORDEM 3.0 was developed by NASA's Orbital Debris Program Office.

## Li-Ion Batteries

### Managing risk to secure reward

Li-ion batteries perform well in packing a lot of energy into a small package. That is why NASA was one of the earliest adopters of the Li-ion battery for use in space, where the advantages of smaller batteries with a long life expectancy are numerous, from fitting nicely into the confines of the International Space Station (ISS) or a space suit, to extending the length of a satellite's mission or an astronaut's walk in space.

#### Li-Ion Advantages and Drawbacks

"We were some of the first to adopt Li-ion batteries in our vehicles, even before the aircraft and auto industries," says Dr. Christopher Iannello, NASA Technical Fellow for Electrical Power. "They have a much better energy density, often more than two times greater than other battery chemistries, so their run time is much longer." As a result, the Agency was an early adopter of Li-ion batteries.

But that high energy density has a flip side. Dr. Iannello explains that the volatility of the constituents, coupled with the flammability and toxicity of typical Li-ion electrolytes, means that at high temperatures the cell becomes thermally unstable where exothermic reactions release heat faster than heat can be dissipated from the cell. This condition, called thermal runaway, often results in the ignition of the venting electrolyte in the form of fire, smoke, and high temperatures in excess of 600° C. Of further concern is that during a single-cell thermal runaway, the high heat of the failing cell can propagate to the next neighboring cell, causing it to go into thermal runaway as well.

"We knew they had aggressive failure modes," says Dr. Iannello, which he likened to a blow torch. "It's a domino effect. If one cell goes, it heats its neighbor, and so on. Then it releases all of that energy, which on one of our vehicles would be catastrophic." Hence, NASA's intense scrutiny of Li-ion batteries. "We've spent a lot of time and money watching the manufacturing to make sure the chances for

cell-level defects are driven to a minimum. We do screening tests when they come in, and this reduces the likelihood that there will ever be a single cell with a problem, much less a propagation scenario.

In the past, the intent had traditionally been to drive the likelihood of a single-cell thermal runaway to as low as possible, but we gave little consideration to what the severity would be if it did occur. Basically, we worked the likelihood side of the risk equation hard, but mostly omitted the severity side, assuming that if a single cell were to go into thermal runaway, propagation was a forgone conclusion."

But when Boeing experienced thermal runaway on its 787 Dreamliner aircraft, "we were concerned," says Dr. Iannello, who worked with the NESC's Electrical Power Technical Discipline Team to support Boeing's investigations into the incidents. Ultimately, says Dr. Iannello, Boeing determined that manufacturing screens are not a perfect solution, and may never be perfect enough to ensure no unscreened defects.

Boeing focused on its screening tests and looked hard at its battery fleet, but not having solid proximate cause, it designed a strong box for its Li-ion batteries that would contain the energy should a thermal runaway happen in the future. Dr. Iannello realized NASA could no longer depend on screens to protect against potential thermal runaway failures and gathered together key battery experts at the Agency to figure out how to minimize the risk of thermal runaway propagation within NASA spaceflight deployments.

#### Mitigating Risks Through Improved Packaging

Building a box to contain the energy is too heavy a solution for Li-ion battery applications in space. And adding additional separation between the individual cells to avoid propagation could make the battery too large, eliminating the benefits of a compact design. But the TDT concluded

that solutions would lie in how the cells were packaged, how vented battery effluents were managed, and how the cells were interconnected electrically. So, with the addition of the NASA Technical Fellow for Passive Thermal and electrochemical specialists, this is where the team concentrated its efforts. In particular, they focused on the Li-ion batteries used on the ISS, the extravehicular mobility unit batteries in spacesuits, as well as the batteries used in hand tools.

"If a satellite has a thermal runaway, the result is catastrophic for the satellite, but there's no human life involved. So we focused on human spaceflight, because that's where it matters the most," Dr. Iannello says.

NASA has never had an issue with its Li-ion batteries, he says. "NASA has had an exceptional track record with no in-flight Li-ion battery incidents, but Boeing's experience made us realize we need to be prepared to manage this catastrophic hazard rather than trust it won't occur based on our screens alone. When that one cell goes off, it's like a blow torch; it pops," he adds, "but if we can ensure that blow torch doesn't impinge on its neighboring cell, we can prevent thermal runaway propagation."

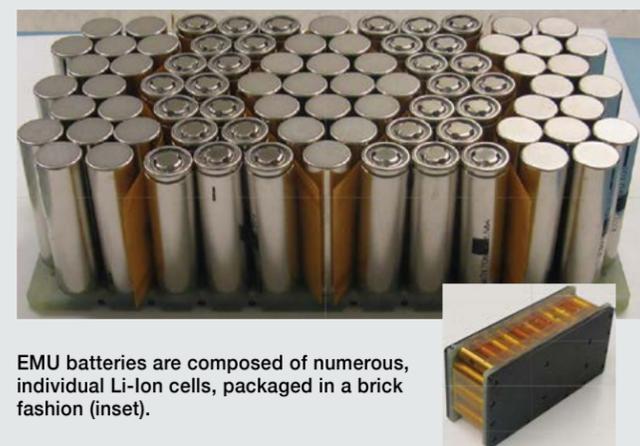
#### Development of Li-Ion Best Practices

Through the NESC assessment's extensive analysis and tests, Dr. Iannello says that several best practices have been identified to help prevent thermal runaway from happening. "Managing the effluent and circulation of electrical energy within the battery is one," he says. Should a Li-ion battery cell experience a failure event, managing emissions from the cell and the transfer of the heat can prevent propagation.

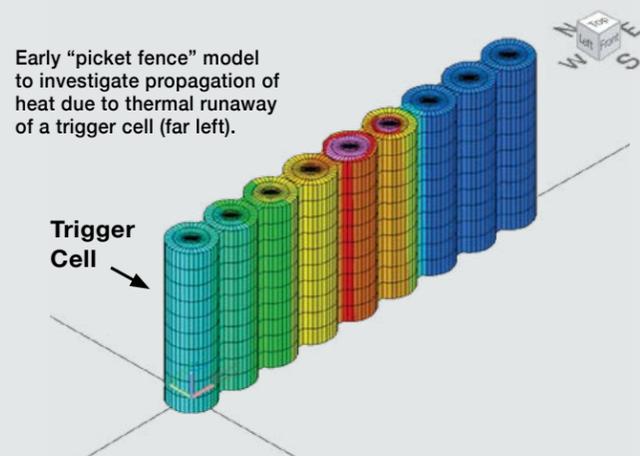
"And when a cell gets hot, you don't want it touching the cell next to it such that all its heat is transferred to the neighbor in a localized way. So, interstitial materials can be added," adds Dr. Iannello. Those materials help absorb and distribute energy so that it is not localized to a single neighbor, which may help to prevent the thermal runaway.

In addition, fusible links help isolate failed cells ensuring circulating energy does not exacerbate the problem.

Additional options are being considered for individual battery types, including resizing of battery housing and the addition of containment bags that are tolerant to flames and other effluent released from a failed cell. Results from the NESC assessments are guiding the production, and in some cases, the redesign of future Li-ion batteries used at NASA. And the NESC assessment team is sharing what it has learned with industry users. "We're publishing our results at conferences as we go," says Dr. Iannello. "In the end, we're making batteries that don't propagate failures, but still remain energy dense – batteries that retain the high energy density benefit of Li-ion, but are safer."



EMU batteries are composed of numerous, individual Li-ion cells, packaged in a brick fashion (inset).



Early "picket fence" model to investigate propagation of heat due to thermal runaway of a trigger cell (far left).

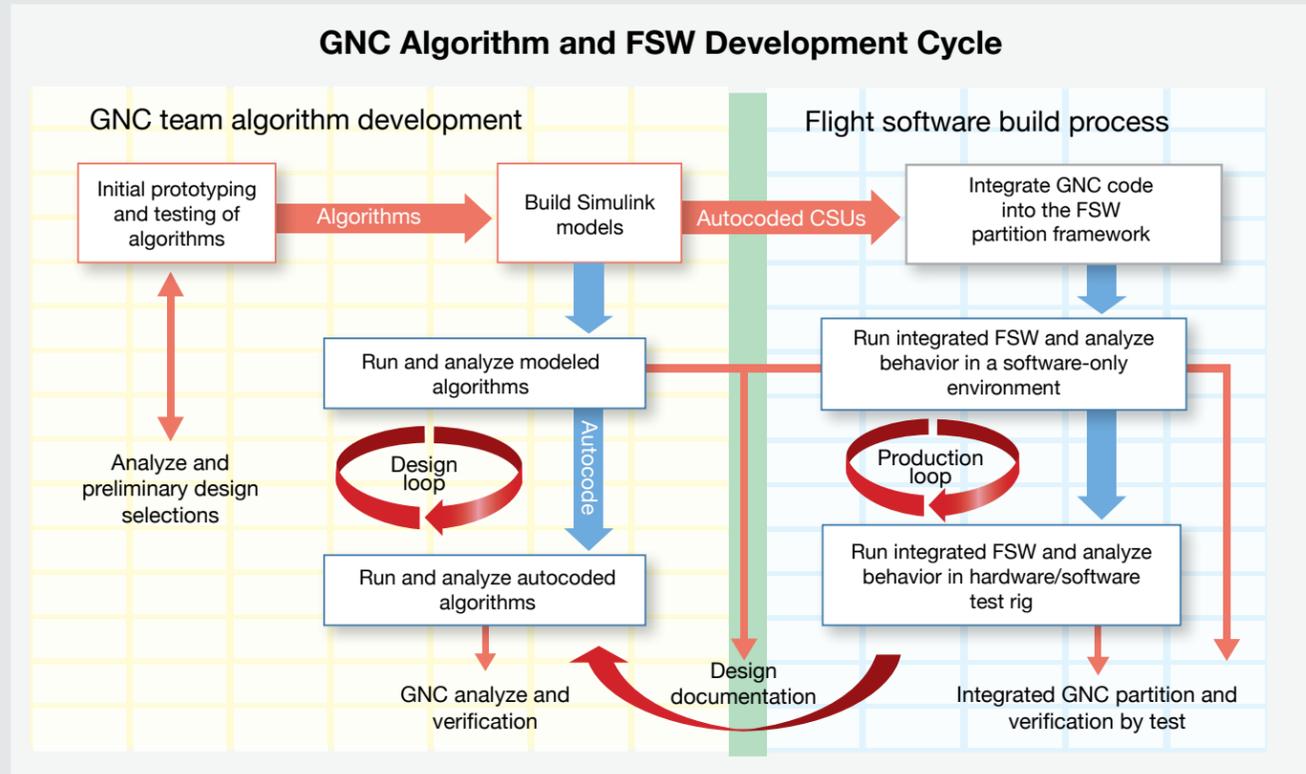


#### EVA Batteries

**Long-life battery:** primary power for EMU life support, communications and data.

Li-ion pistol grip tool

**Li-ion rechargeable EVA battery:** Glove heaters, lights, camera, etc.



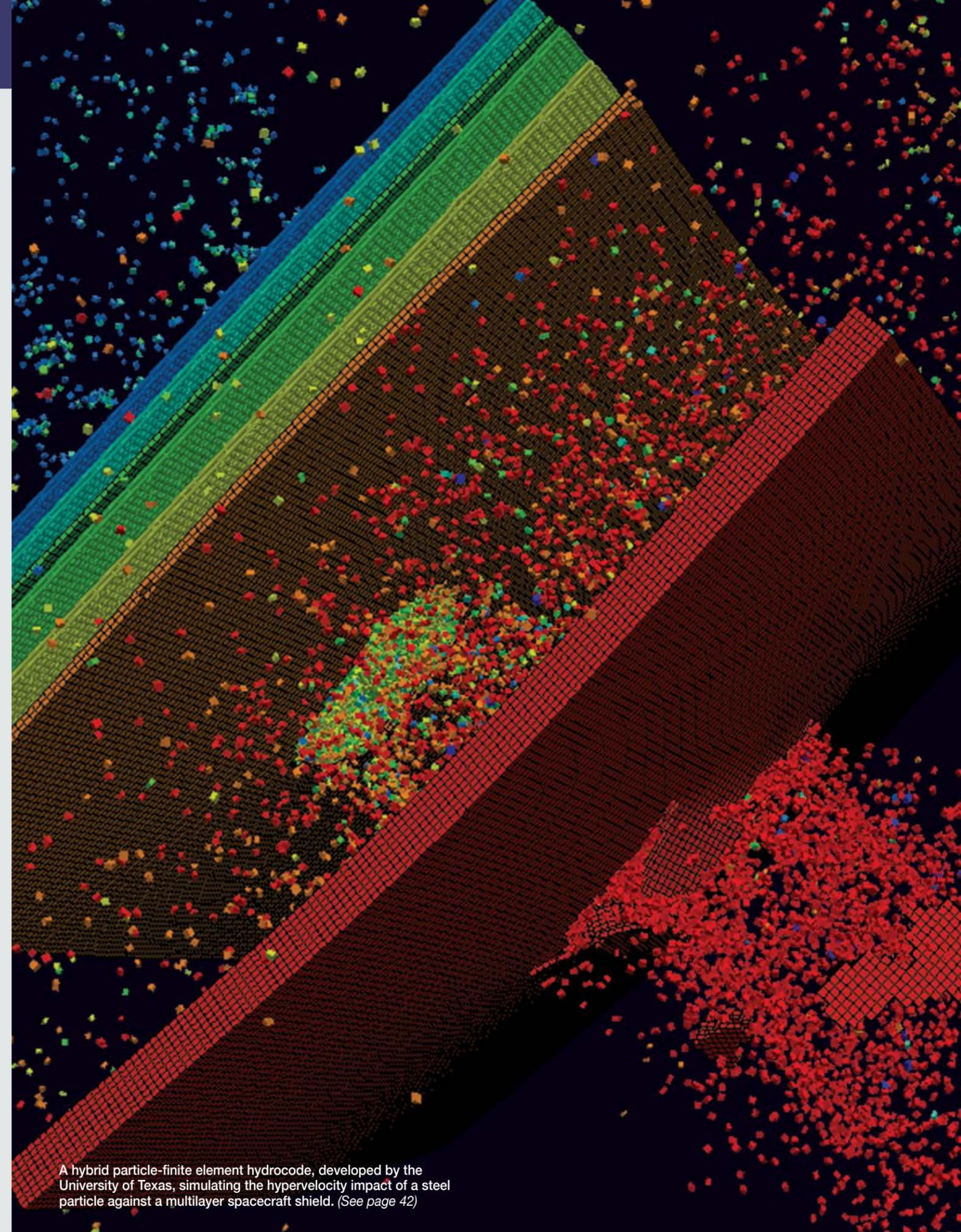
## Applying Model-Based Development to Flight Software

### Implementing autocoded GNC algorithms

The Orion Multi-Purpose Crew Exploration Vehicle (MPCV) Guidance, Navigation, and Control (GNC) design and analysis team is developing the onboard GNC flight software (FSW) algorithms using the Matlab/Simulink tool suite as a model-based approach to FSW development. This approach uses the Matlab/Simulink tool suite for developing the architecture, design, and modeling the GNC executive and its algorithmic computer software unit components. The methods supported unit-level and closed-loop testing simulation, test environments, and the test and verification of the auto-generated code products.

Past GNC flight software development processes on NASA's human-rated spacecraft have been more traditional in nature, whereby the GNC design and analysis team is chartered to develop and validate subsystem level requirements and document the lower-level functional subsystem software requirements (FSSR) in a form of pseudocode within that

documentation. In this paradigm, the GNC team is "hands-off" of the actual flight software implementation. The FSSR documentation is delivered by the GNC design team to the FSW team for implementation, and it then becomes the GNC team's task to interpret the written word and manually translate it into handwritten executable code, which becomes the onboard FSW. The Space Shuttle GNC FSW followed this development process. For the International Space Station (ISS), the development process increased the amount of autogenerated code (known as autocode). The ISS GNC FSW was a mix of handwritten code and from the graphical-based tool MATRIXx. The current Orion MPCV GNC FSW development process intends to use the Matlab/Simulink modeling tools to auto-generate 100% of the GNC algorithmic FSW as C++ code. This approach will involve the GNC design and analysis team working side-by-side with the FSW team in the production of the software artifacts that will lead directly to the onboard flight code.



A hybrid particle-finite element hydrocode, developed by the University of Texas, simulating the hypervelocity impact of a steel particle against a multilayer spacecraft shield. (See page 42)



Left to right, Tim Wilson (NESC Director/presenter); Bohdan Bejmuk (Independent Consultant); Christopher Kostyk (AFRC); Richard Schwartz (AMA); Pamela Sparks (AMA); Michael Kirsch (NESC Deputy Director/presenter); Damon Stambolian (KSC); Carlie Zumwalt (LaRC); Teresa Derby (AMA); Jeremy Shidner (AMA); Regor Saulsberry (WSTF); Sotiris Kellas (LaRC); Richard Russell (KSC); Robert Christie (GRC); Erik Takacs (Textron Systems); Ralph Lucero (MEI Technologies); Erik Merilo (SRI International); James Womack (Aerospace Corp.); Stephen Alter (LaRC); Brian Rochon (JSC); Michael Madden (LaRC); Gregory Brauckmann (LaRC); Brandon Robertson (JSC); Craig Streett (LaRC); Joel Sills (JSC); Pat Forrester (NESC Chief Astronaut/presenter). **Not pictured:** Alfreda Hampton (ManTech International Corp.); Anna Jackson (Valador, Inc.); Dax Rios (WSTF); and Steven Tack (Navy DoD).

## NESC Directors Award

### Brian V. Rochon

In recognition of the tenacity and personal accountability demonstrated in the defense of his alternate opinion on the Orion Ascent Abort two test flight content reduction

## NESC Leadership Award

### Gregory J. Brauckmann

In recognition of outstanding technical leadership of the NASA Engineering and Safety Center Booster Interface Loads Team charged with predicting and reducing aerodynamic buffet environments on the Space Launch System

### Ralph E. Lucero

In recognition of outstanding technical leadership in the field of Nondestructive Evaluation for the NASA Engineering and Safety Center Composite Overwrapped Pressure Vessel Liner Inspection Capability Development and Assessment

### Dax Luis Rios

In recognition of outstanding technical leadership of NASA Engineering and Safety Center frangible joint testing

### Regor L. Saulsberry

In recognition of outstanding technical leadership in the field of Nondestructive Evaluation for the NASA Engineering and Safety Center Composite Overwrapped Pressure Vessel Liner Inspection Capability Development and Assessment

### Richard J. Schwartz

In recognition of outstanding leadership in planning and executing mission control coordination during the Exploration Flight Test-1 NASA Engineering and Safety Center remote thermal imaging campaign

### Jeremy D. Shidner

In recognition of technical leadership and outstanding contributions to the NASA Engineering and Safety Center Exploration Systems Independent Modeling and Simulation Assessment

### Joel W. Sills

In recognition of outstanding technical and management leadership key to the successful completion of the NASA Engineering and Safety Center Space Launch System and Orion Modal Test, Development Flight Instrumentation, and Dynamic Model Correlation Plan Peer Review

### Steven J. Tack

In recognition of outstanding leadership in planning, rehearsing and acquiring NASA Engineering and Safety Center thermal imaging data of the Orion spacecraft during the entry phase of Exploration Flight Test-1

## NESC Engineering Excellence Award

### Robert J. Christie

In recognition of engineering excellence in the development and correlation of NASA Engineering and Safety Center thermal mathematical models to improve the understanding of the thermal runaway phenomena in lithium-ion batteries

### Sotiris Kellas

In recognition of engineering excellence leading to advancements in testing and analysis of Orion heatshield Avcoat material in support of the NASA Engineering and Safety Center Avcoat Team

### Christopher P. Kostyk

In recognition of engineering excellence for a state-of-the-art instrumentation suite for the NASA Engineering and Safety Center Frangible Joint Assessment Data Team

### Erik G. Merilo

In recognition of engineering excellence for innovative analysis of Frangible Joint behavior giving NASA outstanding new evaluation tools

### Craig L. Streett

In recognition of engineering excellence for computational fluid dynamics support to the NASA Engineering and Safety Center critical to mitigating aircraft damage risk during NASA Vehicle Integrated Propulsion Research III testing

### Erik J. Takacs

In recognition of engineering excellence in support of the NASA Engineering and Safety Center during the assessment of anomalies experienced during the processing of the Orion Exploration Flight Test-1 heatshield

### James M. Womack

In recognition of engineering excellence for statistical analysis support to the NASA Engineering and Safety Center Orion Avcoat Team leading to the identification of causes of critical issues experienced during Exploration Flight Test-1 heatshield production

## NESC Administrative Excellence Award

### Teresa B. Derby

In recognition of over 10 years of dedicated, sustained, and superior contributions to the success of the NASA Engineering and Safety Center (NESC) assessment teams and the NESC mission

### Alfreda D. Hampton

In recognition of administrative excellence in supporting the NASA Engineering and Safety Center

### Anna H. Jackson

In recognition of outstanding executive resources support to the NASA Engineering and Safety Center

### Pamela A. Sparks

In recognition of over 10 years of dedicated, sustained, and superior contributions to the success of NASA Engineering and Safety Center (NESC) assessment teams and the NESC mission

## NESC Group Achievement Award

### Composite Overwrapped Pressure Vessel Liner Inspection Capability Development and Assessment Nondestructive Evaluation Team

In recognition of outstanding contributions in the field of Nondestructive Evaluation for the NASA Engineering and Safety Center Composite Overwrapped Pressure Vessel Liner Inspection Capability Development and Assessment

### Exploration Flight Test-1 Remote Imagery Team

In recognition of conceiving, planning, acquiring and processing unprecedented NASA Engineering and Safety Center quantitative thermal imaging data on the Orion spacecraft during Exploration Flight Test-1 hypersonic entry

### Exploration Systems Development Integrated Hazard Development Process Assessment Team

In recognition of innovative NASA Engineering and Safety Center recommendations for improving the Exploration Systems Development integrated hazard identification and mitigation process

### Ground Operations Human Factors Task Analysis Team

In recognition of successful demonstration of a robust NASA Engineering and Safety Center task design and analysis methodology for Exploration Systems ground operations

### Independent Modeling and Simulation for Commercial Crew Program Entry, Descent, and Landing

In recognition of the development and continuous improvement of NASA Engineering and Safety Center entry, descent, and landing 3- and 6-degree-of-freedom simulation capability for commercial crew vehicles and the conduct of independent entry, descent, and landing analyses

### Multi-Purpose Crew Vehicle Avcoat Testing and Analysis Support Team

In recognition of exceptional support to the NASA Engineering and Safety Center Orion Avcoat Team leading to identification of causes of critical Avcoat issues experienced during production of the Exploration Flight Test-1 heatshield

### NASA Standard for Fracture Control 5019A Team

In recognition of outstanding diligence and dedication to the NASA Engineering and Safety Center team demonstrated in the revision of NASA Standard 5019 "Fracture Control Requirements for Spaceflight Hardware"

### NASA Standard 5017A Team

In recognition of outstanding work performed by the NASA Engineering and Safety Center team charged with revising NASA Standard 5017A "Design and Development Requirements for Mechanisms"

### Space Launch System Booster Interface Loads Assessment Team

In recognition of compelling advancement of the state-of-the-art in launch vehicle buffet and aeroacoustic environment prediction, evaluation, and reduction

### Standard Check-Cases for Six-Degree-of-Freedom Flight Vehicle Simulations Assessment Team

In recognition of the development of standard check cases to significantly improve the ability to verify flight simulation tools and reduce risk for numerous NASA and industry flight projects



**Timmy R. Wilson**  
Director



**Michael T. Kirsch**  
Deputy Director



**Michael P. Blythe**  
Deputy Director for Safety



**Jill L. Prince**  
Manager,  
NESC Integration  
Office



**Patrick G. Forrester**  
Chief Astronaut



**Dr. Daniel Winterhalter**  
Chief Scientist



**Patrick A. Martin**  
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Safety (2003-04)

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

Kenneth D. Cameron  
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NESC Chief Engineer at  
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Derrick J. Cheston  
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(2005-08)

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Stennis Space Center  
(2007-08)

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Technical Support Office  
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NESC Chief Engineer at  
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Julie A. Kramer White  
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(2003-06)

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

**Nans Kunz**, NESC Chief Engineer at Ames Research Center, passed away in February 2016. As a valued member of our team, he made numerous significant contributions to the NESC, Ames Research Center, and NASA. He was extremely proud of his contributions to the Stratospheric Observatory for Infrared Astronomy (SOFIA) Project, which he was involved in for over 20 years. Our colleague and friend will be greatly missed.



## NESC Principal Engineers



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**Dr. Nancy J. Currie-Gregg**



**Dr. Michael G. Gilbert**



**Michael D. Squire**

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**Dr. Thomas M. Brown**  
Propulsion



**Cornelius J. Dennehy**  
GNC



**Dr. Michael J. Dube**  
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**Oscar Gonzalez**  
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**Jon B. Holladay**  
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**Dr. Christopher J. Iannello**  
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**Dr. Curtis E. Larsen**  
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**Dr. Joseph I. Minow**  
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Environments



**Daniel G. Murri**  
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Mechanics



**Dr. Cynthia H. Null**  
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Factors



**Dr. Robert S. Piascik**  
Materials



**Dr. William H. Prosser**  
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See [nesc.nasa.gov](http://nesc.nasa.gov) for full bios

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

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### Loads and Dynamics

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2. Irvine, T.: Using a Random Vibration Test Specification to Cover a Shock Requirement via a Pseudo Velocity Fatigue Damage Spectrum, 3rd International Conference on Material and Component Performance under Variable Amplitude Loading, VAL2015, Procedia Engineering, Vol. 101, pp. 211-218.
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### Mechanical Systems

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1. Brust, F. W.; Punch, E. F.; and Kurth-Twombly, E.: Weld Residual Stress (WRS) Modeling of Layered Pressure Vessels (LPV) and Fracture Assessment, ASME 2015 Pressure Vessels & Piping Division Conference, July 19-23, 2015, Boston, MA, PVP2015-45784.
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3. Koshti, Ajay M.: Ultrasonic Measurement and Monitoring of Loads in Bolts Used in Structural Joints, SPIE Smart Structures/NDE Conference, March 8-12, 2015, San Diego, CA.
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2. Ku, J. and Robinson, F.: Testing of a Helium Loop Heat Pipe for Large Area Cryocooling, 2015 NASA Thermal Fluid Analysis Workshop, August 3-7, 2015, Silver Spring, MD.

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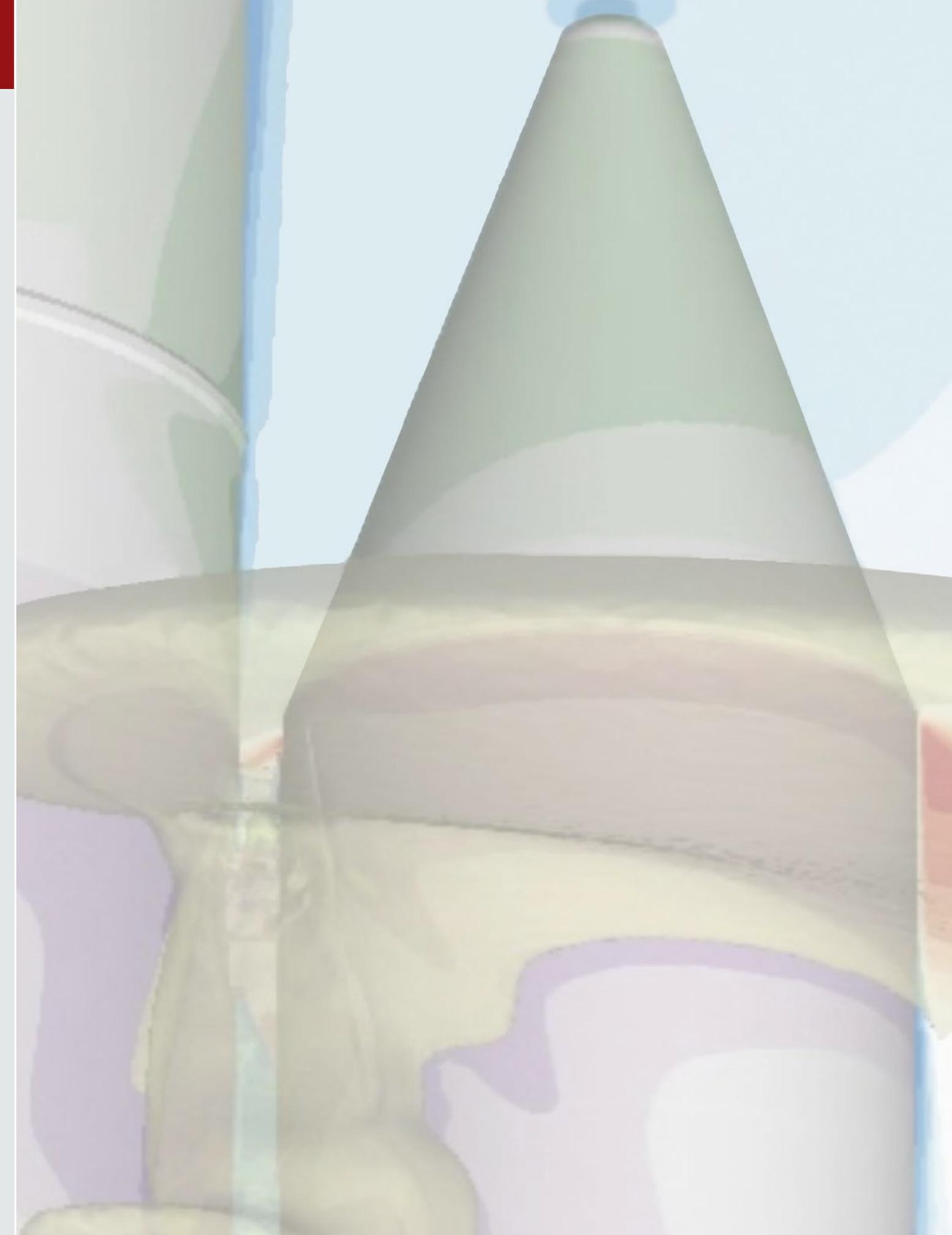
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3. Dennehy, C. J.: Guidance, Navigation & Control (GNC) Lessons Learned from Spacecraft Relative Motion Missions, European Control Conference 2015, July 15-17, 2015, Linz, Austria.
4. Gilbert, M. G.: The Max Launch Abort System - Concept, Flight Test, and Evolution, 7th IAASS Conference, October 20-22, 2014, Friedrichshafen, Germany.
5. Greenbaum, A.; Brady, T.; Dennehy, C. J.; Airey, S. P.; Roelke, E.; and Judd, S. B.: Understanding International GNC Hardware Trends, 2015 IEEE Aerospace Conference, March 7-13, 2015, Big Sky, MT.
6. Karpenko, M.; Ross, M.; Stoneking, E. T.; Lebsack, K.; and Dennehy, C. J.: A Micro-Slew Concept for Precision Pointing of the Kepler Spacecraft, 2015 AAS/AIAA Astrodynamics Specialist Conference, August 9-13, 2015, Vail, CO.
7. Kolaini, Ali, Moderator, and Larsen, Curtis E., Panelist: Panel Discussion: Extreme Peak, Spacecraft and Launch Vehicle Dynamic Environments Workshop, June 2-4, 2015, El Segundo, CA.
8. Larsen, C. E.: A Perspective on Loads and Dynamics in NASA Programs and Engineering, Spacecraft and Launch Vehicle Dynamic Environments Workshop, June 2-4, 2015, El Segundo, CA.
9. Larsen, C. E.: 86th Shock and Vibration Symposium NASA Status and Perspectives, 86th Shock and Vibration Symposium, October 5-8, 2015, Orlando, FL.
10. Larsen, C. E. and Irvine, T.: A Review of Spectral Methods for Variable Amplitude Fatigue Prediction and New Results, 3rd International Conference on Material and Component Performance under Variable Amplitude Loading (VAL 2015), Procedia Engineering, Vol. 101, pp. 243-250.
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14. Mendenhall, M. R.; Lesieutre, D. J.; and Kelly, M. J.: Trailing Vortex-Induced Loads During Close Encounters in Cruise, AIAA Aviation 2015, June 22-26, 2015, Dallas, TX.
15. Minow, J. I.: Chandra Space Weather Vulnerabilities and Needs Update, 7th Space Weather & NASA Robotic Mission Ops Workshop, September 29-30, 2015, GSFC, Greenbelt, MD.

16. Minow, J. I.: DMSP and ISS Auroral Charging Events, March 17-18, 2013, GEM-CEDAR Storm, GEM Mini-Workshop, December 13, 2015, San Francisco, CA.
17. Minow, J. I. and Willis, E. M.: Ionospheric Drivers of ISS Charging, Abstract SA41C-02, AGU 2015 Fall Meeting, December 14-18, 2015, San Francisco, CA.
18. Null, C. H.: Designing for Human Reliability: Human Factors at NASA, 4th Human Dependability Workshop (HUDEP) 2015, October 6-7, 2015, Darmstadt, Germany.
19. Prosser, W. H.: NASA Experiences in Structural Health Monitoring, Deep Space Deep Ocean, April 7-8, 2015, Houston, TX.
20. Prosser, W. H.: The NASA Engineering and Safety Center Nondestructive Evaluation Technical Discipline Team, 14th International Symposium on Nondestructive Characterization of Materials, June 22-26, 2015, Marina Del Rey, CA.
21. Raju, I. S.: Structures, Failures, and Lessons, Invited Lecture at Vidya Jyothi Institute of Technology and Anurag College of Engineering, February 6-9, 2015, Hyderabad, India.
22. Raju, I. S.: Observed Trends in Finite Element Structural and Damage Tolerance Analyses, NAVAIR Presentation at Pax River, October 27, 2015, Patuxent, MD.
23. Raju, I. S.; Knight, N. F.; and Shivakumar, K. N.: Some Observations On The Current Status of Performing Finite Element Analyses, SCITECH 2015, January 5-9, 2015, Kissimmee, FL.
24. Raju, I. S. and Knight, N. F.: Observations and Comments on the Current Status of Practice of Finite Element Analyses, NAFEMS Seminar on Engineering Analysis & Simulation in the Aerospace Industry, October 6, 2015, Montreal, Canada.
25. Reiff, P.; Sazykin, S.; Bala, R.; Coffey, V.; Chandler, M. O.; Minow, J.; Anderson, B. J.; Wolf, R.; Huba, J.; Baker, D.; Mauk, B.; and Russell, C. T.: Investigating Storm-Time Magnetospheric Electrodynamics: Multi-Spacecraft Observations of the June 22, 2015, Magnetic Storm, Abstract SM41C-2498, 2015 AGU Fall Meeting, December 14-18, 2015, San Francisco, CA.
26. Rickman, S. L.: Form Factors, Grey Bodies and Radiation Conductances (Radks), Thermal and Fluids Analysis Workshop (TFAWS) 2015, August 3-7, 2015, Silver Spring, MD.
27. Rickman, S. L.: Overview of the NASA Engineering and Safety Center (NESC), Thermal and Fluids Analysis Workshop (TFAWS) 2015, August 3-7, 2015, Silver Spring, MD.
28. Rickman, S. L.: Status of NESC Wire Thermal Analysis, Science and Technology Electrical Systems and Wiring Inter-Agency Meeting, December 9, 2015, Houston, TX.
29. Sazykin, S.; Coffey, V.; Reiff, P.; Chandler, M. O.; Minow, J.; Huba, J.; Anderson, B.; Wolf, R.: Magnetosphere-Ionosphere Coupling during the June 22-24, 2015, Magnetic Storm, Abstract SA44A-07, 2015 AGU Fall Meeting, December 14-18, 2015, San Francisco, CA.
30. Schuster, D. M.: MAX Launch Abort System Flight Test, Seminar at the University of Cincinnati, October 31, 2014, Cincinnati, OH.
31. Schuster, D. M.: Recent Progress in Prediction of Buffet and Aeroacoustic Environments at NASA, International Forum on Aeroelasticity and Structural Dynamics, June 30, 2015, Saint Petersburg, Russia.

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1. A Comprehensive Analysis of the X-15 Flight 3-65 Accident  
**NASA/TM-2014-218538**
2. NASA Workshop on Hybrid (Mixed-Actuator) Spacecraft Attitude Control  
**NASA/TM-2014-218539**
3. Maximum Expected Wall Heat Flux and Maximum Pressure after Sudden Loss of Vacuum Insulation on the Stratospheric Observatory for Infrared Astronomy (SOFIA) Liquid Helium (LHe) Dewars  
**NASA/TM-2014-218540**
4. James Webb Space Telescope's (JWST) Near-Infrared Spectrograph (NIRSpec) Micro Shutter Subsystem (MSS) Alternate Materials and Coatings  
**NASA/TM-2014-218541/Volume I**
5. James Webb Space Telescope's (JWST) Near-Infrared Spectrograph (NIRSpec) Micro Shutter Subsystem (MSS) Alternate Materials and Coatings Appendices  
**NASA/TM-2014-218541/Volume II**
6. International Space Station (ISS) External Thermal Control System (ETCS) Loop A Pump Module (PM) Jettison Options Assessment  
**NASA/TM-2014-218542**
7. Alternative Software Programming for Human Spaceflight  
**NASA/TM-2014-218546**
8. NASA Engineering and Safety Center (NESC) Independent Review and Support of the International Space Station (ISS) Extravehicular Activity (EVA) Water Anomaly and EVA Recovery Team (ERT) Failure Investigation  
**NASA/TM-2014-218547**
9. The Growth of Small Corrosion Fatigue Cracks in Alloy 7075  
**NASA/TM-2015-218672**
10. Spin Forming Aluminum Crew Module (CM) Metallic Aft Pressure Vessel Bulkhead (APVBH) - Phase II  
**NASA/TP-2015-218674**
11. Check-Cases for Verification of 6-Degree-of-Freedom Flight Vehicle Simulations  
**NASA/TM-2015-218675/Volume I**
12. Check-Cases for Verification of 6-Degree-of-Freedom Flight Vehicle Simulations Appendices  
**NASA/TM-2015-218675/Volume II**
13. Review of Exploration Systems Development (ESD) Integrated Hazard Development Process  
**NASA/TM-2015-218676/Volume I**
14. Review of Exploration Systems Development (ESD) Integrated Hazard Development Process Appendices  
**NASA/TM-2015-218676/Volume II**
15. Multi-Purpose Crew Vehicle (MPCV) Alternate Heatshield Carrier Structure  
**NASA/TM-2015-218683/Volume I**
16. Multi-Purpose Crew Vehicle (MPCV) Alternate Heatshield Carrier Structure Appendices  
**NASA/TM-2015-218683/Volume II**
17. Payload Performance Analysis for a Reusable Two-Stage-to-Orbit  
**SA/TM-2015-218760**
18. Advancing the State-of-the-Practice for Liquid Rocket Engine (LRE) Combustion Stability Assessment  
**NASA/TM-2015-218771/Volume I**
19. Advancing the State-of-the-Practice for Liquid Rocket Engine (LRE) Combustion Stability Assessment Appendices  
**NASA/TM-2015-218771/Volume II**
20. Joint Polar Satellite System (JPSS) Micrometeoroid and Orbital Debris (MMOD) Assessment  
**NASA/TM-2015-218780**
21. Empirical Model Development for Predicting Shock Response on Composite Materials Subjected to Pyroshock Loading  
**NASA/TM-2015-218781/Volume I**
22. Empirical Model Development for Predicting Shock Response on Composite Materials Subjected to Pyroshock Loading Appendices  
**NASA/TM-2015-218781/Volume II/Part 1**
23. Empirical Model Development for Predicting Shock Response on Composite Materials Subjected to Pyroshock Loading Appendices  
**NASA/TM-2015-218781/Volume II/Part 2**
24. Empirical Model Development for Predicting Shock Response on Composite Materials Subjected to Pyroshock Loading Appendices  
**NASA/TM-2015-218781/Volume II/Part 3**
25. Glenn Extreme Environments Rig (GEER) Independent Review  
**NASA/TM-2015-218809**
26. Simplified Methodology to Estimate the Maximum Liquid Helium (LHe) Cryostat Pressure from a Vacuum Jacket Failure  
**NASA/TM-2015-218810**
27. International Space Station (ISS) Anomalies Trending Study  
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28. International Space Station (ISS) Anomalies Trending Study Appendices  
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