NASA Engineering & Safety Center

TECHNICAL UPDATE

Annual Report of NESC Technical Activities

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ON THE COVER

The 20 images represent disciplines led by NASA Technical Fellows.

Disciplines listed in chart on page 3.

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NESC Members
May 2023

Except where noted, all photographs and illustrations are NASA images.

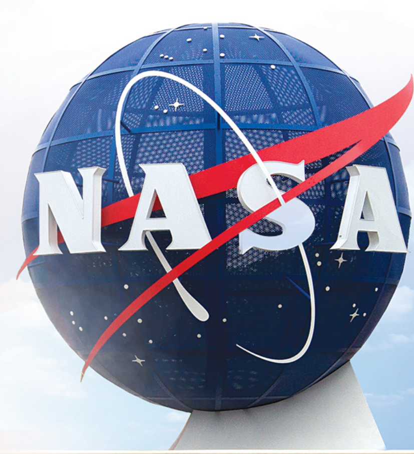
Messages from NASA Leadership

"NASA had another amazing and inspiring year in 2023. With the launch of new satellites, the development of new technologies, and the important science being performed daily by our employees, NASA is giving the world access to data about our planet and the universe that is unparalleled. The selection of our astronauts for the next Artemis mission brings us another step closer to returning to the Moon, but there's still much for us to do. We are gathering data from Artemis I to ensure that when we fly crew on Artemis II, we do it in the safest way possible. Of all the challenging things the Agency does, the most important is taking care of our people. When we launch missions and humans to space, we make countless, critical decisions to ensure the safety of our crews and the success of our missions. The work the NESC has done over the last 20 years has helped us make those tough decisions and remain vigilant in understanding the risks inherent to spaceflight and doing our best to ensure mission success and the safe return of our crews. The hundreds of assessment teams the NESC has assembled in the last two decades have addressed NASA's most demanding technical questions and concerns, leaving lasting impacts on NASA's safety culture, and aiding the Agency in protecting its most important asset—our amazing workforce."

Robert D. Cabana, NASA Associate Administrator

"In my 22 years at NASA and 35-plus years in the industry, I've had immeasurable opportunities to witness and be a part of the amazing work this Agency does. And when I stepped into the role of NASA Chief Engineer earlier this year, I took the time to reflect on the countless people I've had the good fortune to meet and the many programs and missions I've been lucky enough to take part in and see through to their successful culminations. Along this incredible journey, I served as both an NESC Chief Engineer and NASA Technical Fellow and saw firsthand how this organization has helped transform NASA's safety culture, foster open communications, and create a One-NASA mindset. I came to appreciate the vast extent and depth of skills at every center that come together to resolve the many challenges of spaceflight. It's why, after 20 years, the NESC is still going strong, fielding requests, and giving programs unique perspectives and solutions to their technical questions. Their recent work with the Commercial Crew Program, Artemis I post-flight assessments, support of robotic missions, and efforts to aid our Moon-to-Mars exploration activities have been important to the success NASA has achieved in this new Artemis era. As I oversee the Agency's portfolio of engineering work, I will rely on the NESC for the insight and technical excellence they bring to the table and, more importantly, their ability to delve into a problem, find the potential risks that are such a fundamental part of space travel, and help put us on a path to mitigating them."

Joseph W. Pellicciotti, NASA Chief Engineer



NASA ENGINEERING & SAFETY CENTER

Independence & Objectivity

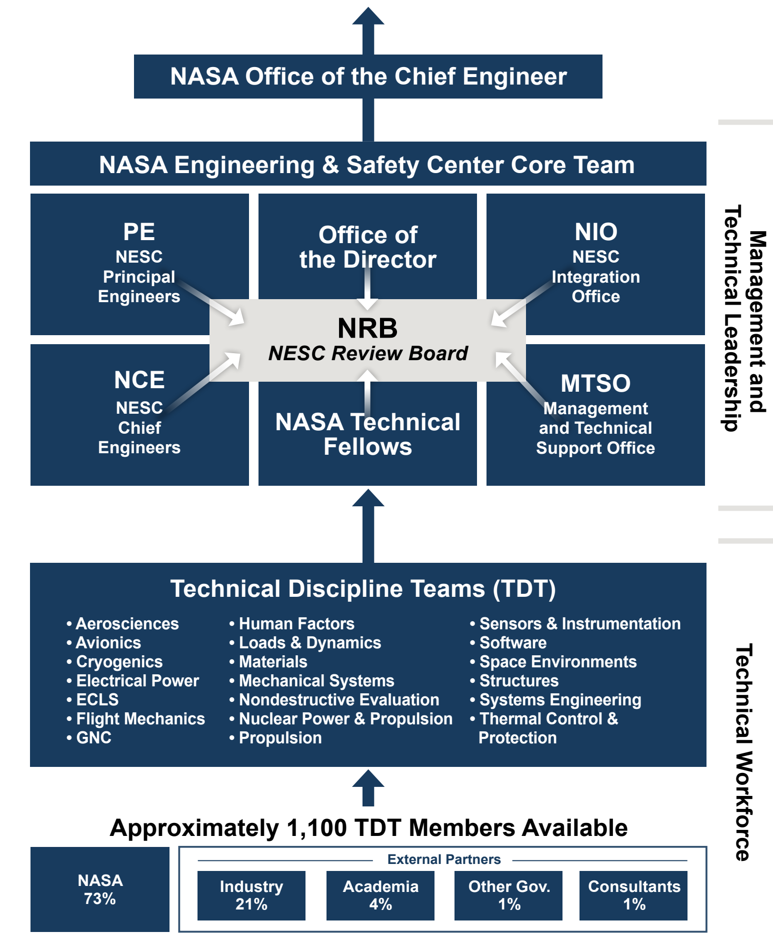
The NESC performs technical assessments and provides recommendations based on independent testing and analysis. Funding and reporting independent of NASA's programs and projects ensures objective technical results for NASA.

Engineering Excellence

The NESC draws on the knowledge base of technical experts from within NASA, industry, academia, and other government agencies. Collaborating with leading engineers allows the NESC to consistently optimize processes, strengthen technical capabilities, and broaden perspectives. This practice further reinforces the NESC's commitment to engineering excellence.

A Unique Resource

The NESC is an Agency-wide resource that provides a forum for reporting technical issues and contributing alternative viewpoints to resolve NASA's highest-risk challenges. Multidisciplinary teams of ready experts provide distinctively unbiased technical assessments to enable more informed decisions.

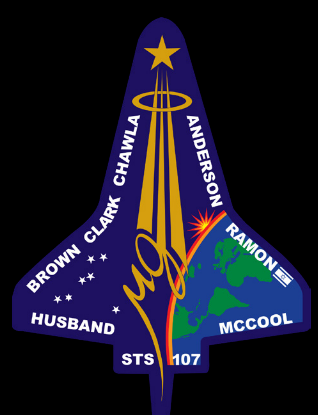


The NESC's mission is to perform value-added independent testing, analysis, and assessments of NASA's high-risk projects to ensure safety and mission success. The NESC also engages proactively to help NASA avoid future problems.

Reflecting on 20 Years

NASA emerged from the shadow of the Columbia accident with a new organization, the NESC, to help create safer and more resilient missions by using the talent and resources of the nation's engineering community.

2023



"Having friends and colleagues who were on the crews of both Challenger and Columbia certainly focuses you—that you need to do everything you can do to make sure spaceflight is as safe as it can be. Everyone who went through those experiences is changed in some way, and our whole organization was created to help prevent these things from ever happening again."

- Ralph R. Roe, Jr.
Former NESC Director (2003-14)

In 2003, the Columbia Accident Investigation Board specified a need for a technically strong, program-independent resource to provide an alternative perspective on difficult technical issues and provide independent technical investigations for NASA programs and projects. In response, the NASA Engineering & Safety Center (NESC) was created. Twenty years later, the NESC continues its mission. The NESC also engages proactively to help NASA avoid future problems.

The Next Accident: How Do We Prevent It?

By Andrew Chaikin, Independent Space Historian and member of the NESC Human Factors Technical Discipline Team

I recently watched NESC Deputy Director Mike Kirsch stand before a roomful of engineers at the Langley Research Center and tell them that with every passing day, NASA breaks a record: the longest stretch without a major accident in the nation's human spaceflight program since the Space Shuttle Columbia disintegrated during reentry on February 1, 2003. NASA's challenge, he told them, was to make sure the record keeps being broken.

Mike's sobering message set the perfect tone for my presentation of "Principles of Success in Spaceflight," the class I created with Victoria Kohl on the human behavior elements of success and failure in spaceflight projects. With the NESC's support, I have given it at every NASA center, and it's always a rewarding experience. You can't spend the day with a group of NASA engineers and not experience their keen intelligence, passion, and commitment to excellence. As I lead them through case studies of the Apollo 1 fire in 1967, the Challenger accident in 1986, and Columbia, I tell them that no matter how good we are at the "rocket science," we invite failure if we don't pay attention to the attitudes, beliefs, and assumptions we bring to the work—in short, our mindset.

Before the Apollo fire, there was a widespread belief that because Mercury and Gemini had used pure oxygen with no fires, there wouldn't be any in Apollo. And the Apollo spacecraft program manager missed opportunities to prevent the accident due to his belief that the fire hazard created by combining pure oxygen with exposed wiring and flammable materials was not a "real" problem, one that warranted slowing the train barreling down the tracks to meet John F. Kennedy's end-of-the-decade deadline for a lunar landing.

When I talk about the Challenger accident, I caution that it's essential to pay attention to the stories we tell ourselves. NASA had promised itself and Congress that the Shuttle would make spaceflight routine and affordable, a goal that required unrealistically high flight rates. Mounting schedule pressure in the lead-up to Challenger skewed decision makers' perceptions of the SRB field joint anomalies that had occurred intermittently on previous launches and were not well understood. In the Columbia discussion, I recount the shocking swiftness with which NASA lost the lessons of Challenger and paved the way for another accident with renewed schedule pressure and a belief that external tank foam shedding was "not a safety of flight issue." Accidents jolt us into new awareness, but Columbia is a painful reminder that awareness has a shelf life.

What will it take to keep breaking the record that Mike spoke about? I believe we must talk to each other regularly about the behaviors that either invite success or lead us down the slippery slope to failure. Are we in the grip of what I call the "reality distortion field," created by cost, schedule, and/or political pressure, that clouds our perceptions of risk? Are we unconsciously indulging in hard-wired "us vs. them" tribal behaviors that cut us off from the diverse "spotlights of awareness" we must have to navigate the unforgiving demands of human spaceflight? Are we telling ourselves a story that, under clear-eyed scrutiny, doesn't hold up? These are the questions we need to ask ourselves again and again. The answers are critical.

A section of the fuselage recovered from Space Shuttle Challenger, left, and the flight deck windows recovered from Space Shuttle Columbia at the Kennedy Space Center Visitor Complex in Florida.

LOOKING BACK, MOVING FOWARD

Interview with NESC Director Tim Wilson

Upon reaching its 20th year of operations at NASA in 2023, the NESC is busier than it has ever been. With a portfolio of more than 160 in-progress requests from Agency programs, NESC Director Tim Wilson spends much of his day prioritizing, allocating funds from the organization's fixed budget to NASA's most pressing issues. Of late, the NESC has focused on priority-one requests—projects in the flight phase—such as the Artemis missions and those of NASA's commercial partners, while lower priority requests like discipline-advancing activities have been placed on hold until the next fiscal year. For Mr. Wilson, each day is a new shuffle of requests, funding, and resources.

When he joined the newly formed NESC in 2003, Mr. Wilson could not have predicted the impact the organization would have on Agency operations. "To be honest, I didn't really think we'd still be here," he said. "The NESC was an experiment." Initiated by the results of the Columbia accident investigation, the idea behind it was that NASA programs would benefit from expert, unbiased perspectives on its tough engineering problems. The vision for the organization was straightforward, but the execution was far more challenging than Mr. Wilson expected.

"When we started those first assessments with the CALIPSO satellite and Shuttle, we had to elbow our way to the table to be accepted. We were new, and no one knew who we were or what we were doing. Back then, programs were worried that we might slow them down or cause problems."

Though Agency leadership had given them the green light, it was up to Mr. Wilson and the NESC's early members to prove they deserved a seat at those tables. "You have to produce some results before folks respect you," he said. It was hard won, but with each assessment, the NESC gained that respect by bringing ideas and solutions programs could use.

Two decades in, Mr. Wilson is happy to say the NESC is now invited to the table. "That's part of why demand has grown as much as it has. Our team is respected, and we're asked to participate. We've gone from being an unknown to an organization they reach out to as a trusted partner: someone who can help them be successful, bring expertise or resources they don't have, or sometimes just bring another perspective to break a logjam and help them get things done. That's the shift I have seen over the years. It's been really encouraging to see it."

The NESC portfolio of work also has shifted from the early, hectic pace of Shuttle assessments where quick, real-time solutions were needed. In the years following the Shuttle's retirement, the NESC had the luxury of time to invest in longer-term projects like the design and construction of a composite crew module that would be leveraged in the development of Orion and commercial spacecraft. Today, the pace has ramped up again as Artemis, Dragon, and Starliner head to the Moon and ISS.

"These are real-time activities where you have to engage immediately and be able to add value out of the chute. You don't have time to come up to speed on the system," Mr. Wilson said. "We learned with Shuttle that it was important to move quickly and be pre-positioned to help."

"I have not seen very many Agency initiatives persist the way the NESC has, so I'm thrilled that we have met the needs that we were placed here to meet and that we continue to deliver value, because I think that's what has kept us rolling and growing over all of this time."

Over the years the NESC has cultivated good relationships with programs—keeping people plugged in to their day-to-day activities so that when problems arose, they could engage right away.

"The lesson we learned is you need people doing routine work for those programs all along so that they understand the subsystems and hardware and they're ready to engage when there's a real-time problem." It's been a balancing act to keep close ties yet remain independent, but Mr. Wilson said the NESC has found an equilibrium. Independent yet parallel modeling and simulation (M&S) is a good example of finding that balance, he said. "We build our own M&S tools in parallel with the programs' tools to give them a second set of eyes to a problem." Since 2012, for example, NESC-built M&S trajectory tools have help mitigate risks for Artemis missions' ascent to orbit, and entry, descent, and landing simulations for CCP provider vehicles.

With capped budgets, the NESC must adjust its scope continually to keep up with the increasing tempo of space exploration. For now, that means focusing on what is most critical and has the highest payback. "We'll continue to focus on the heavy hitters, the programs that are flying and have a critical immediate need. There are a lot of those, and the pace is ramping up."

As for the future, Mr. Wilson said, "I have not seen very many Agency initiatives persist the way the NESC has, so I'm thrilled that we have met the needs that we were placed here to meet and that we continue to deliver value, because I think that's what has kept us rolling and growing over all of this time."

Reflecting on 20 Years...

"Every day is a new record for this Agency. Every day, NASA sets a new record for number of days in space without a loss-of-crew accident. We are at 20 years and counting, every day. Formed after the tragic loss of the Space Shuttle Columbia, the NESC provides Agency programs and projects access to subject matter expertise that can weigh in on their toughest technical challenges. With a virtual rolodex of on-call experts from all NASA missions, centers, contractors, other government agencies including DoD and DoE, and academia, the NESC can provide ready access to experts and facilities in hours or days as opposed to months. This agile approach has been critical to providing results to over 1,200 technical assessments spanning the entire NASA mission portfolio. Our mission is to help our programs ensure we are flying as safely and robustly as we can and continue to build that record. I have had the fortune of being a part of this team since 2004. To participate in the evolution of the NESC supporting Space Shuttle return to flight, successfully enabling commercial access to low Earth orbit, NASA Artemis to return to the Moon, and first ever science and aeronautical achievements has been more rewarding than I could have ever imagined."

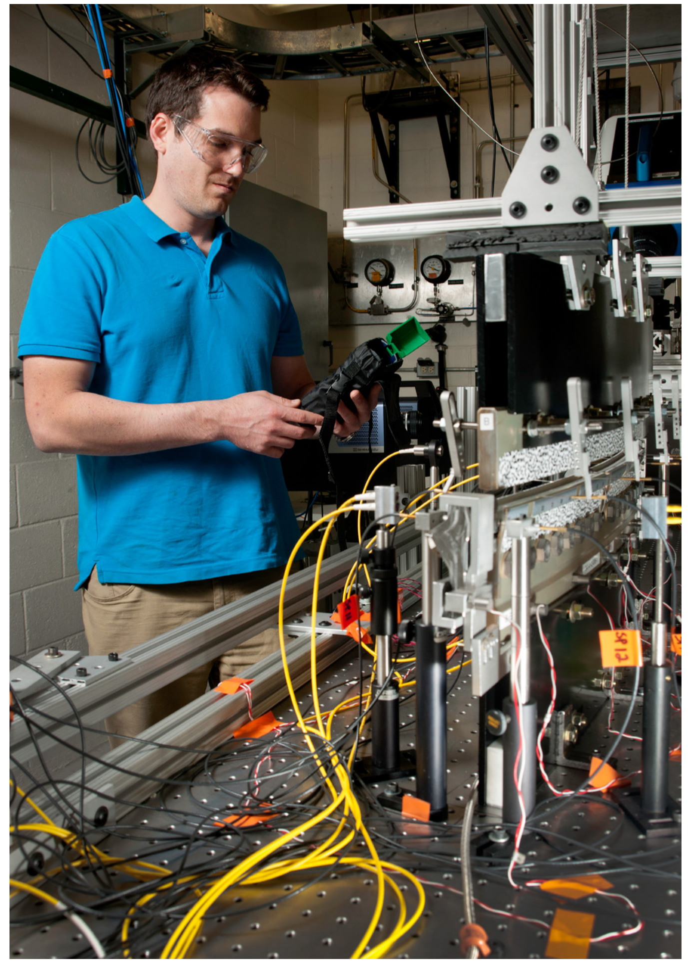
Michael T. Kirsch, NESC Deputy Director

"NASA's mission portfolio has reached unprecedented numbers with government and commercial human spaceflight endeavors, while at the same time scientific exploration of our universe flourishes and aeronautical advancements drive innovative solutions for the next generation of flight vehicles. As we continue to make these technological breakthroughs, engaging NASA's resources in the most effective manner to ensure safe and efficient aeronautical and space travel is paramount. What inspires me every day about working with the NESC is its unique ability to engage NASA's entire workforce to solve technical issues. The NESC can quickly respond through pre-established relationships with Agency and industry resources, to implement an agile approach to learn from our past while continuously growing from the complex challenges we face today and, most importantly, its commitment to grow the next generation."

Mary Elizabeth Wusk, NESC Integration Office Manager

MOST IMPACTFUL NESC ASSESSMENTS

After reflecting on the more than 1,200 assessments completed by the NESC over the last 20 years, Director Tim Wilson selected these assessments as his top three. They were selected because they would likely have the greatest and most lasting impact on human life and the furtherance of the NESC mission. He shared why their effects were so far-reaching.



2013-2019

Assessing Risks of Frangible Joint Designs

At the request of the Commercial Crew Program, the NESC took on an empirical test program of frangible joints (FJ) to provide confidence in their use for human spaceflight. "Many programs use these joints, so understanding the margins and what drives their designs has helped us keep flight crews safe and make missions successful," said Mr. Wilson.

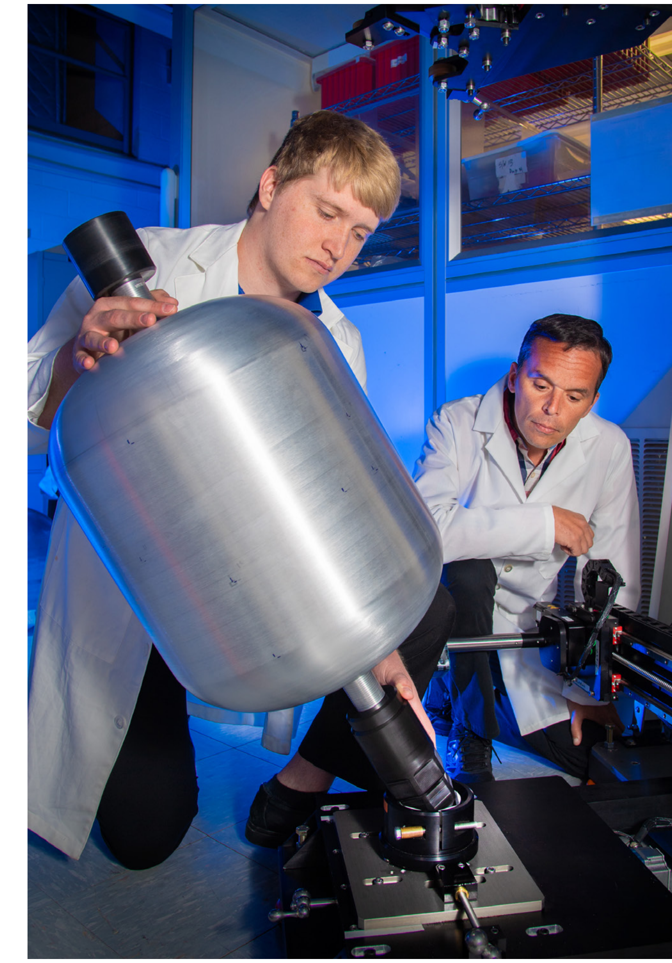
The joints provide a debris-free separation of launch vehicle stages and payload fairings. To determine the effects various design parameters and environmental factors have on jointseparation capability, the NESC conducted more than 140 tests on a variety of designs and generated more than 100 million lines of data that were used to anchor models, develop design sensitivities, and make reliability estimates. Their comprehensive work was foundational to later assessments for the Space Launch System, Orion, and Launch Services Programs. The NESC also started the FJ Working Group, which serves as the Agency's technical community of practice. It ensures programs understand the risks associated with their use and is proactive in ensuring NASA is implementing safe and reliable FJ technologies.

2018-2021

Pilot Breathing Assessment

When the U.S. Navy was experiencing an increase in pilot physiological episodes across their F/A-18 fleet that was leading to mission aborts, "No one really understood what was going on or why," said Mr. Wilson. "It was a difficult problem, and our NESC team was able to come up with compelling answers."

Over the NESC's three-year study, its Pilot Breathing Assessment (PBA) team designed novel instrumentation to measure pilot physiological states and interactions with aircraft life support systems. NASA test pilots flew instrumented NASA F/A-18 and F-15 aircraft through pre-specified flight profiles while wearing specialized breathing equipment augmented with an advanced sensor system. Aligned data streams identified pilot/aircraft interactions with the potential for negative cognitive and physiological impact. After more than 100 scripted flights and 250 million data points, the PBA team determined that breathing pressures and airflows were often mismatched, increasing a pilot's efforts to maintain sufficient ventilation. The PBA team's work has benefited the field of aviation and the advancement of human system integration in modern aircraft and has direct application for NASA vehicles such as the T-38, F-15, X-59, and the ISS.

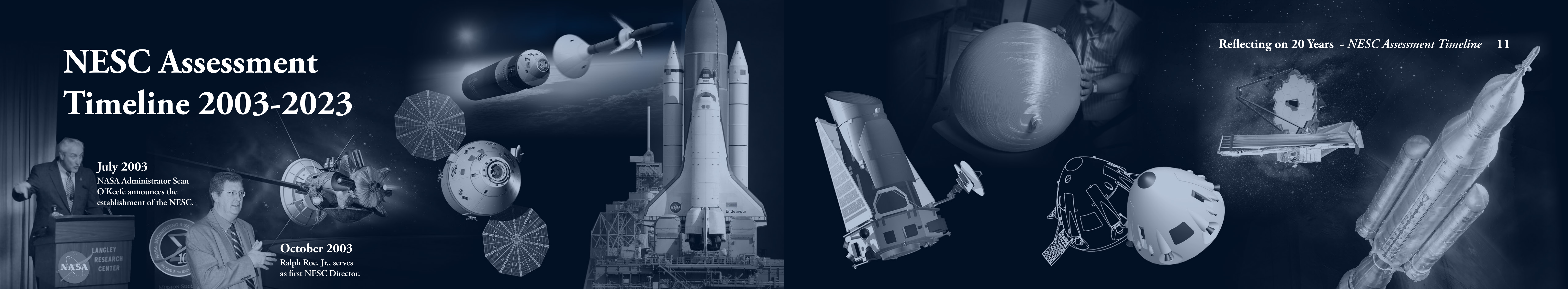


2020-2023

Unconservatism of LEFM Analysis Post Autofrettage

The NESC has invested significant time and resources to understanding the complex behavior of composite overwrapped pressure vessels (COPV), which are used extensively in spaceflight. Most recently, an NESC team found there was a lack of conservatism in the damage tolerance analyses conducted on COPV liners using linear-elastic fracture mechanics (LEFM), particularly in understanding the influence of autofrettage (AF).

During AF, a COPV is subjected to high pressures to compress the inner surfaces, making them less susceptible to operational stresses later. In verifying damage tolerance life, the team found that separating the AF cycle from subsequent elastic cycles in LEFM analysis led to unconservative life predictions. Cracks remained open during compressive cycles after AF and allowed for a larger stress range to contribute to crack growth in each subsequent elastic cycle. The team provided corrections to NASGRO (programs that analyze fracture and fatigue crack growth) to make predictions less unconservative. "I'm convinced that someday crew will fly, come home, disembark, and never know that it was the improvements to those analytical tools made by this NESC team that kept them safe. I think it's going to have wide-ranging impact."



NESC Assessment Timeline 2003-2023

July 2003
NASA Administrator Sean O'Keefe announces the establishment of the NESC.

October 2003
Ralph Roe, Jr., serves as first NESC Director.

2003-2007

July 2003
The NESC is Established
Shortly following the Columbia accident, NASA Administrator Sean O'Keefe announced plans to create the NESC to serve as an Agency-wide technical resource focused on engineering excellence to proactively help NASA avoid future problems.

November 2003
CALIPSO Proteus Propulsion Bus Design Concerns
Prior to launch of NASA's CALIPSO satellite, the hydrazine-fueled propulsion bus design was reviewed to assess the risk for propellant leakage and recommend measures to mitigate potential personnel exposure hazards during system fill and pressurization.

August 2004
Cassini/Huygens Entry, Descent, & Landing
EDL analysis for the Saturn exploration probe included a focus on parachute-deployment trigger performance, prediction of the aerodynamic and radiative heating environment encountered at Titan, and the corresponding thermal protection system response.

September 2004
SOFIA Acoustical Resonance
A review of technical reports and an independent parametric study helped resolve concerns about the acoustic environment within the telescope cavity of the SOFIA airborne observatory and the potential for structural damage from resonance or tones.

January 2006
CEV Smart Buyer Support
The Crew Exploration Vehicle Smart Buyer design was a multi-center, in-house effort to formulate an innovative CEV design. Seven key trade studies including propulsion, launch abort systems, and reusability helped generate driving requirements and alternatives.

March 2006
Composite Crew Module Pressure Vessel
A composite structural test article was designed, built, and tested with the help of a network of engineers within the Agency with hands-on experience using composites on habitable spacecraft designs.

May 2006
CEV LAS Aerodynamic Evaluation
Computational fluid dynamics analyses and wind tunnel testing examined the aerodynamic and shape sensitivities of a launch abort tower (tractor design) versus a set of side mounted launch abort motors (pusher design) on the service module.

March 2007
Shell Buckling Knockdown Factor
Discipline experts developed new analysis- and test-based shell buckling knockdown factors for high-performance aerospace shell structures to enable significant weight savings for programs such as the Space Launch System.

May 2007
Orbiter Wing Leading Edge RCC Panel
Instances of reduced adherence between the protective coating on the orbiter wing's leading edge and the underlying substrate led to investigations into root cause and the development of improved nondestructive evaluation methods for inspection.

June 2007
Launch Abort System Risk Mitigation
An alternative launch abort system concept was designed, developed, and demonstrated with a full-scale pad abort test as a risk mitigation for the Orion Program and to provide a fallback design for the Constellation Program.

2008-2012

February 2008
Kepler Reaction Wheel Usage Plan
Reaction wheel assembly failures on spacecraft prompted an assessment of mission risk for RWAs planned for the Kepler space observatory. Experts evaluated design, life requirements, and wheel usage and reviewed strategies to maximize RWA life.

October 2008
CPAS Reliability Analysis
Because the Capsule Parachute Assembly System is the top contributor to loss of crew risk for Orion, recommendations were provided on design, development, testing, and verification planning to help develop a more reliable parachute design.

April 2009
COPV Life Prediction Model Development
To address the Agency-wide problem of predicting COPV stress rupture lifetimes, an empirically based test program began to develop data at various stress levels and investigate effects of design, materials, temperature, and scaling on reliability.

October 2009
Crew Module Water Landing Modeling
To more accurately model and predict the interaction of the Orion CM with water during landing, a series of drop tests of a full-sized CM boilerplate helped characterize vehicle responses and improved the modeling approach.

March 2010
Launch Abort Systems Risk Mitigation
The NESC performed a conceptual design study for a follow-on to the successful launch abort system flight test in 2009. This concept used six abort motors with thrust vector control to perform active stabilization.

August 2010
Support to Trapped Chilean Miners
Recommendations were given to the Chilean Government in the areas of air and water supply, hygiene, communications, medical advice, and design requirements for the capsule that rescued 33 miners trapped 2,220 feet below ground.

April 2011
JWST NIRSpec Microshutter Subsystem
The NESC assessed the NIRSpec Microshutter Subsystem qualification for fight. Design modifications were recommended to reduce the wear debris noted during life tests and subsequent NESC tests. Alternate materials were evaluated in follow-on work.

February 2012
HST Gyroscope Anomaly & Reliability
Two of the Hubble Space Telescope's six gyroscopes experienced performance anomalies caused by flex lead corrosion. This led to an update of gyroscope reliability models and a management plan for the gyroscopes' remaining life.

June 2012
Alternate Spacecraft Geometries on SLS
Testing of five generic spacecraft shapes representative of commercial provider concepts that may be launched using SLS was performed on an SLS wind tunnel model to provide preliminary data and determine aerodynamic performance during ascent.

September 2012
Independent M&S for CCP EDL
A sustainable independent modeling and simulation capability was developed to investigate entry, descent, and landing issues for three commercial providers' crew transport vehicles, allowing independent analyses throughout the vehicles' life cycles.

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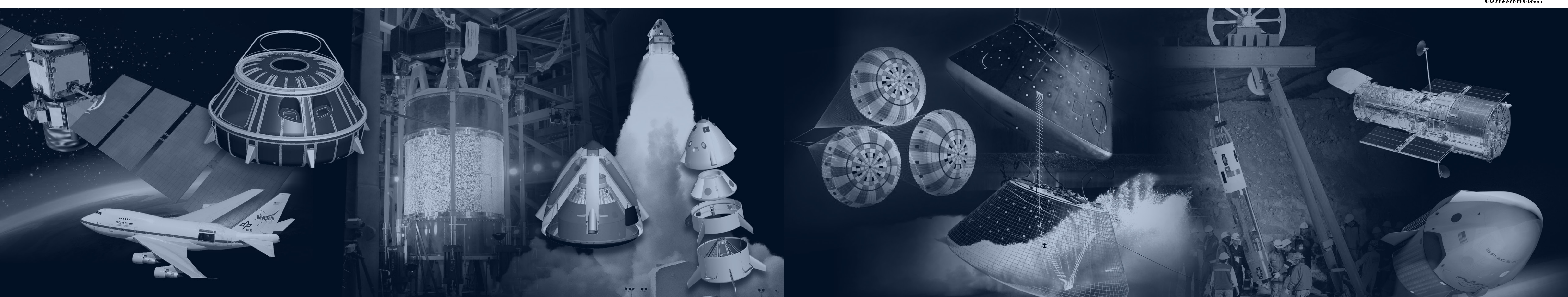
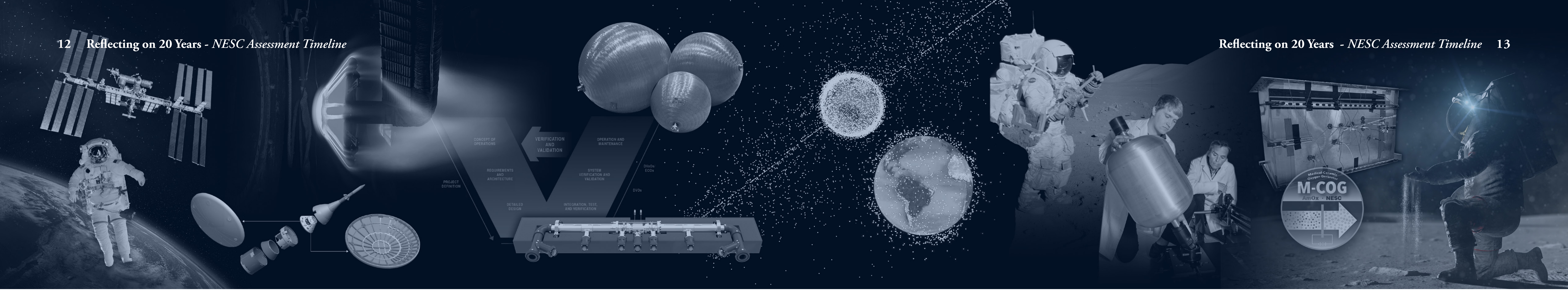




2013-2018

May 2013
EMU Li-ion Battery Assessment

Boeing Dreamliner lithium-ion battery fires prompted an assessment of the ISS EMU batteries and charger system. The assessment compared the EMU and charger to the list of potential contributing factors developed from the Dreamliner investigation.

July 2013
Orion MPCV Avcoat Study

Processing of the Exploration Flight Test-1 heatshield resulted in material strength degradation and cracking. Testing, analysis, and modeling helped determine the root causes of the issues and whether proposed mitigations would be effective.

July 2013
Assessing Risks of Frangible Joint Designs

Frangible joints were instrumented and tested to develop analytical FEMs of frangible joint operation that were anchored to test data. A design of experiments approach was used along with the FEMs to estimate design reliability.

February 2014
Testing Ringsail & DGB Parachutes

Wind tunnel tests of subscale, supersonic parachute designs were conducted to measure the static aerodynamic coefficients and dynamic motions of canopies in both reefed and unreefed configurations for use in future Mars missions.

February 2015
ESD Avionics & Software V&V Plan

To assess the risk of integrated testing of MPCV, SLS, and GSDO avionics and software systems across multiple test facilities, model-based systems engineering techniques were employed to perform a detailed analysis of ESD's V&V plan.

December 2015
Fast Coupled Loads Analysis via NTRC

To advance the loads and dynamics discipline, an approach was developed to capture changes in payload/launch vehicle coupled system interface accelerations due to payload finite element model updates without having to re-run the CLA.

March 2016
Proof Factors for COPVs

Historical data, the NASA experience base, and information from commercial and government launches and COPV suppliers aided the development of an understanding of risk and a rationale for reduction in the proof-test factor for COPVs.

June 2016
CCP Load-and-Go Assessment

A load-and-go approach for loading cryogenic propellants after crew have entered the flight vehicle versus traditional ingress after propellants are loaded was assessed to determine any hazards and the adequacy of mitigations.

January 2018
Calorimetry for Large Li-ion Cell TR

Lithium-ion cells can experience thermal runaway and rapidly release energy. The NESC prototyped a calorimeter that could tally the total thermal energy released plus the fractions liberated and energy conducted through the cell casing.

April 2018
Pilot Breathing Assessment

NAVAIR requested an independent review of their number one safety issue: an increased occurrence of physiological events across their F/A-18 fleet, and to advise and or confirm they are taking the proper corrective steps to address the issue.

2019-2023

March 2019
ORDEM 3.1 Orbital Debris Model Review

ORDEM is a tool for modeling the Earth's orbital debris environment to inform spacecraft shielding design. The NESC peer-reviewed and exercised the new software to evaluate its performance and operational characteristics.

March 2019
Alternative O-Ring Materials for Hypergols

O-rings seal high-pressure lines that contain liquid engine propellants and gases. Material obsolescence caused an O-ring supplier to stop producing a popular product. The NESC tested replacement materials compatible with hypergolic propellants.

August 2019
Second Lunar Dust Workshop

Lunar dust is a concern for future lunar missions. An NESC workshop addressed concerns about the physical nature of the dust, its impact on human health, and its impact on lunar surface systems and operations.

January 2020
Nuclear Propulsion for Mars Missions

Both nuclear electric and thermal propulsion are under consideration for Mars missions. The NESC recently assessed a range of components and systems to determine their technical maturity and potential to reach flight qualification by 2035.

July 2020
Unconservatism of LEFM Analysis Post-Autofrettage

NESC testing showed a lack of conservatism in LEFM analyses that did not account for damage a COPV liner incurs during the compressive portion of autofrettage, which could result in unconservative life predictions.

August 2020
Arecibo Observatory Failure Investigation

The NESC provided nondestructive evaluation, materials, and structures expertise to an investigation into an auxiliary cable socket failure on the Arecibo Observatory.

March 2021
Medical Ceramic Oxygen Generator

The NESC supported the design of a more energy efficient medical ceramic oxygen generator for long-duration missions and astronauts during EVAs beyond low Earth orbit, as well as for providing medical-grade oxygen to patients in remote locations on Earth.

January 2022
P&P Element Battery Safety

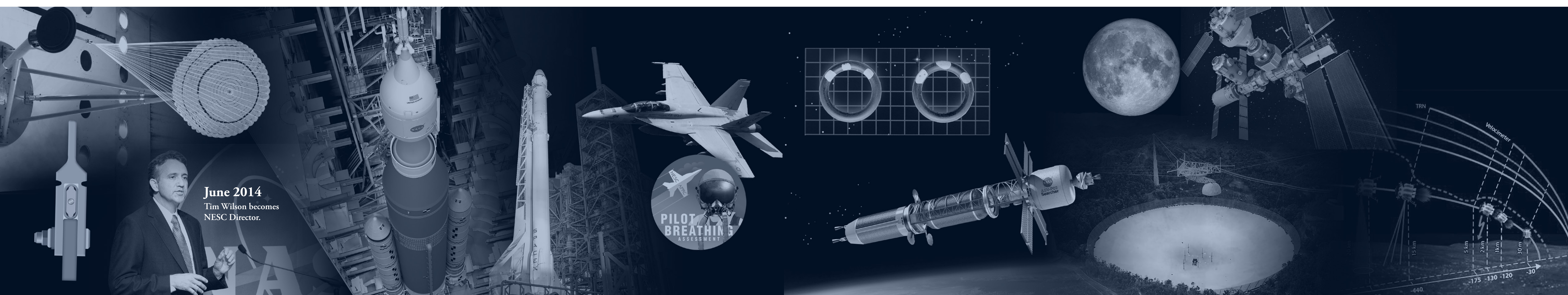
The Power and Propulsion element of Gateway will use batteries to store electrical energy. Battery safety is an ever-present concern and the NESC is investigating battery risks.

January 2023
Lunar Suit Tribocharging Risk Assessment

Because triboelectric charging on the lunar surface is a top risk for Exploration EVAs, the NESC provided independent reviews and expertise to help mature a charging model that will inform future crew and missions on those risks.

March 2023
Expansion of Check Cases for 6DOF Simulation

The NESC is providing check cases for 6DOF simulations of lunar-focused and manual-control missions. The cases will be added to an extensive library of benchmark cases NASA uses to validate critical design simulations.



June 2014
Tim Wilson becomes NESC Director.

ASSESSMENTS & SUPPORT ACTIVITIES FY23

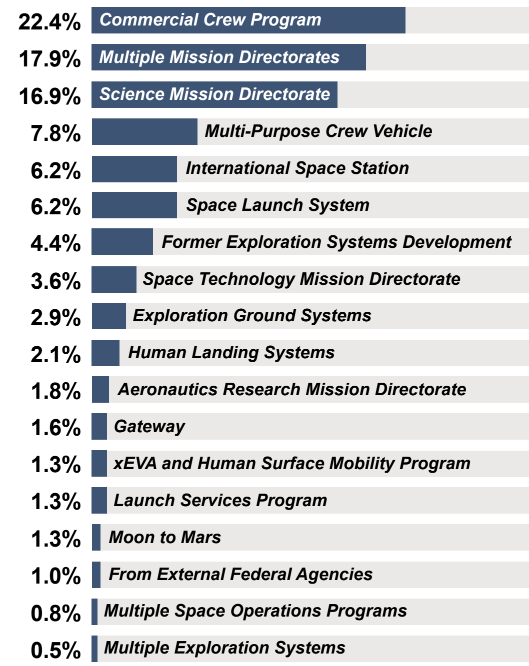
ASSESSMENTS typically include independent testing and/or analyses, the results of which are peer reviewed by the NESC Review Board and documented in engineering reports.

SUPPORT ACTIVITIES typically include providing technical expertise for consulting on program/project issues, supporting design reviews, and other short-term technical activities.

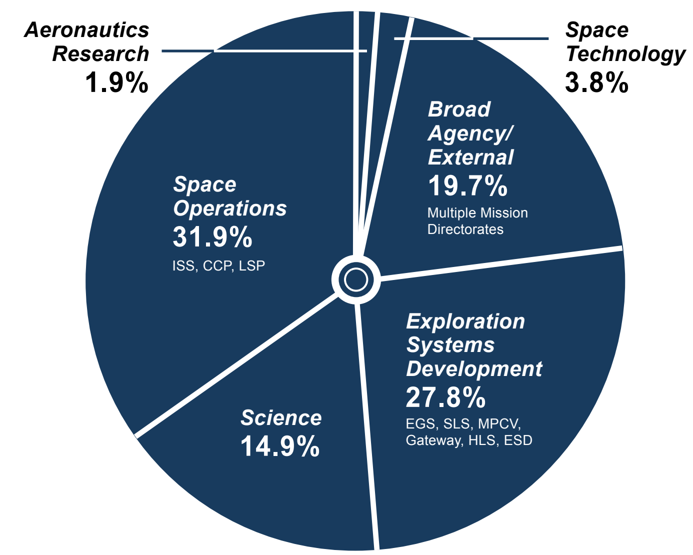
2023 REQUEST ACTIVITY SUMMARY:

- 80 Accepted Requests in FY23
- 80 Completed Requests in FY23
- 1,240 Accepted Requests since 2003
- 1,081 Completed Requests since 2003

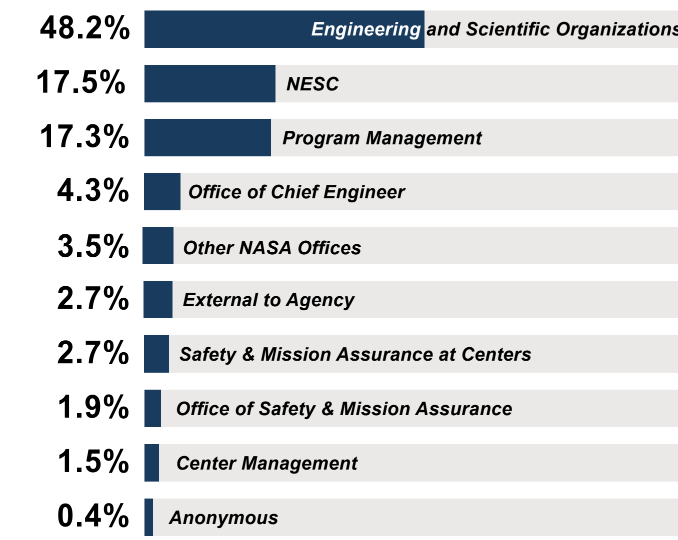
Data as of September 30, 2023



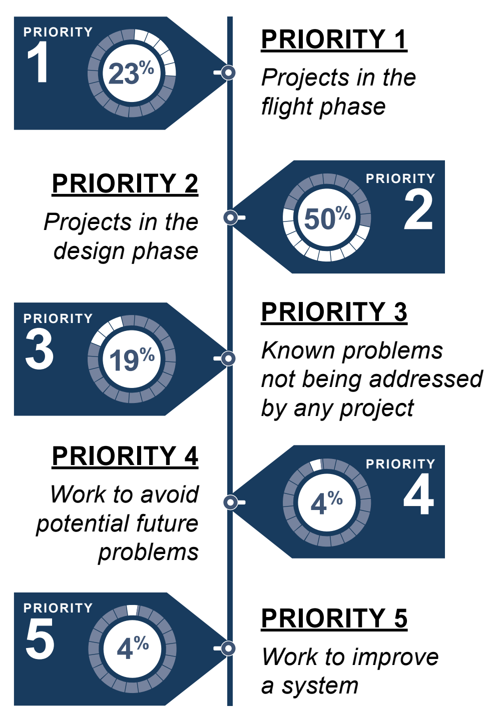
385 ACCEPTED REQUESTS BY ORGANIZATION
FY19-FY23



ACCEPTED REQUESTS BY MISSION DIRECTORATE
FY19-FY23



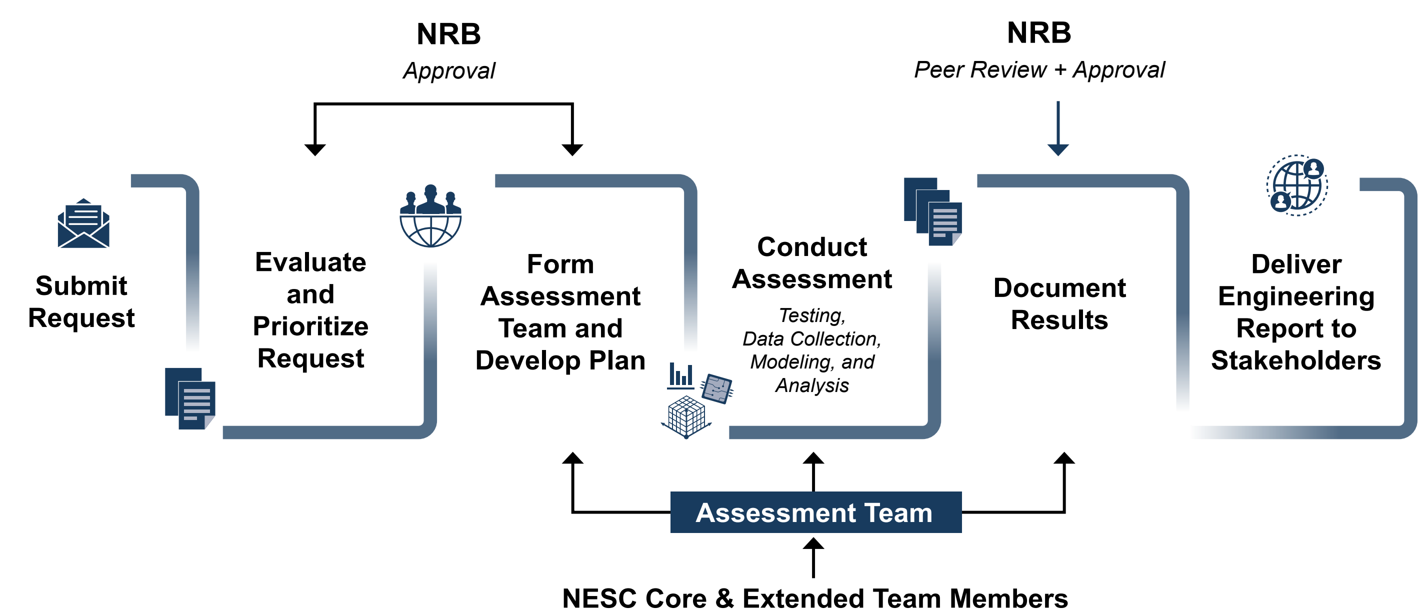
SOURCES OF ACCEPTED REQUESTS
FY04-FY23



159 IN-PROGRESS REQUESTS BY PRIORITY

Submitted Requests are Evaluated Based on NESC Selection Priorities and OCE Risk List

NESC ASSESSMENT PROCESS



The NESC assessment process is key to developing peer-reviewed engineering reports for stakeholders. Requests for technical assistance are evaluated by the NESC Review Board (NRB). If a request is approved, a team is formed that will perform independent testing, analyses, and other activities as necessary to develop the data needed to answer the stakeholder's request. An NESC team's findings, observations, and recommendations are documented within an engineering report and are peer reviewed and approved by the NRB prior to release to the stakeholder.

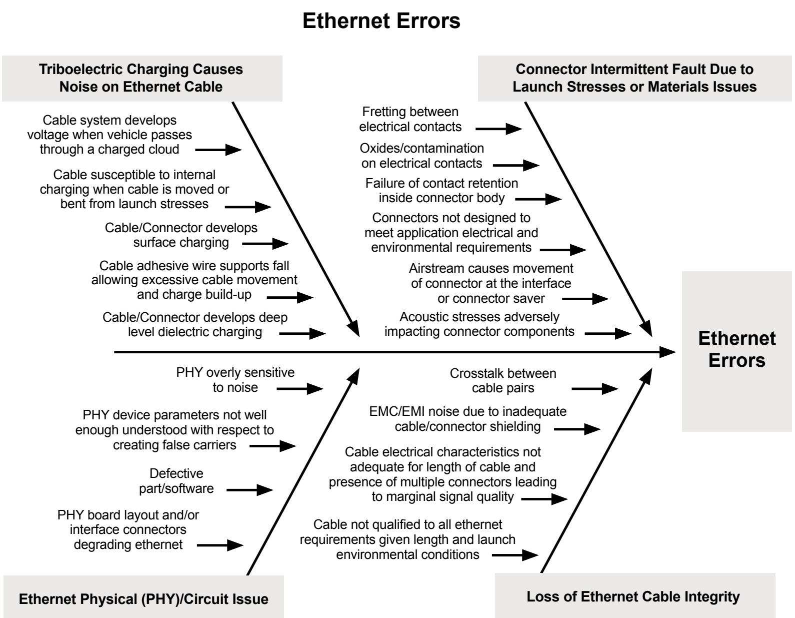
Priority 1: Projects in the Flight Phase

Assessments Completed in FY23

Examination of Space Vehicle Ethernet Interconnects

Both NASA and the aerospace community have increased their use of Ethernet-based command and control designs. For the Agency, the application of Ethernet in space vehicles must overcome unique challenges such as electrostatic discharge resilience, controlling impedance through long runs with multiple connectors, shielding through interconnects, and shock/vibration environments. In 2021, the NESC began examining the performance of Ethernet in these configurations to help address some flight anomalies characterized by excessive bit-error rates (BER). The team's goal was to develop guidance for system designers that would help ensure network robustness when used in flight-critical space applications.

The team reviewed studies on the best Ethernet design and manufacturing practices and consulted with subject matter experts on recent challenges with Ethernet spacecraft systems. After procuring Ethernet cables and connectors, the team developed a test matrix and designed harnesses and test apparatuses to measure and characterize critical electrical properties such as loss of link, false carriers, and BERs under spacecraft environments. They also measured attenuation, near-end crosstalk, the impact of charging on cables and at connector interfaces, temperature extremes, vibration, and shock. Their results were leveraged to develop guidance and provide feedback on requirements for building Ethernet cables that will be distributed to communities using and developing these systems. *This work was performed by LaRC, GSFC, JPL, KSC, MSFC, JSC, GRC, and NAVAIR. LLIS Entry 31403.*

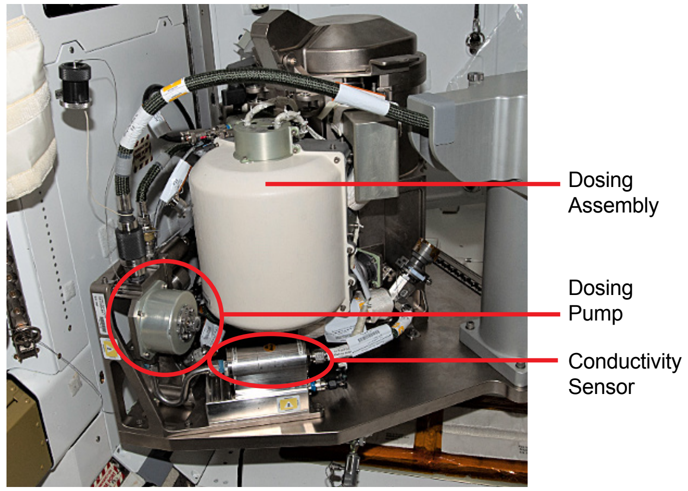


Simplified Ethernet Error Fishbone Chart

Prototype Sensor Developed for ISS UWMS

A new toilet for the ISS, called the Universal Waste Management System (UWMS), uses a unique sensor that measures the proper mixing of a diluted pretreat compound with urine for processing. The concentration of this pretreat is carefully measured prior to its injection into the urine stream not only to limit use of the pretreat but also to protect the processing systems from biological activity. Optimal performance requires accurate and stable sensor measurements. Thus, a study was undertaken to compare the performance of the existing conductivity sensor, which exhibits output voltage decay over time, with an optical sensor, whose output voltage should be stable over time.

The NESC assisted the ISS program in exploring the potential use of an optical sensor and in developing a prototype. To determine whether an optical sensor could reliably measure UWMS pretreat concentrations, the NESC assessment team conducted visible wavelength transmission spectroscopic testing of the pretreat compound at various concentrations and found an optical sensor was a feasible candidate for this application. The team then constructed and tested preliminary devices that ultimately led to a self-contained prototype, which was offered to the ISS Program for further testing. *This work was performed by LaRC, KSC, and MSFC. NASA/TM-2023000765.*



Key components of the ISS UWMS.

Priority 1 In-Progress Assessments

- Optimal Slew Sequence to Calibrate ST-to-IMU Misalignment
- Orion Side Hatch Analysis and Correlation
- PFE Microgravity Compatibility Test
- Energy Modulator Extension Testing
- LOX-Methane QD and Safety
- Hardline O2 and Fire Response
- Cracked Samples for NDE Standards
- Capsule Dynamic Pitch at Transonic Speeds
- Software Erroneous Output During Entry Risk
- ECLSS-ATCS Review
- Cross-Program Exposure Testing Review
- Fracture Control Risk Reduction
- Hot Gas Intrusion in Engine Bays
- Fire Cartridge Investigation, Manufacturing, and Hardware Verification
- Ti-NTO Compatibility Cross-Program Impact and Lessons Learned

Priority 1 In-Progress Support Activities

- Orion Digital Motor Controller Support
- ML 2 Turn-Flow Pressure Tabletop Review
- SLS Debris Resolution Team
- SLS Booster Design and Construction
- Orion Separation Bolt Thermal Analysis
- Pressure Sensor Anomaly
- TEMPO Post-Launch Acceptance Review
- Alternate Approach to NASA-STD-5020
- ISS Air Leak
- Mass Properties Evaluation of CCP Providers
- Artemis I Acoustic and Blast Load Environments
- WB-57 Actuator Gear
- X-57 Project
- Heatshield Char Investigation
- Lunar Flashlight Anomaly Support
- Artemis I Orion PCDU Latching Current Limiter
- MPCV Power Distribution Unit
- Ti-NTO Ignition Spots
- EMU Water Management

Priority 1 Completed Support Activities

- Review of CCP Ablation/Thermal Analysis
- Integrated Propulsion Controller Backup
- Krytox Contamination
- Artemis I SciFli Imaging Support
- Artemis I SLS FTS Battery
- Artemis I SLS Cryo Servicing Team
- Review of SHREC Failure Investigation
- Parachute Impact Damage Tolerance Evaluation
- EVA Fan/Pump/Separator Mitigation
- Heatshield ATP
- CCP Engineering & Safety Review Efforts
- Water in Helmet Investigation
- LNG Detank Anomaly Investigation Team
- Lucy Project ART Kevlar Lanyard Testing
- ISS FGB Air Leak
- Coolant Leak Fault Tree Closure

Reflecting on 20 Years...

"Congratulations to the NESC team on its 20th anniversary. In the wake of the Columbia disaster in 2003, we were reminded, unfortunately once again, that we are never as smart as we think we are. We established the NESC to provide our programs with a team of highly responsive independent technical experts that could help our decision makers better understand and thus more effectively mitigate their toughest engineering risks. In these 20 years, under the leadership of Ralph Roe and Tim Wilson, the NESC has established itself as the go-to, independent technical resource that programs from all Agency enterprises can depend on to make them smarter about their designs, environments, and operations concepts, thus enhancing their ability to meet NASA's safety and mission success goals."

Bryan D. O'Connor, NASA Chief of Safety and Mission Assurance, 2002-11

"It is hard to believe it was 20 years ago that the NESC went from concept to reality. In those intervening years, the NESC has proven its worth time and again by engaging its technical experts in some the Agency's most difficult challenges. I will always fondly remember my time at the NESC as some of the most interesting and challenging, yet fulfilling, experiences of my NASA career."

Dr. Richard J. Gilbrech, Stennis Space Center Director
(NESC Deputy Director, 2003-05)

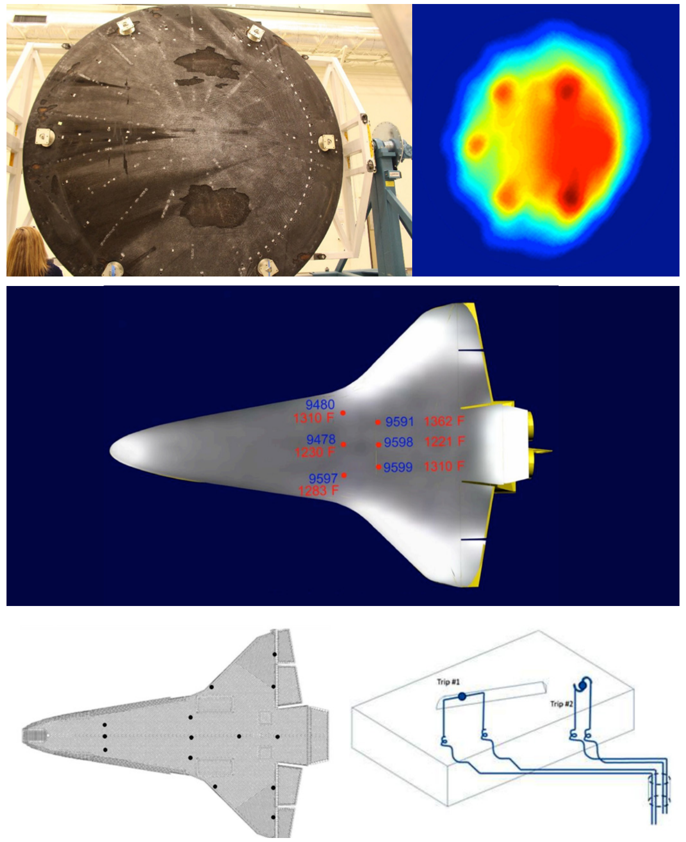
Priority 2: Projects in the Design Phase

Assessments Completed in FY23

Mitigating Thermocouple Interference During High-Speed Earth Entry

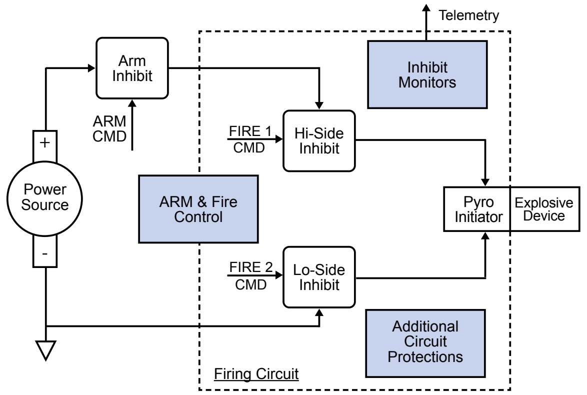
NASA uses thermocouples (TC) to measure temperatures of the thermal protection system during a spacecraft's high-speed atmospheric entry. During Space Shuttle missions and the Exploration Flight Test (EFT)-1, TCs experienced sporadic anomalous temperature indications. The suspicion was that the plasma environment of entry affected the heatshield TCs causing electrical signals that appeared as temperature changes. The team concluded that a direct current was formed between the plasma and the TC circuitry, causing the anomalies.

To help understand and prevent TC issues for future missions, the NESC performed tests and analyses, including the evaluation of heatshield material thermal and electrical properties, verification of TC installation orientation and electromagnetic response, and simulation of voltage generated from the plasma flow fields and by electromagnetic induction caused by high-velocity travel through the Earth's magnetic field. The NESC recommended mitigations including insulating the TCs from external electrical sources, optimizing TC circuitry, and considering other heatshield TC integration design options. The NESC also suggested flying TCs of the type that exhibited the temperature abnormality alongside modified TCs to validate the efficacy of the changes made to mitigate the anomaly. *This work was performed by LaRC, WSTF, KSC, JSC, ARC, MSFC, and JPL.*



(Top) Orion EFT-1 heatshield included embedded TCs. Colorized infrared (IR) reentry image data used to correlate temperature with TC readings. (Middle) IR image of STS-115 overlaid on orbiter CAD model showing location of TCs. (Bottom) Location of TCs on Endeavor and TC configurations for reentry temperature measurement experiment on STS-134.

Autonomous Flight Termination Systems



Notional Pyrotechnics Firing Circuit

Pyrotechnic systems are in a unique category of safety-critical systems because inadvertent activation of a pyrotechnic device resulting from a system fault, and/or lack of safe electrical margins, can lead directly to loss of crew. For example, unplanned activation of pyrotechnics used for an autonomous flight termination system (AFTS) could override an abort capability. That abort capability, if activated, could have safely propelled a capsule away from the launch vehicle to a potentially safe landing. Over the years, NASA and the military have learned lessons about safe pyrotechnic circuit design and test. However, with NASA's recent efforts to move toward a development model that leans more heavily on commercial partners, these requirements have not always been directly levied on projects, and in some cases have been misinterpreted. Key design features that should be included in human spaceflight pyrotechnic systems include: two-fault tolerance, arming firing circuits only when firing is imminent, monitors to verify the state of inhibit circuits, fault-containment regions, electrical and physical isolation to contain faults, and knowing the electrical margins so spurious noise will not initiate pyrotechnics. These considerations and others are critical when repurposing commercially available flight termination systems from uncrewed to crewed launch vehicles. *This work was performed by KSC, LaRC, GSFC, and JPL. NESC Technical Bulletins No. 23-01, No. 23-02, and Lesson Learned No. 30602.*

Applying Advanced CFD to Determine Dynamic Stability

Artist illustration of the MSR-EES reentry.

To return surface and atmospheric samples collected on Mars by the Perseverance rover, NASA will employ the Mars Sample Return Earth Entry System (MSR-EES), a conical capsule that will protect the samples from the heat of reentry. The EES will enter Earth's atmosphere at high speed and must decelerate and land without parachutes. To ensure accurate landing and precise attitude at impact, the MSR-EES team investigated the aerodynamic and dynamic stability characteristics of the EES over a wide range of low supersonic, transonic, and subsonic Mach numbers. To assist the MSR team, the NESC performed complementary analyses, applying advanced computational fluid dynamics (CFD) methods to predict key stability parameters. The results were used in trajectory simulations to assess dynamic pitch stability characteristics and vehicle performance, and help determine if additional design modifications might be required. The NESC team also performed dynamic forced oscillation CFD simulations and evaluated multiple independent methods for extracting key stability parameters from the CFD data. The team also used data from static and dynamic wind tunnel tests for CFD validation. The team's findings and recommendations can also be applied to future vehicles. *This work was performed by MSFC, LaRC, and ARC.*

Reflecting on 20 Years...

"Thinking back to the earliest days of the NESC, we were initially met with a fair bit of skepticism. Would this be just another initiative that would fade over time? What set the NESC on its path to success was strong, visionary leadership and a visible commitment from Agency leaders by providing the necessary resources—not just finding but by enabling recognized, respected experts to join the NESC. With this foundation, it did not take long for the NESC to take hold and make a positive impact. No longer would a decision maker be faced with nowhere to turn to get additional data or an independent assessment. What we perhaps did not anticipate was an even greater long-term impact of the NESC—breaking down the barriers across the Agency to enable more effective cooperation, collaboration, and knowledge sharing."

Dawn M. Schaible, Deputy Center Director, GRC
(Manager of NESC Systems Engineering Office, 2003-14)

"As a founding member, it has been interesting to me to watch the organizational evolution of the NESC over the last 20 years. The NESC has become a fundamental part of the framework that supports our human spaceflight programs. They provide much needed independent assessment, but also can pivot to step in and provide critical in-line surge and specialty capabilities. Their ability to bring key subject matter experts to bear on complex problems and their independent line of funding in many ways are the model of what NASA engineering should be able to provide for the Agency. As Engineering Director at JSC, and as Orion Chief Engineer, I really value the ability to call on the NESC for assistance—people or dollars—and they are always there to make the mission successful."

Julie Kramer White, Director of Engineering, JSC
(NESC Discipline Expert for Mechanical Analysis, 2003-06)

Evaluation of Launch Pad Modifications

A NASA commercial provider, which operates KSC's Launch Complex (LC)-39A, modified the pad's flame trench to better accommodate ground support equipment and surface operations on the pad. The modifications to pad geometry included extending the flame duct ceiling and increasing the duct length of the trench, which is unique to LC-39A in that the top is completely closed. A water-based sound suppression system is used in the trench to protect the launch vehicle and surrounding structures against ignition by injecting large amounts of water in the trench.

NASA's Launch Services Program requested that the NESC analyze the effects of the pad's modifications on the pressure loads experienced by the provider's launch vehicle. The interaction between the launch vehicle engine plumes and water system results in a highly nonlinear two-phase flow environment, which necessitated a unique approach to analysis. For the model simulations, teams from three NASA centers used three different CFD solvers to model the launch vehicle's overpressure waves generated by the engines and boosters at locations on the vehicle. The models were then qualitatively validated by comparing simulations of the vehicle's LC-39A launch environment to previous flight data. *This work was performed by LaRC, ARC, MSFC, SSC, and KSC.*

Flame duct ceiling extension shown on LC-39A. Credit: Google Maps

A Review of Pressurized Rover Concepts for Lunar Use

Both NASA and an international partner have developed concepts for pressurized lunar rovers that would not only provide transport for astronauts living and working on the Moon but have designs flexible enough to extend their use to Mars. Critical to these concepts is validating the rovers' overall mass to ensure they do not exceed mass delivery capabilities of launch vehicles or landers.

Systems engineering (SE) experts from the NESC SE Technical Discipline Team reviewed the conceptual designs for maturity and evaluated mass management, including allowances for mass growth. The team reviewed systems engineering products such as the concept of operations, requirements, and the mass management plans, and then assessed key design drivers, critical functions, and system responses. In addition, the team looked at subsystem descriptions for structures and mechanics, power and avionics, active and passive thermal control, and environmental control and life support systems. The NESC also used a tailored mass growth allowance table based on the ANSI/AIAA S-120A *Mass Properties Control for Space Systems* standard to evaluate the designs. Opportunities were identified for design improvements and possible mass reductions. *This work was performed by GSFC, LaRC, KSC, JPL, MSFC, JSC, ARC, and GRC. LLIS Entry 31801.*

Illustration of a lunar pressurized rover concept.

Reflecting on 20 Years...

"From my perspective, the NESC brings tremendous benefit to the Agency. Their ability to tap crucial expertise, not only within and across NASA, but also reaching out to industry, academia, and other government agencies for crucial subject matter expertise is extraordinary. I think the NESC also brings crucial leadership in conducting assessments, innovative analyses tools and processes for root cause and problem resolution, and a rigorous documentation process with succinct actionable findings and recommendations, key for communication to stakeholders. All of this is really important and has proven invaluable for safety and mission success in our HSF programs like CCP, Artemis, and ISS, where rigor in understanding our risks and uncertainties, and knowing our margins, is essential. In these busy times, I also appreciate the responsiveness and the yes, can-do philosophy. Just knowing you will get a yes on request and knowing the best of the best will be engaged eases my mind. Human spaceflight asks for a lot, and the NESC is always there for us!"

John P. McManamen, Chief Engineer, Moon-to-Mars Program/ESDMD
(NASA Technical Fellow for Mechanical Systems, 2003-07)

"The safety and mission success of NASA's missions is fundamentally based on engineering excellence. The NESC is vital to maintaining excellence and further growing the capabilities needed for our increasingly complex and challenging missions. The NESC provides world-class expertise and an independent evaluation of our most critical issues. Their ability to identify solution paths for acceptable risk is a significant strength of this Agency."

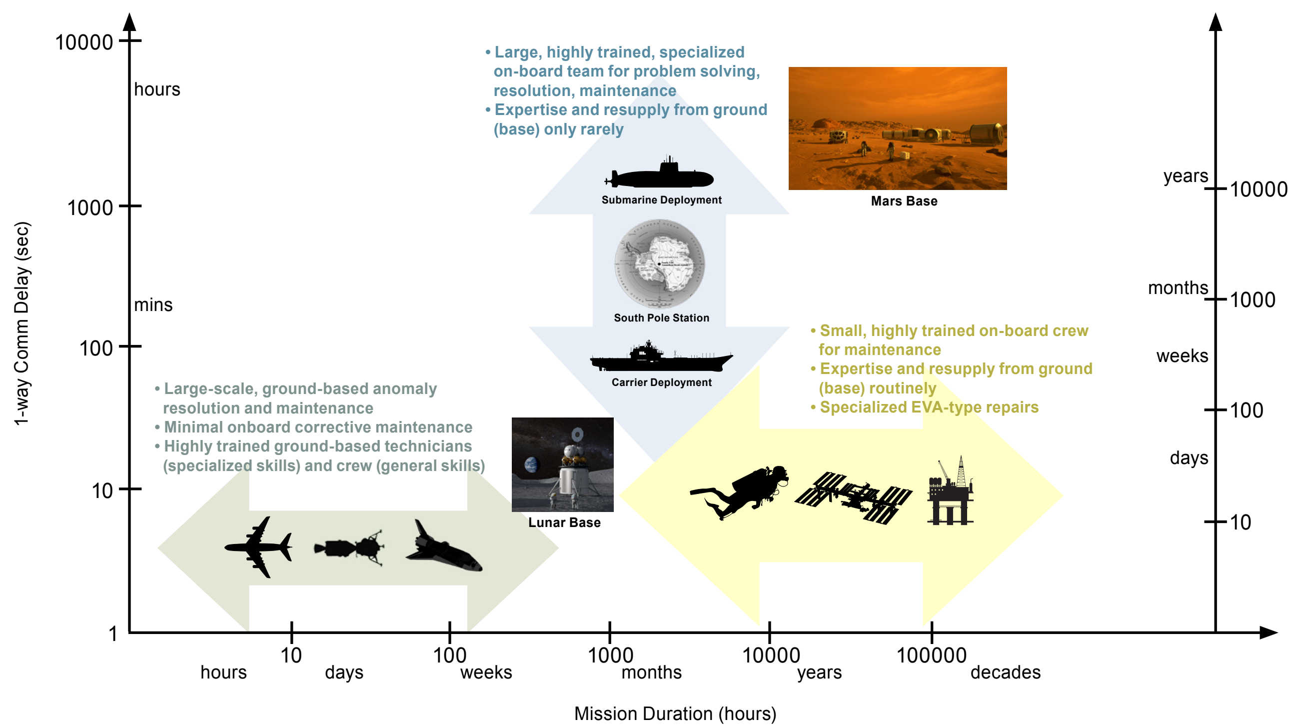
W. Russ DeLoach, NASA Chief of Safety and Mission Assurance

Updating NASA Maintainability Standards for Missions Beyond LEO

Throughout much of NASA's history of human spaceflight, maintenance was performed by trained mechanics at depot facilities on the ground after vehicles returned from missions. The launch of the ISS brought space-vehicle maintenance into a new era of in-mission maintenance by astronauts under the instruction of flight controllers. However, as NASA moves to crewed missions beyond low Earth orbit (LEO), updated system-maintainability standards will be necessary to support a more autonomous crew and eliminate risks for crew health and safety that will come with communication and resupply delays in the extreme environments of deep space.

In partnership with Office of the Chief Health and Medical Officer and the Office of Safety and Mission Assurance, the NESC studied the maintainability state-of-practice to identify potential gaps in applicable NASA standards. They also reviewed related standards from government agencies and industry as well as reports and guidebooks, lessons learned from past space missions, crew comments, and other maintainability and maintenance materials. In addition, numerous subject matter experts were interviewed on current maintenance practices and challenges, latest design trends in maintainability, and the demands of performing maintenance in extreme environments with a small, isolated, or remotely operating team.

The study resulted in multiple new requirements and revisions proposed for NASA-STD-3001 Volume 2, *NASA Space Flight Human System Standard: Human Factors, Habitability, and Environmental Health*. In addition, updates were proposed for NASA-STD-8729.1 *NASA Reliability and Maintainability Standard for Space Flight and Support Systems* and content was drafted for a guidebook to provide additional information on the process of designing systems for maintainability. *This work was performed by GSFC, ARC, JSC, KSC, and NASA HQ. NASA/TM 20230011306.*



Notional map of the domains the NESC assessment team investigated by mission factors including mission duration, resupply, and communication delay with support teams.

Reflecting on 20 Years...

"The Office of Chief Health and Medical Officer works closely with the NESC to solve human health and performance engineering issues. Being able to collaborate with NESC technical expertise and combine it with health and medical expertise has been invaluable in ensuring that NASA missions are safe and productive".

Dr. James D. Polk, NASA Chief Health and Medical Officer

Analysis of Side Hatch Loads on the Orion Crew Module

Since 2018, the NESC has provided hydrodynamics and loads support as well as model development for the Orion Crew Module Uprighting System, which is a set of five airbags that inflate upon splashdown to ensure the capsule returns to the upright position after landing. Leveraging this prior work, the NESC completed an assessment of the crew module side hatch loads, which are driven by acceleration of the crew module in the open ocean. During nominal and off-nominal landing and recovery scenarios, the hatch must operate and remain open for crew egress while exposed to waves. Understanding and predicting the loads the hatch will encounter in various sea states will help ensure it will open properly for crew egress after splashdown.

The NESC conducted dynamic analysis of the Artemis I and II upright configurations in relevant wave environments to provide the side-hatch team with accelerations at the crew module's center-of-gravity and side-hatch locations. This involved enhancing an existing capsule model, comparing the results with data collected during an underway recovery test, and evaluating Orion-defined wave spectra for use as model inputs. The team provided the Orion Program with acceleration profiles across the wave environments and crew module mass properties along with recommendations for identifying design wave events that drive peak loads. *This work was performed by KSC, JSC, MSFC, General Dynamics, and The Aerospace Corporation. NASA/TM 20230004154.*

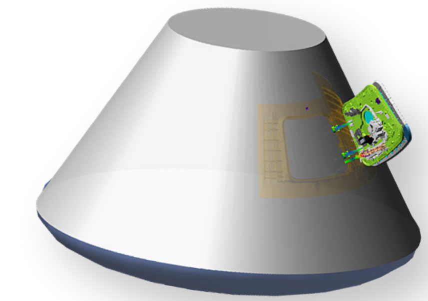


Illustration of crew hatch in open position.

Artemis I Orion crew module in upright position after splashdown.

Understanding Software Defect Density in Risk Analysis

As an aid to supporting software risk analyses, the NESC collected software defect data across multiple NASA programs and projects including the ISS, Orion Multi-Purpose Crew Vehicle, Space Launch System, Mars 2020 and others. The aim was to characterize the quantity and severity of software defects and assess whether a given number of defects could be considered "in family" or "out of family" at key points in a program's life cycle with an emphasis on human-rated first flights and early phases. The NESC team found that projects collect and handle defects differently, even using differing definitions or categories of severity. Despite this, the team was able to compare problem removal rates and efficiency, defect severities, defect closures over time, and defect density for the final build of software prior to launch. As a result of their analyses, the team made multiple recommendations. NASA should determine a consistent approach for collecting defect data across its programs/projects, update NASA-HDBK-2203, *NASA Software Engineering*, to provide additional guidance on the use of tools to track workflow versus defect resolution, and develop an Agency-wide defect-data repository to advance the software discipline. *This work was performed by JSC, GRC, MSFC, GSFC, and LaRC.*

The NESC team compared the software defect densities leading up to the initial operation of multiple NASA and commercial systems.

Priority 2 In-Progress Assessments:

- Landing Risk Assessment
- Expansion of Check Cases for 6DOF Simulation
- Lunar Suit Tribocharging Risk
- MSR Orbiting Sample Model Review
- M&S of MAV Ascent Phase of Flight
- Self-Reacting Friction Stir Weld Anomalies
- Material Flammability in Lunar Gravity
- SLS Core Stage Thick Plate
- Space-Shielding Radiation Dosage Code Evaluation and Identification
- Dragonfly Dynamic Stability
- Hot-Fire Testing of 5 lbf Class Reaction Control System Thrusters
- Exploration Systems Exterior Lighting Design Guidance
- Material Sensitivities to N2O4/MON Exposure
- Oxidizer Tank Design and Qualification
- COPV Helium Tank w/Large Grain Aluminum Alloy
- Gateway PPE COPV Damage Tolerance Life Support
- Frangible Joint Technical Support to SLS
- Energy Modulator Webbing Shredding Testing
- MAV Buffet/Aeroacoustics Numerical Simulations
- COPV Damage Tolerance Life by Analysis Risk
- CFD Assess. of Ascent Abort Axial Force Anomaly
- Alternate Helium Pressure Control Component
- Trade Space Analysis: Balancing Crew and Mission Design Parameters
- Tube Test Coupon for COPV Mechanics
- Anaerobic Hydrogen Detection Sensor
- Qualification of Radiographic NDE Techniques
- Post-Flight Reference Radiation Environments
- Midpoint Monitoring in Batteries
- Material Compatibility and EAC Data for Metals in Hypergolic Propellants
- Hydrodynamics Support for Orion CM Uprighting System
- Orion Titanium Hydrazine Tank Weld
- CPV Working Group
- Stress Ruptures COPV
- Independent M&S for CCP EDL
- SLS Aerosciences Consultation and Review
- Reaction Wheel Performance for NASA Missions
- Exploration Systems Independent M&S
- Peer Review of MPCV Aerodynamic/Aerothermal Database Models and Methods

Priority 2 In-Progress Support Activities:

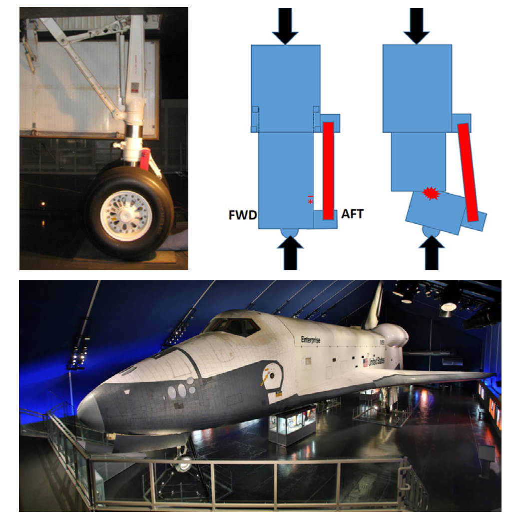
- MSR EES Release Engineering Peer Review
- Moon to Mars Artemis II Critical Event
- Spin Chute Design Consultation for Sustainable Flight Demonstrator
- Next Gen Radioisotope Thermoelectric Generator Project
- Roman Outer Barrel Assembly
- SLS B1B FSW CDR Review Team
- Dragonfly Replan Scenarios
- Tape Flammability Risk
- ISS Urine Pretreat Tank NDE and Fracture
- MEGANE Instrument Gamma-Ray Spectrometer
- Farside Seismic Suite Project Loop Heat Pipe
- Commercial LEO Development Program
- Vulcan Centaur Mishap Investigation
- Roman Wide Field Instrument Materials Analysis
- X-59 Fuel Tank Ignition
- OSAM-1 Tiger Team
- CO2 Removal Expertise for JAXA I-Hab
- Systems Engineering SME and MBSE Support to Advanced Capabilities Division
- DaVinci Mission Technical Support
- MPCV Flywheel Exercise Device Acoustic Reduction
- CCP Technical Support
- Friction Stir Welding support
- CCP Design Certification Review
- Orion Mass Gauging Development Support
- Display Management Computer Reset Anomaly
- Composite Consult for New Launch Vehicle Application
- Lunar Ground Testing Guidebook Support
- Psyche Mission RAD750-V3
- OSAM-1 Assembly Joint Mechanism Test
- SubC Safety Review
- Lunar Glove Thermal and Dust Risk Mitigation
- Contamination Control for Carruthers Observatory
- LSP Frangible Joint Support
- Mars Sample Return MMOD Protection Review
- Space Charging of Ocean Color Instrument Rotating Mechanism
- Orion, NDSB2, and Gateway Material Electrical Properties Support
- Parachute Flight/Ground Tests & Packing/Rigging

Priority 2 Completed Support Activities:

- MAV Flight Test Risk Assessment
- ESDMD and SOMD Facilities Review for Future Architecture Elements
- EGS Mobile Launcher 2 Structure Design
- SLS Block 1 ISPE Crew CDR
- Refractory Concrete Subject Matter Expertise
- Mars Ascent Vehicle Preliminary Design Review
- Mobile Launcher 2 Potential Cost Drivers
- Lunar Landing Plume Surface Interaction TIM
- Artemis I Supplemental Parachute Imagery
- HALO CDR SE SME Support
- Psyche FSW and GNC SME Support
- Mars Sample Return CCRS-OS Charging
- Roman Radiation and Charging
- HLS GNC Landing System Sensor Milestone Review
- xEVA Design and Construction Adjudication
- SLS Block 1B CDR
- ESCAPADE Propulsion System Trade
- Orion Reusability Evaluation
- SLS SE&I Programmatic Review
- HLS Avionics Fault Tolerance
- DART Solar Array Loads
- DOLILU Certification Review
- Operational Modal Analysis of Dynamic Rollout Test Data
- Sensor Anomaly Investigation
- CCP Launch Vehicle Support
- SLS Design Certification Review
- Bond Verification Plan for Orion Heatshield Design

Priority 3: Known Problems Not Being Addressed by Any Project

Assessments Completed in FY23



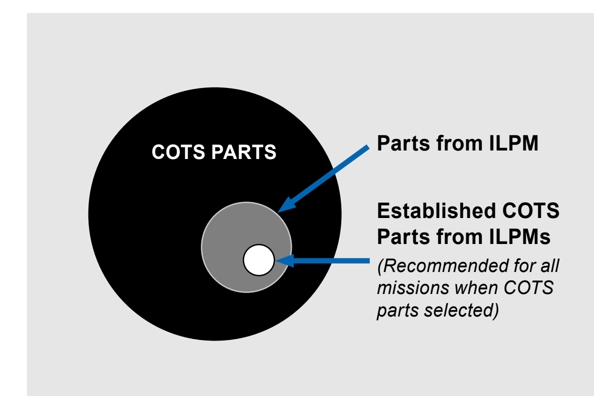
Investigation of Shuttle Enterprise Landing Gear Fracture

The Space Shuttle orbiter, Enterprise, now owned by the Intrepid Sea, Air & Space Museum, resides on public display on the deck of the retired aircraft carrier USS Intrepid, moored at Pier 86 on the Hudson River in New York City. When the left main landing gear (MLG) piston failed in late 2018, the NESC assisted in the investigation to help the museum determine whether the right MLG was at risk of similar failure and evaluate the display environment prior to the reopening of the exhibit. The NESC team conducted hardware visual and nondestructive evaluation inspections, examined the display, and provided quick feedback for the museum. *This work was performed by LaRC, KSC, MSFC, ARC, JSC, and AFRC.*

Top: Depiction of MLG display loading before and after fracture (right).
Bottom: Enterprise on display at the Intrepid Museum.

New Agency Guidance for COTS Use

Increasingly, NASA programs and commercial partners are incorporating commercial-off-the-shelf (COTS) electrical, electronic, and electromechanical (EEE) parts in their missions to meet challenging size, weight, power, and performance requirements. NASA standards consider COTS parts as non-standard parts, therefore they are subjected to MIL-SPEC screening and lot acceptance from each procured parts lot. In the past two decades, many top-tier commercial part manufacturers have evolved significant manufacturing, statistical control, and technological improvements that can provide reliable parts. In appropriate applications, COTS can offer performance and supply availability advantages, while careful review and a thorough understanding of manufacturer specifications and verification of reliability for space application are required.

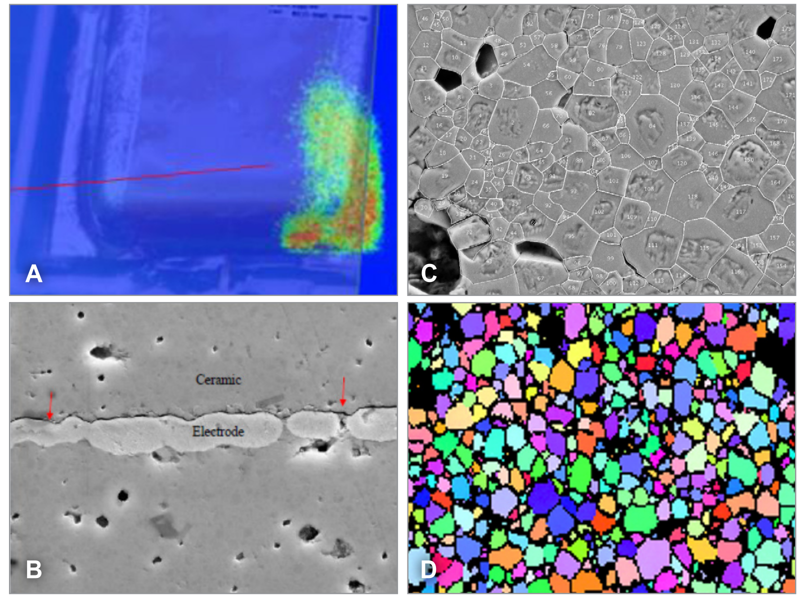


Established COTS parts are a subset of parts from an ILPM. An ILPM is a subset of COTS manufacturers.

The new guidance recommends MIL-SPEC screening and non-radiation-related lot acceptance testing be reduced or eliminated in cases where evidence of sufficient quality and reliability exists for COTS parts. The extent of NASA's insight into COTS manufacturers and the amount and nature of the needed evidence will differ by mission and will likely be driven by a mission's resources and associated risk posture. To facilitate this goal, criteria were defined for "Industry Leading Parts Manufacturers (ILPM)" who have best practices for "zero defects" parts quality, reliability, and workmanship, and a willingness to share their quality and reliability data. Also defined was an "Established COTS Part," which included criteria such as a stable production processes, automatic manufacturing, and 100% electrical testing of each part. When COTS parts need to be used, Established COTS Parts from ILPMs are recommended for all missions to ensure parts meet mission, environment, application, and lifetime requirements. The NASA Electronic Parts and Packaging Program is currently working on the implementation details of the guidance. *This work was performed by LaRC, ARC, JSC, MSFC, GSFC, JPL, KSC, GRC, and OSMA. NASA/TM 20205011579, NASA/TM 20220018183, LLIS Entry 23502.*

Ceramic Capacitor Microstructure Analysis Tool Development

Latent defects within multilayer ceramic capacitors (MLCC) have resulted in multiple space mission failures and episodic failures during system integration and test. Defects include delaminations that can develop into cracks, which can become conductive over time, and are characterized by significantly reduced insulation resistance—potentially resulting in increased leakage current. Because hundreds of capacitors can be used on a single circuit card assembly, part reliability is a crucial factor for mission success.



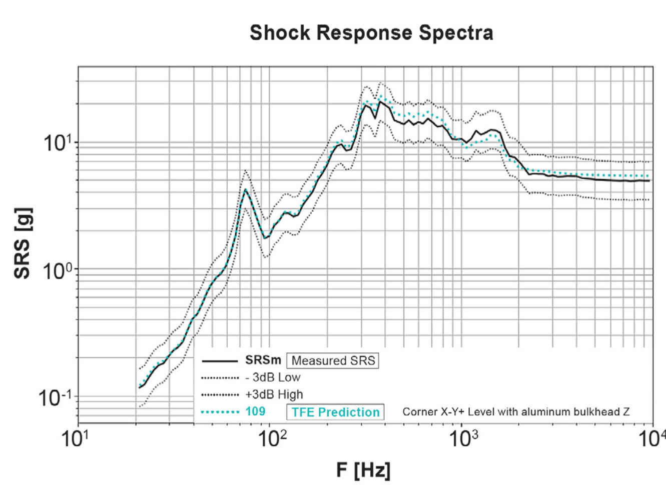
(A) Infrared image showing hot spot during powered test. (B) Electron microscope image showing delamination along the electrode plate associated with a crack (red arrows), which correlates with the IR region identified in A. (C) Manual tracing of grains (dark areas) on a scanning electron microscope image. (D) EBDS image. ImageJ software can analyze the EBDS image and provide statistics of colored grain regions to dark void regions.

The literature establishes a clear relationship between grain size and ceramic fracture toughness, the latter of which controls the propensity for ceramic cracking. The NESC was requested to study the existing analysis tools available to evaluate MLCC microstructure and produce less subjective, faster, more accurate, and repeatable ceramic grain-size measurements and grain-size distribution data. The study team found that an electron backscatter diffraction system (EBDS) worked well for quickly quantifying grain-size distributions. However, EBDS showed no significant difference in grain-size distributions among the evaluated specimens, which included "problem" lots associated with instrument failures on NASA missions. Nevertheless, the EBDS enabled rapid quantification of grain-size distributions and potential relation to capacitor reliability, which would benefit NASA and the overall space community when investigating capacitor failure root causes. The team recommended using EBDS to investigate future capacitor lots to develop a library of grain-size distribution data for future reference. *This work was performed by LaRC and GSFC.* NASA/TM 20230004147.

TFE Offers an Advancement in Shock Prediction

Accurately predicting shock response is a top priority for NASA and industry. For aerospace projects, assessing the shock environment is critical in determining hardware susceptibility to shock failure and qualifying the hardware for predicted shock environments. Several methods have been attempted over the past decades, but none have been fully adopted. This prompted the NESC to evaluate the use of finite element analysis (FEA) in shock prediction and resulted in the Transient Finite Energy (TFE) Predictor methodology.

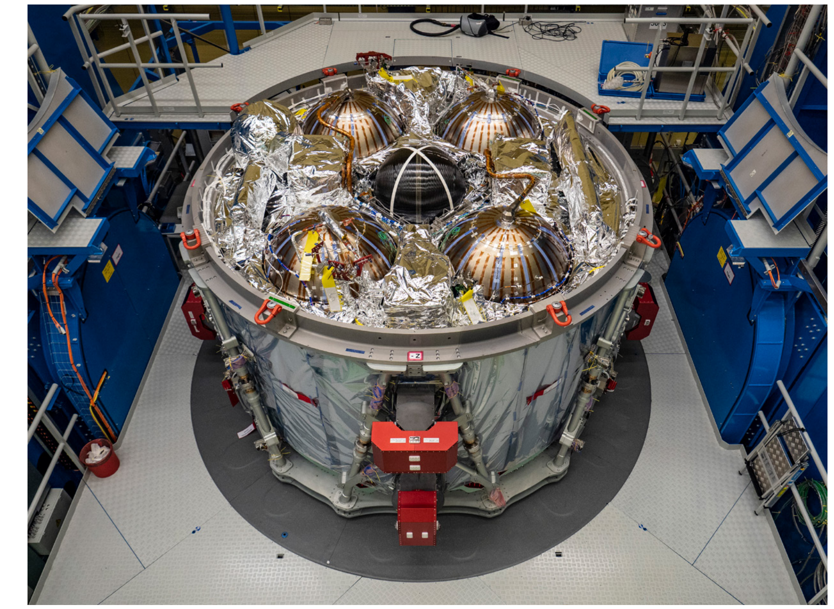
Shock environments are defined in terms of the drive-point acceleration shock response spectrum (SRS), but the shock force is not readily available. The NESC team noted the that the drive-point acceleration can be complex, while the underlying shock force is simple, leading to a simpler model of the force. This methodology attempts to construct a TFE forcing function (FF) that replicates the drive-point absolute acceleration SRS to within ±3 dB. The TFE FF can then be applied to the drive point and predict the SRS throughout the system, whether it is a finite element model (FEM) based or test based (i.e., tap test). Though a fundamental departure from prior shock prediction methodologies, the TFE validation work, which used NASA's ShockSat test data, met the SRS prediction accuracy of ±6 dB for FEM-based and ±3 dB for test-based TFE methods. *This work was performed by GSFC, ASD, LaRC, and JPL.* NASA/TM 202300110680, NESC Technical Bulletin No. 23-03.



TFE prediction against actual data from a satellite model.

Unconservatism of LEFM Analysis Post-Autofrettage

In 2020, an NESC team of structures and materials experts found a lack of conservatism in the damage tolerance analyses conducted on COPV liners using linear-elastic fracture mechanics (LEFM), particularly in understanding the influence of autofrettage (AF). During AF, a COPV is subjected to high pressures to compress the inner surfaces, making them less susceptible to operational stresses later. The team employed testing, finite element analysis validated by test data, and NASGRO simulations (computer programs that analyze fracture and fatigue crack growth) to study crack growth in elastic cycles with and without the AF cycle. They used strains and elastic cycles that enveloped typical COPV stress ratios.

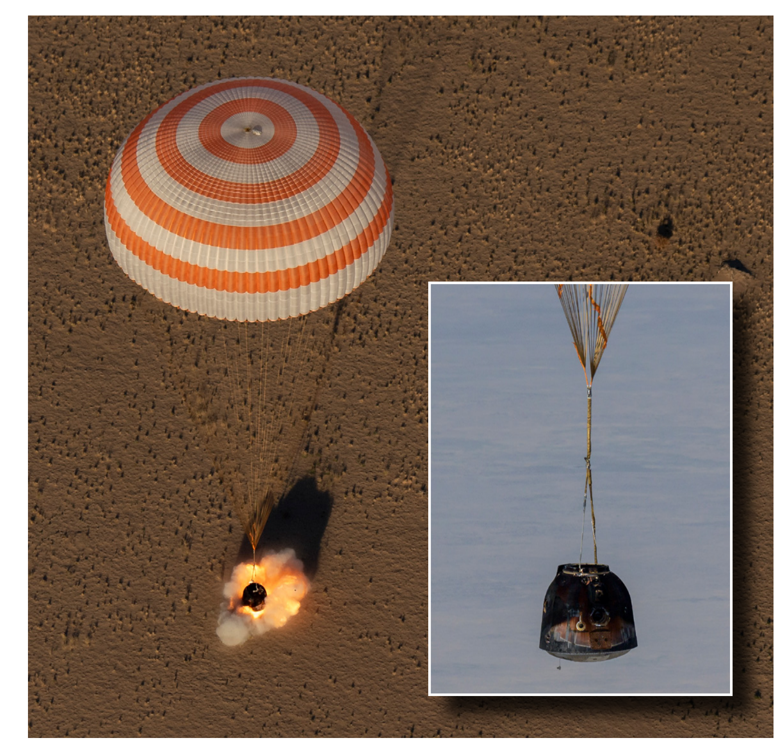


COPVs are used extensively in the Orion spacecraft service module.

In verifying damage tolerance life, the team found that separating the AF cycle from subsequent elastic cycles in LEFM analysis led to unconservative life predictions. Cracks remained open during compressive cycles after AF and allowed for a larger stress range to contribute to crack growth in each subsequent elastic cycle. Currently, ANSI/AIAA S-081B *Space Systems-Composite Overwrapped Pressure Vessels* provides baseline requirements for COPV damage tolerance analyses but does not account for this detrimental influence of the AF cycle. As a result, the team provided corrections to NASGRO that make predictions less unconservative. See related article on page 55. *This work was performed by GRC, LaRC, JSC/WSTF, KSC, and JPL.* NASA/TM-20230013348.

Simulating Crew-Seat Landing Loads for Soyuz Vehicles

Before the SpaceX Crew Dragon Capsule began flying NASA astronauts to and from the ISS, U.S. and Russian crews traveled in Soyuz vehicles. Unlike Dragon's water landings, Soyuz vehicles touch down on land using a combination of a parachute and soft-landing engines to reduce the vehicle descent velocity. Risk-prediction tools like anthropomorphic test devices (ATD) and the Brinkley Dynamic Response Criterion help NASA estimate vehicle seat loads experienced by crew during landings. But these loads data were not available for the Soyuz. To better understand those loads, an NESC team of human factors and biomechanics modeling experts developed an FEM of the Soyuz descent module and landing environment.



Soyuz decent module landing (inset) and firing of soft-landing rockets to reduce landing loads.

The team generated a semi-deformable model of the Soyuz module and interior components to capture the acceleration loads transferred to the occupant compartment during landing. Human surrogate ATD models and biomechanically representative human body models were incorporated into the Soyuz seat models. The assessment team then simulated generalized landing-condition distributions to identify the effects of landing on vehicle/seat response. *This work was performed by ARC, LaRC, JSC, and Texas A&M University.*

Unique Science from the Moon in the Artemis Era

Since the beginning of the space age, the Moon has been proposed as a platform for astronomical observations. With Artemis missions returning humans to the lunar surface in the 2020s, there has been renewed interest in using the Moon as a location for studies ranging from observing the solar system to studying the early universe. The NESC brought stakeholders together for an interdisciplinary workshop to explore leveraging the Artemis era infrastructure to conduct unique science experiments and observations from the lunar surface. They addressed maximizing return on investments, advancing synergistic approaches between human and robotic exploration, and identifying and addressing key engineering challenges and risks including lunar dust; communications/navigation; preserving the radio-quiet far-side environment; extreme thermal conditions; power generation/storage; and lighting.

Key takeaways included developing sustainable and synergistic science and human exploration programs by designing future observatories or instruments deployed on the lunar surface using the Hubble Space Telescope model, where standards were followed to make the hardware astronaut friendly for assembly and repair. And early-stage integration of decadal-level science requirements into the Artemis Program would be key to leveraging the lunar surface as a platform for science opportunities. *This work was performed by GSFC, JSC, WSTF, GRC, KSC, MSFC, ARC, NASA Headquarters, Johns Hopkins Applied Physics Laboratory, University of Colorado, Endless Frontiers, and Space Science Solutions.* NASA/TM 20220017053.

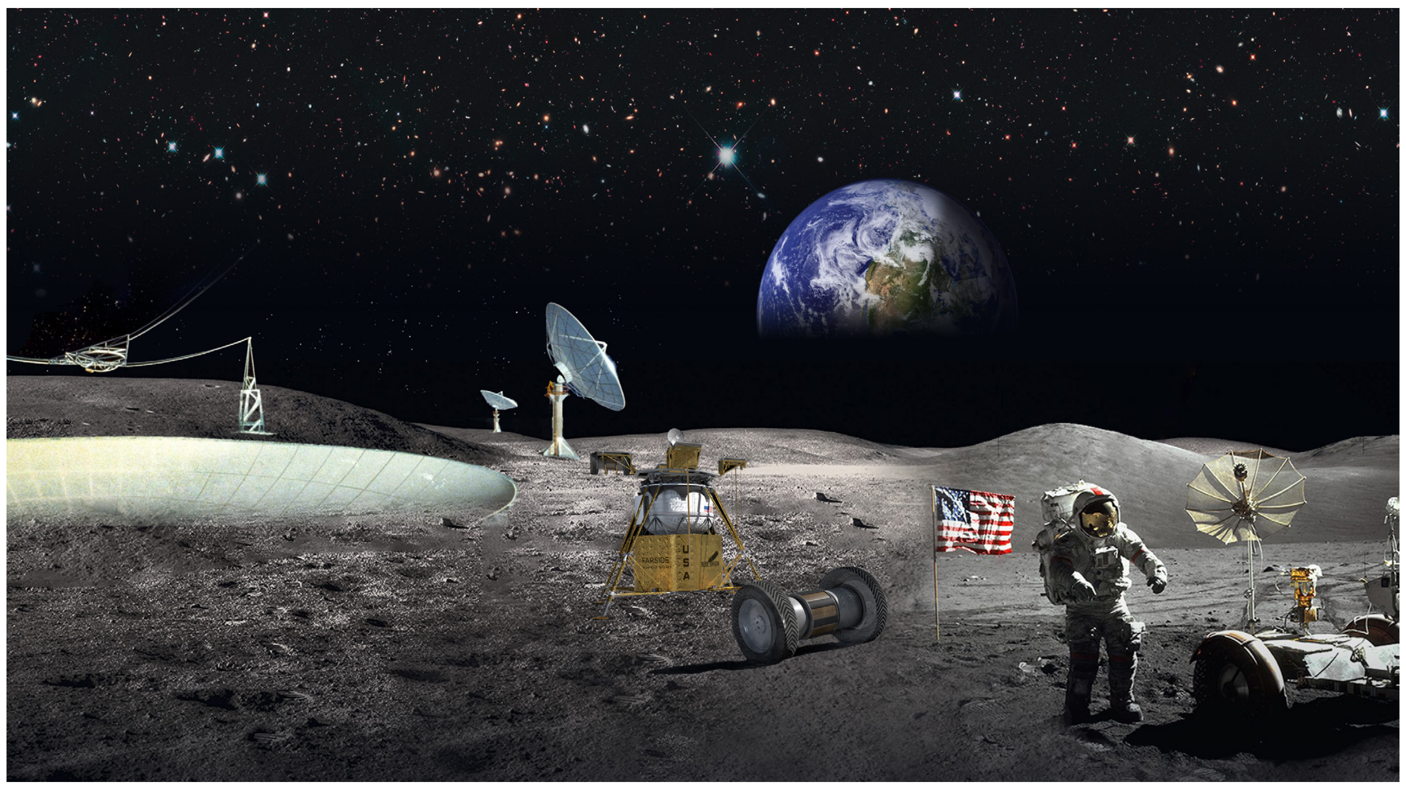


Illustration of multiple science instruments operating from the lunar surface.

Priority 3 In-Progress Assessments:

- Nuclear Electric Propulsion Technology Maturation Plan Non-Advocate Review
- SpaceVPX Interoperability Open Standard
- NASA's Meteor Shower Forecasting Sustainability
- NASA Space Observatory Precision Pointing Benchmark Problem Development
- Phased Array Microphone System Development
- AACT Risk Reduction Project - Safe Life Category
- AACT Risk Reduction Project - in Situ Monitoring Category
- AACT Risk Reduction Project - Metallurgy Category
- Assessment of Degradation in Microfabricated Detectors and MEMS Devices
- NESC COG Technology Development
- Thermophysical Properties of Liquid TEA-TEB
- Test and Modeling to Predict Spacesuit Water Membrane Evaporator Failures
- Characterization of Internal Insulation Thermal Performance
- Occupant Protection Testing
- Parachute Reefing Line Cutter Modification and Qualification
- Southern Hemisphere Meteoroid Environment Measurements

Priority 3 In-Progress Support Activities:

- Rocket Lab Triboelectric Support
- Review of Propulsion Motor Design for ARMD
- Cryogenic Fluid Management Support to DARPA
- Sandia National Lab Cooperative Agreement
- NASA-STD-6001 Revision C Variable Investigation Testing
- Human System Interactions in Closed Breathing Systems
- EPIC/Athena Assessment Group

Priority 3 Completed Support Activities:

- GSFC SE Future Capability Independent Review Team
- TALOS Project Venting
- Low Temperature Coefficient of Thermal Expansion Measurement Capability
- OSAM-1 Human Factors Support

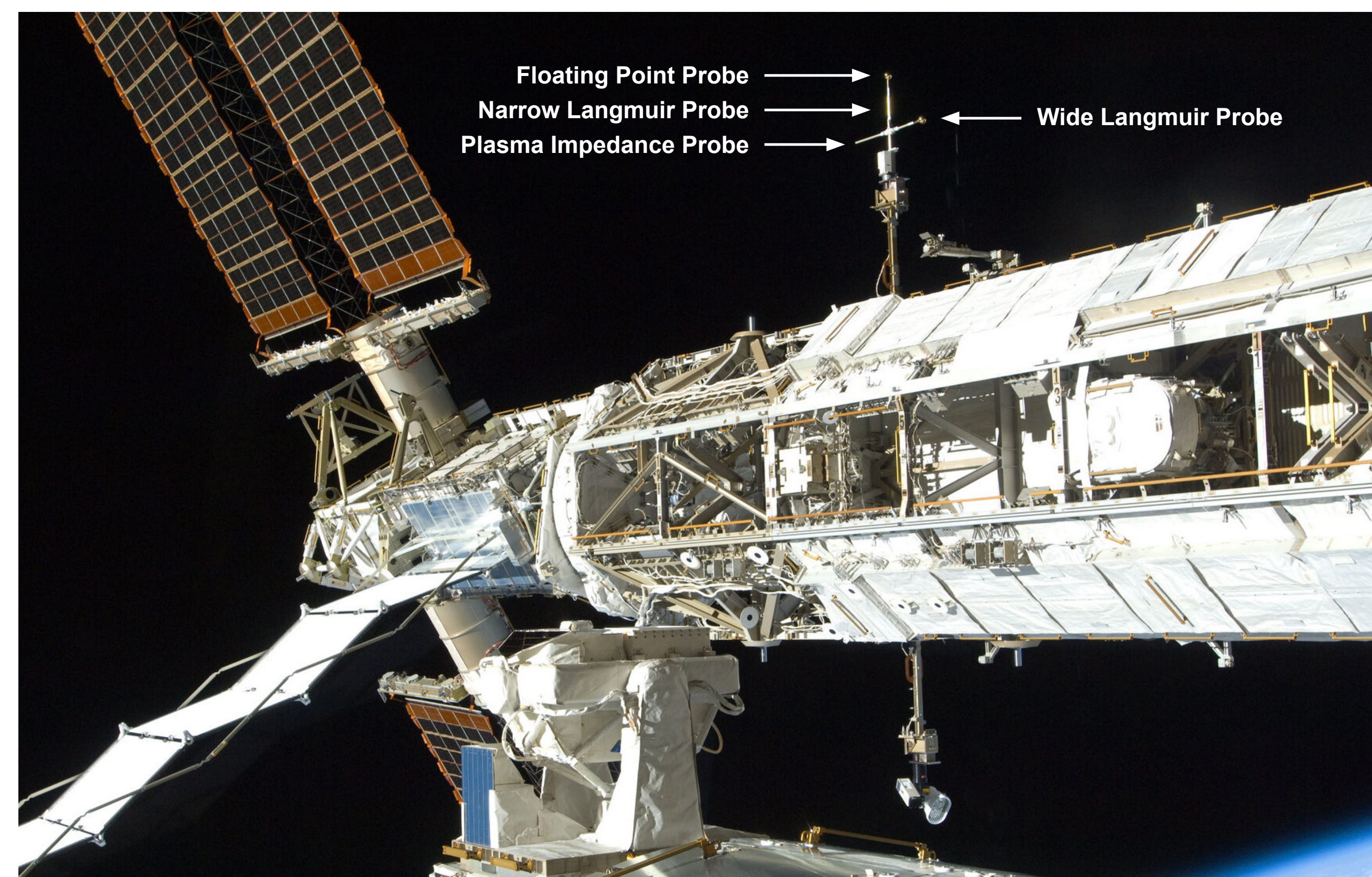
Priority 4: Work to Avoid Potential Future Problems

Assessments Completed in FY23

Updating Measurement of the ISS Charging Environment

The Floating Potential Measurement Unit (FPMU), a suite of four plasma instruments, has operated on the ISS since 2006 to monitor the charging environment around the station for astronaut safety during extravehicular activities (EVA). Additionally, data from the FPMU Langmuir and impedance probes also proves valuable to the science community in studying the LEO plasma environment. Operating well beyond its intended life span, the FPMU's algorithms had not been optimized to maximize its full potential for providing science-quality data, and age-related issues needed to be addressed.

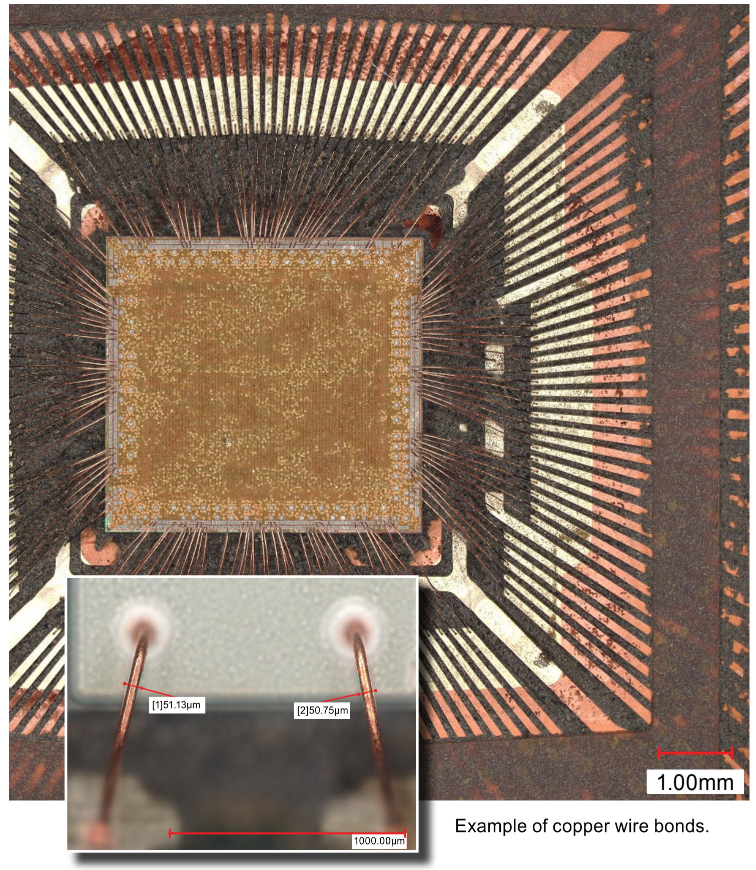
The NESC brought in subject matter experts from Embry-Riddle Aeronautical University to work with the MSFC FPMU data analysis team to help improve the data quality and instrument utility. The goals were to modify the algorithms to improve the quality of estimates of plasma density, plasma temperature, and spacecraft potential parameters, and use the algorithms to evaluate FPMU data for significant events. After extensive analysis, the team developed a modified algorithm that corrected erroneous artifacts in the data and provided estimates consistent with ground-based incoherent scatter radars and the FPMU's coexisting impedance probe. Continued evaluation and monitoring should ensure the health of all FPMU components and that the FPMU data quality does not degrade with time. *This work was performed by MSFC and Embry-Riddle Aeronautical University.* NASA/TM-20230013386.



FPMU mounted to an ISS truss.

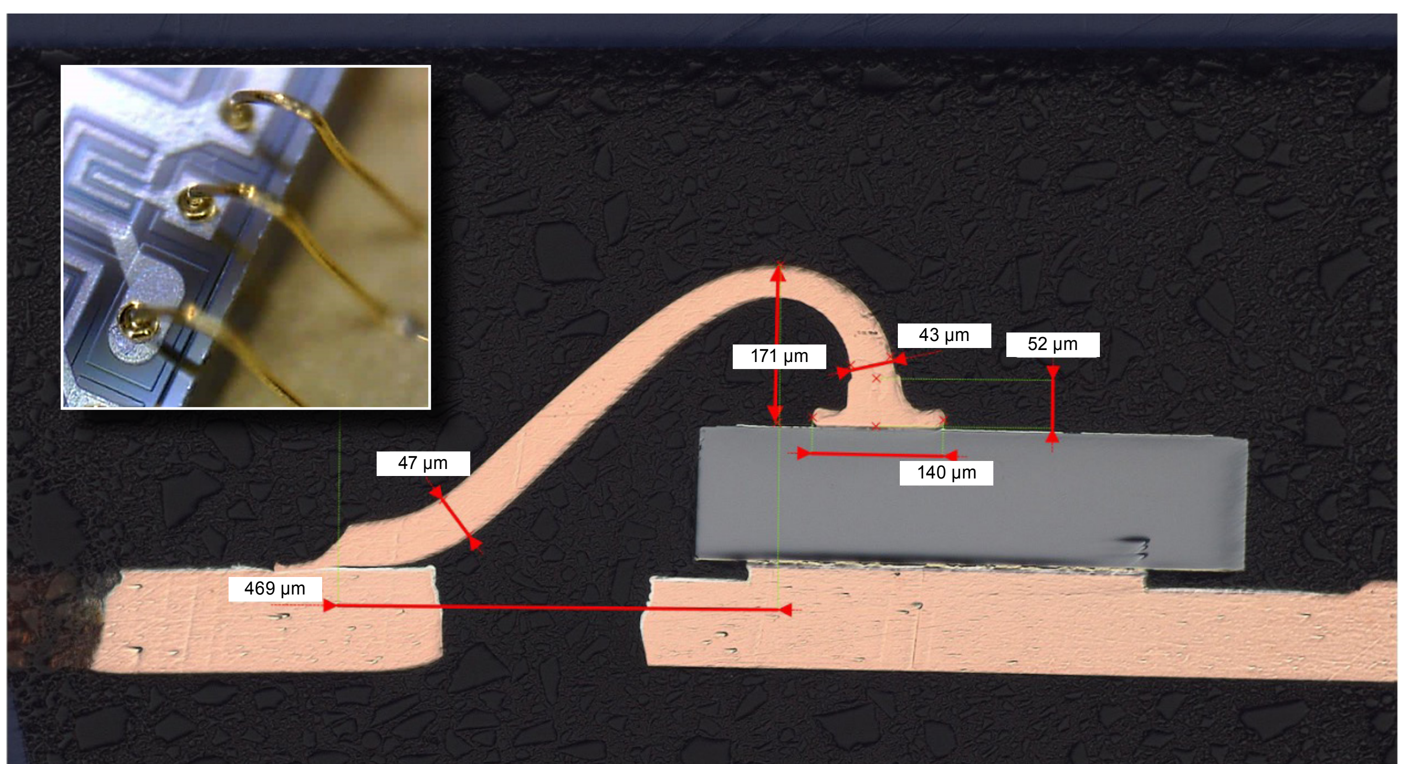
Determining Reliability of EEE Parts Copper Wire Bonds for Space Programs

Economics as well as the thermal and electrical properties of copper wire have driven the replacement of gold wire bonds in the majority of commercial semiconductor devices, especially for new and emerging technologies. Aside from being more economical than gold, copper has a 25% lower electrical resistivity, 30% higher thermal conductivity, 75% higher tensile strength, and 45% higher modulus of elasticity. But there are concerns with their use in high-reliability applications with long-mission lifetimes. To date, no military standard for copper-bond-wire qualification or standards for destructive physical analysis and plastic encapsulated microcircuit construction analysis have been developed.



Example of copper wire bonds.

This knowledge gap prompted the NESC to look at bond-technology data for copper and other materials and determine the reliability of copper-wire bonds. A team of avionics experts performed a combination of construction analysis, mechanical testing, environmental testing, and statistical analysis to determine the reliability of copper-wire-bonded parts at the part and assembly levels. They used mission, environment, application, and lifetime (MEAL) conditions and existing MEAL projection models to determine test conditions that encompassed the widest range of NASA mission conditions. Based on results for the parts tested, they found the reliability of copper wire bonds to be comparable to gold bonds. The team also developed screening and lot acceptance testing guidelines for evaluating copper-wire bonds in plastic parts for a range of NASA flight conditions and mission risk classifications. *This work was performed by LaRC, JPL, GSFC, JSC, KSC, WFF, MSFC, and OSMA.* *NASA/TM 20230014536*.



Example of gold wire bonds. Wire bonds transfer electrical signals to/from an integrated circuit's external terminals and the internal microcircuits.

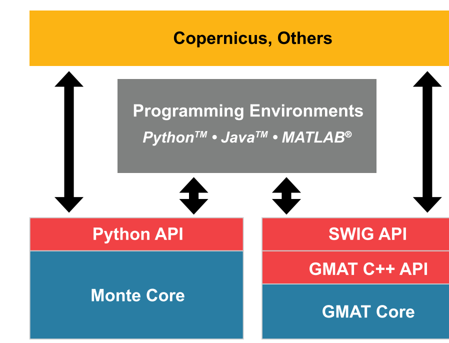
Priority 5: Work to Improve a System

Assessments Completed in FY23

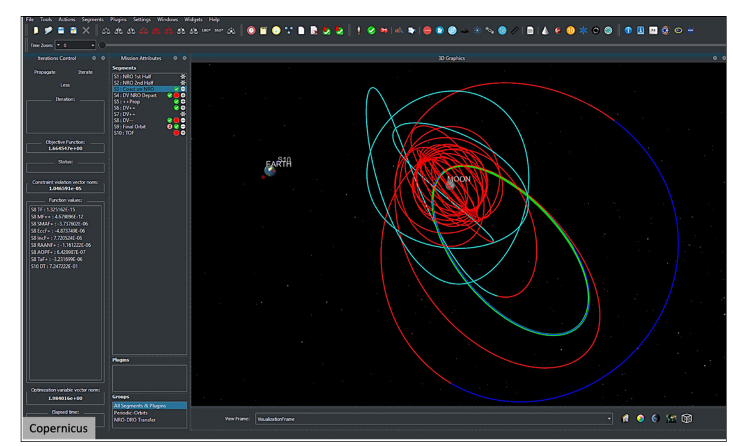
Flight Mechanics Analysis Tools Interoperability and Component Sharing

Over the years, NASA Centers have developed flight mechanics tools to support their own unique goals and missions. From Copernicus and General Mission Analysis Tool (GMAT) to the Mission-Analysis Operations Navigation Toolkit Environment (Monte), the tools provide maneuver planning, orbit determination, error analysis, trade studies, and flight products for a variety of spaceflight regimes and mission lifecycles. Because each tool was tailored for a specific center and the missions it supported, each had variations in capability, and as such, could not easily share data, models, or components.

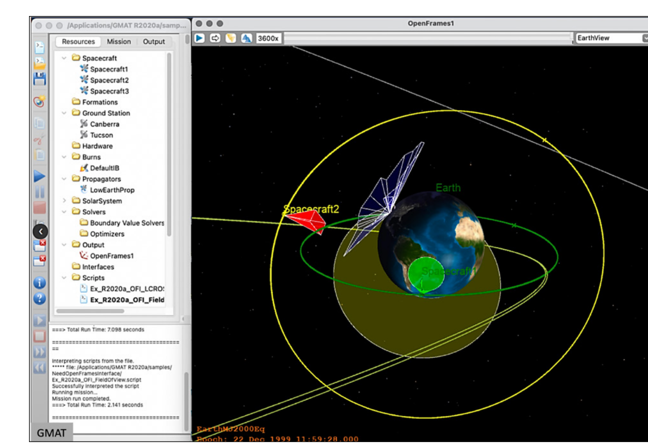
In 2018, the NESC began analysis of a framework that could connect the tools and allow users to leverage the strengths of each with a goal of increasing Agency efficiency and reducing costs. An enterprise system of systems using application programming interfaces (API) and plugins was developed to enable interoperability between tools. The team focused on high-level task development areas including GMAT-Monte, GMAT-Copernicus, and Monte-Copernicus interoperability. The newly developed functionality between these commonly used tools enables solutions to more complex trajectory design problems than can be accommodated with each individual tool by itself. Use cases developed under this effort are available and demonstrate the new interfaces, plug-ins, graphics updates, and trajectory transfer features. *This work was performed by MSFC, GSFC, LaRC, JSC, and JPL.* NASA/TM 20230006507, NESC Technical Bulletin No. 23-05.



System-of-systems approach to interfacing Copernicus, Monte, and GMAT functionality.



Copernicus OpenFrames 3D Graphics Implementation.



Updated GMAT using Copernicus OpenFrames 3D Graphics Implementation.

Priority 4 In-Progress Assessments:

- Design/Test of Battleship Hypergolic Propellant Thruster
- Lessons Learned on DART NEXT-C Ion Engine
- BON GCR Model Improvements
- Wire and Wire Bundle Ampacity Testing and Analysis
- Solderless Interconnects and Interposers

Priority 4 In-Progress Support Activities:

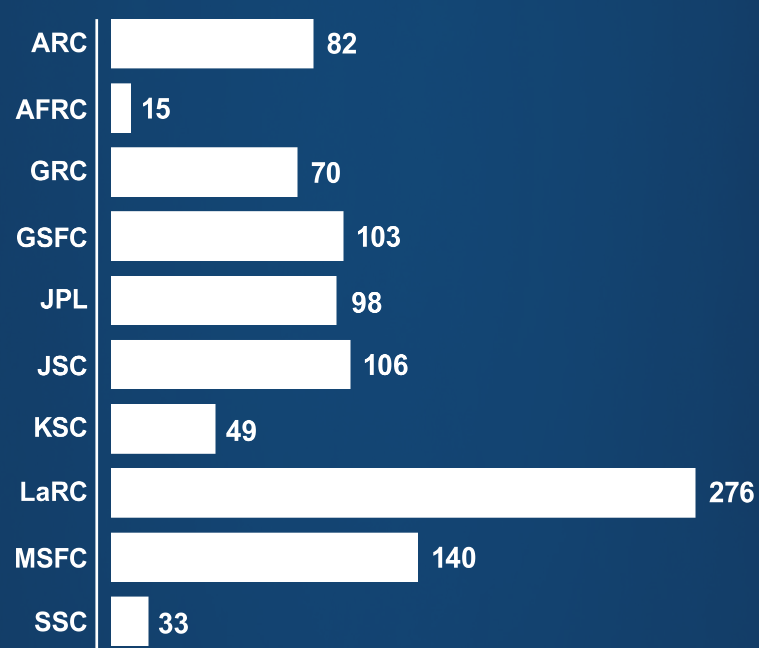
- Parachute Design Guidelines Revision and Development

Priority 5 In-Progress Assessments:

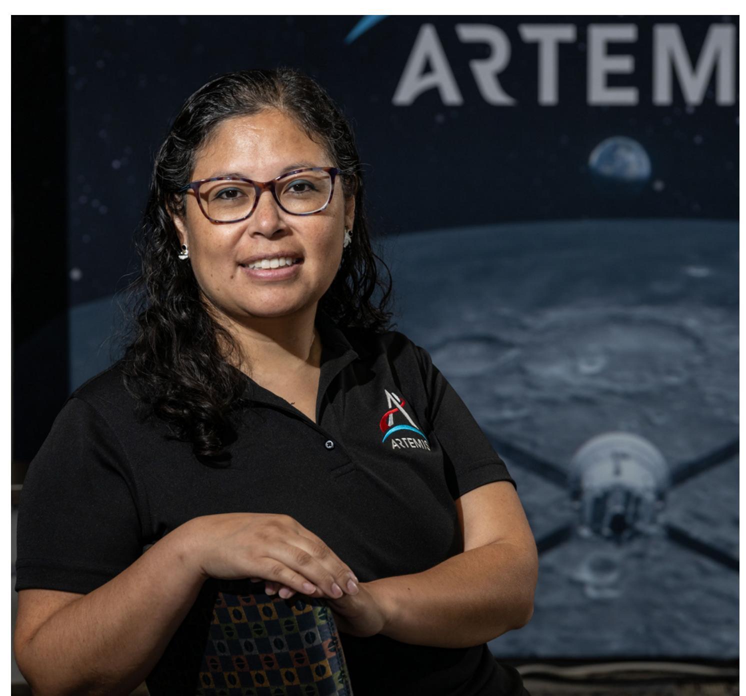
- Updates and Modernization of the CEA Code
- Frangible Joint Working Group
- NASA Quantum Sensing Capability

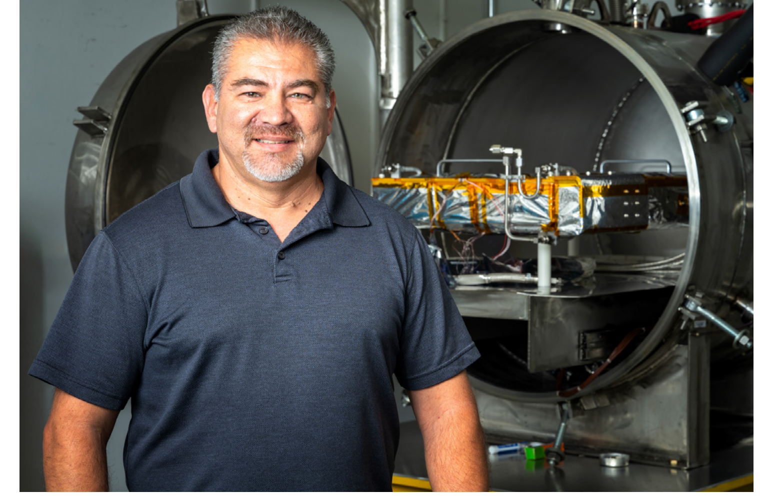
NESC AT THE CENTERS

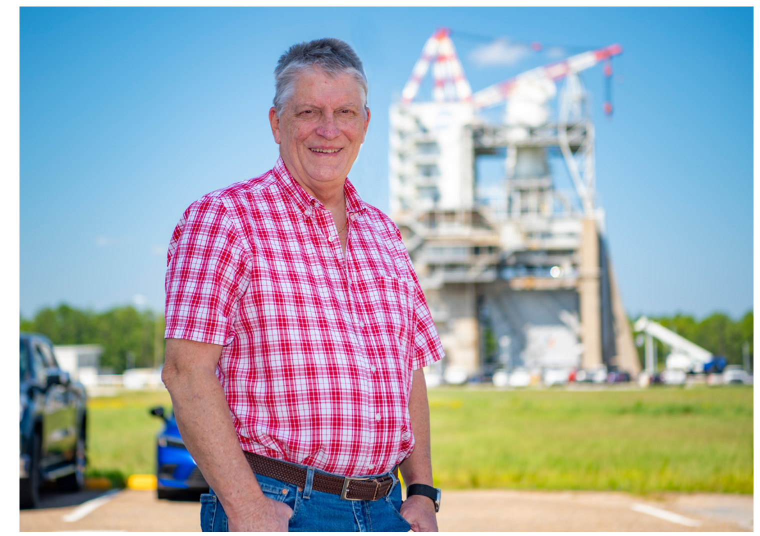
Meet the engineers and scientists who lend their expertise to NESC technical activities.

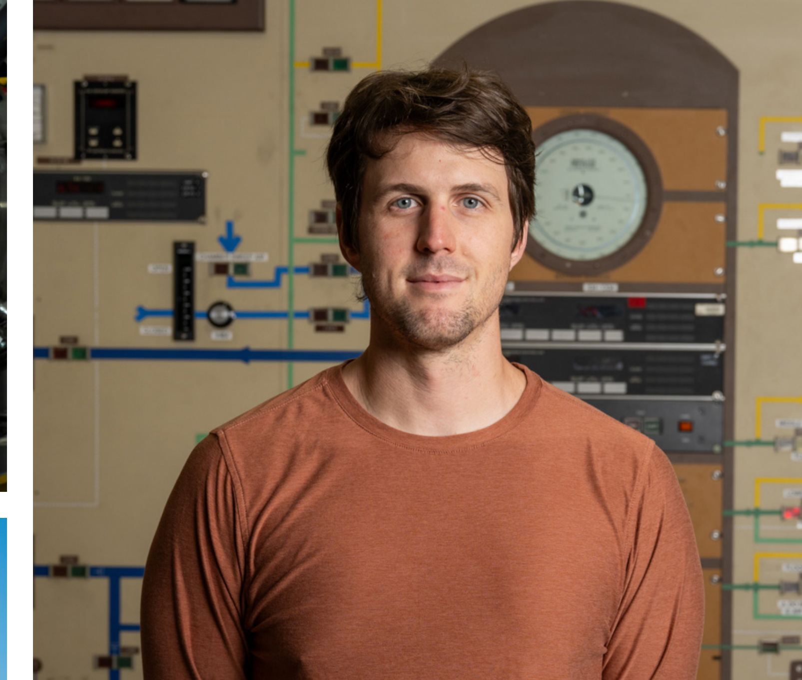


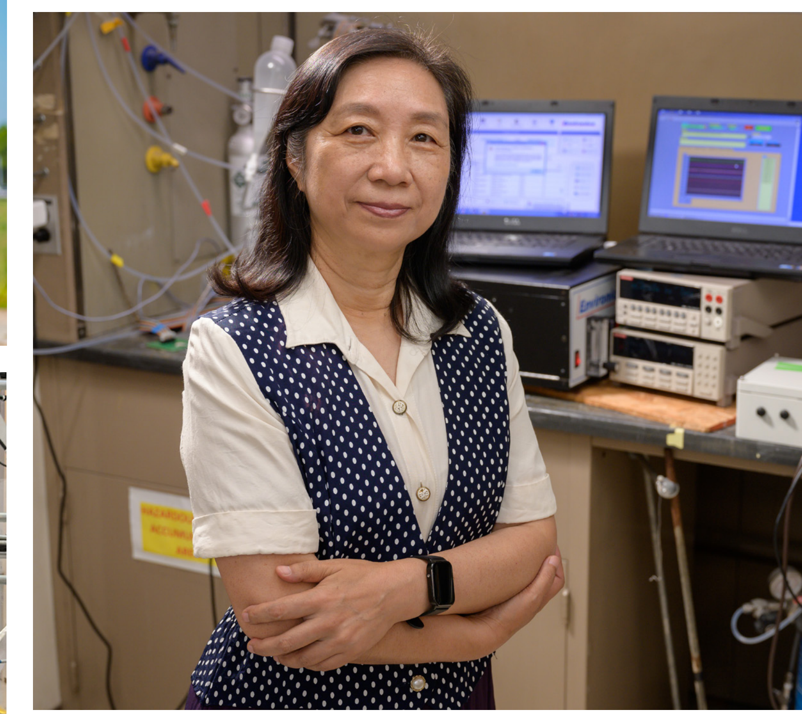
972 CENTER EMPLOYEES SUPPORTED NESC WORK IN FY23

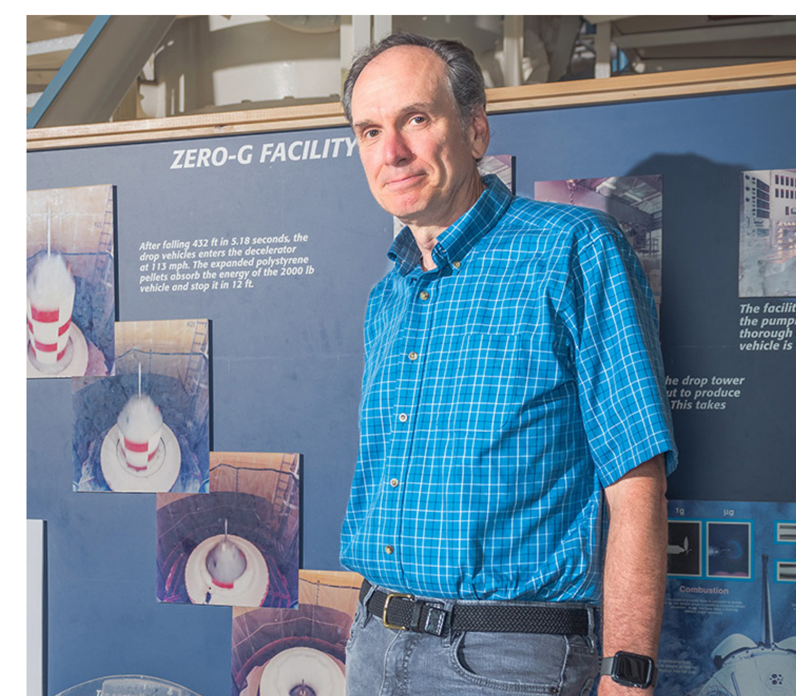












Ames Research Center

Kenneth R. Hamm, Jr., NESC Chief Engineer
82 ARC employees supported NESC work in FY23

The Ames Research Center (ARC) supports a diverse suite of capabilities for the NESC, including advanced computing, software, aerodynamics testing, intelligent systems, aerothermal/entry, descent, and landing (EDL) modeling, thermal protection materials, and human factors research. Technical Fellows for Aerosciences and Human Factors are both resident at ARC. Personnel at ARC are represented on 18 NESC Technical Discipline Teams and supported 22 independent technical assessments and studies including: Independent EDL Modeling for Commercial Crew Program, Verification of Testing Standard for CO_2 Partial Pressure in Extravehicular Activity Suits, and Orion Crew Module Heatshield Avocat Char Investigation. This year's profiled individuals participated directly in these assessments and demonstrate the diversity of expertise present at ARC.

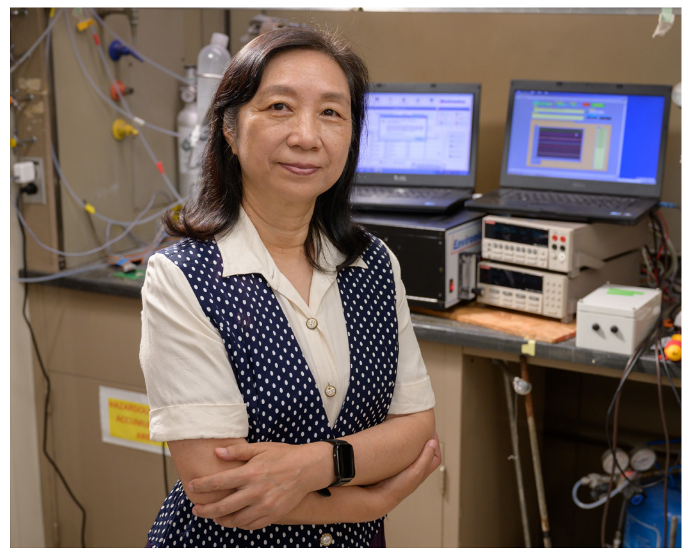
Dr. Sarah D'Souza

As a member of two NASA Technical Discipline Teams (TDT), Dr. Sarah D'Souza brings her expertise to Flight Mechanics, where her focus is on overall vehicle dynamics, and to Guidance, Navigation, and Control, where that focus shifts to the mechanics and algorithms needed to steer that vehicle. She finds her work with both TDTs vital to her job as the ARC Deputy System Manager for Orion's Thermal Protection System.

"Both TDTs have people with many different viewpoints who don't shy away from sharing them, which is really important. It's the only way we flesh out things properly, explore all the avenues, and debunk what isn't right. That lets us find the path that makes sense for solving a problem."

That team diversity is a fundamental tenet of the NESC, which Dr. D'Souza and her Orion team have been working with to find the root cause of a heatshield anomaly with analyses, scanning, and arcjet testing to find solutions for future Artemis missions.

"I can't think of a better job than working for Orion, to be part of a project where we understand there's no cutting corners. Human beings are going to be on the next Artemis mission. It is exciting and at the same time, a great responsibility to make sure we do this right."



Dr. Jing Li

Dr. Jing Li, a member of the Sensors and Instrumentation TDT, is a leading expert in the development and implementation of new sensor technologies. Her expertise also includes sensor-module miniaturization, where she works to make sensors smaller, lighter, and low power. Her background and contributions were integral to the NESC's efforts to verify the testing standard for carbon dioxide (CO_2) in extravehicular activity suits. Because Dr. Li builds chemical sensors, including those for CO_2 detection, she had the first-hand experience and in-depth knowledge required for this assessment. She built her own custom sensors, which allowed successful verification of test data, and supported the design and build of a unique test apparatus. In addition, she developed new laboratory procedures to support testing and provided detailed laboratory notes and data analysis that were crucial to the success of the effort. "This was my first NESC assessment, and the work was very complicated. I worked online as well as in the lab at JSC."

Dr. Li is also responsible for organizing the Sensors and Instrument TDT monthly webinars in which she brings in speakers from other centers or universities to discuss all aspects of sensor development. "I enjoy the chance to meet many people from different disciplines and different centers. I learn so much from them."

Armstrong Flight Research Center

Dr. W. Lance Richards, NESC Chief Engineer
15 AFRC employees supported NESC work in FY23

The Armstrong Flight Research Center (AFRC) provided engineering technical expertise to multiple, high-profile NESC activities across the Agency, industry, and the Department of Defense (DoD). AFRC pilots and life support specialists supported an NESC task to train the DoD on how to use pilot-worn instrumentation systems, which are essential to acquire critically important pilot breathing parameters in flight. Specifically, they assisted their counterparts and life support engineers on the F-35 Joint Strike Fighter, Integrated Test Force, and the new USAF Trainer, the T-7A Red Hawk program, all at Edwards Air Force Base, CA. These efforts were in direct support of the nation's efforts to better understand the underlying reasons for physiological episodes in the DoD fleet of tactical aircraft. Additionally, AFRC engineers and instrumentation specialists from the Fiber Optic Sensing System team designed the instrumentation layout for a large scale cryogenic tank, installed the sensor array, and supported drop-tower testing at Dugway Proving Grounds, UT.

Daniel Jones

Mr. Daniel S. Jones is an aerospace engineer in the Aerodynamics & Propulsion Branch at AFRC. After working as a mechanical draftsman/designer in the private sector for 11 years, he joined NASA in 1999. Since that time, his primary duties have been focused on flight testing, flight research, and ensuring airworthiness of advanced propulsion systems. While at NASA AFRC, Mr. Jones has contributed to several high-visibility projects including the X-43A/Hyper-X, the Orion Pad Abort 1, and the Aeronautics Research Mission Directorate Test Data Portal. For the past seven years, he has been a member of the NESC Propulsion Technical Discipline Team (TDT), where he participates in monthly and annual meetings with propulsion experts across the Agency and the country.

"The TDT meetings have been incredibly valuable, not only for growth within my expertise, but also to provide insight for potential collaborative opportunities," he said. He finds the face-to-face meetings as particularly beneficial to build rapport with counterparts at other NASA centers and to understand capabilities across the Agency. "The two most important roles for me within the TDT are to look for growth opportunities for members within my branch and to look for opportunities where AFRC can contribute to Agency-level goals."

Francisco Peña

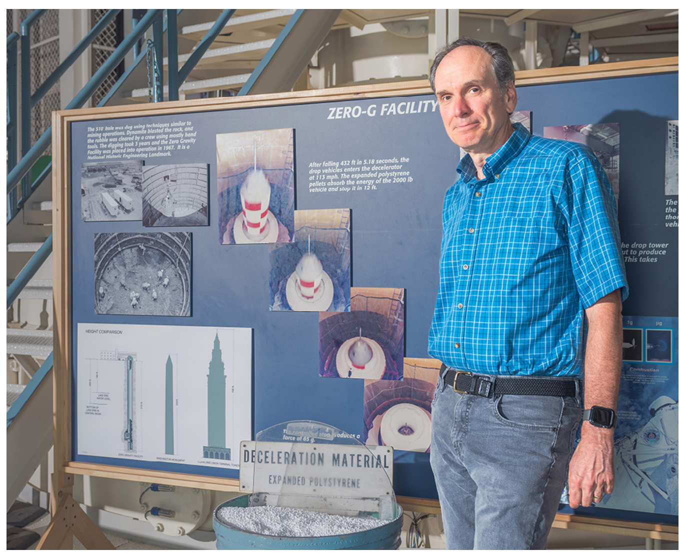
As part of the AFRC Fiber Optic Sensing System (FOSS) Team, Mr. Francisco Peña assisted the Commercial Crew Program in analyzing strains on a structure undergoing testing. "We installed nearly 300 fiber optic sensors to help identify strains at locations where two different materials came together," he said. "The FOSS allows us to make measurements at half-inch intervals, so we can cover a good portion of the surface of a structure. In this case, measurements couldn't be made with a camera system, and to get the distributed strain or stress measurements needed, fiber optics was the only technology that would work in that specific scenario where the line of sight to the structure was obscured."

Mr. Peña collected and plotted strain data from the fiber optics, which gave a good visualization of where the highest stresses were occurring on the structure. He and the FOSS team have supported several NESC assessments, particularly in cases where conventional strain gage and thermocouple technology cannot provide the data needed. "We are constantly making improvements to the FOSS to reduce measurement uncertainty, and it evolves depending on the mission we are supporting. If we don't already have a technique a customer is looking for, then we will develop it."

Glenn Research Center

Robert S. Jankovsky, NESC Chief Engineer
70 GRC employees supported NESC work in FY23

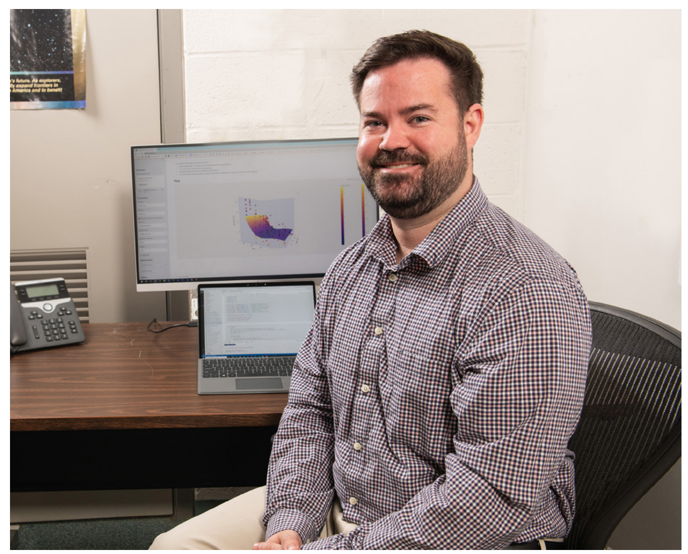
The Glenn Research Center (GRC) provided a broad spectrum of technical expertise to 36 NESC technical assessments/activities and 19 NESC Technical Discipline Teams (TDT). These activities supported all NASA Mission Directorates and several cross-cutting discipline efforts. Significant GRC contributions this year were in support of understanding friction stir weld processes and breathing systems on high-performance aircraft. The NASA Technical Fellows for Cryogenics and Loads & Dynamics and deputies for the Cryogenics, Electrical Power, Materials, Thermal Control & Protection, Propulsion, Nuclear Power & Propulsion, and Software TDTs, are resident at GRC.



Dr. Daniel L. Dietrich

Technology developed by Dr. Daniel Dietrich was key to helping the NESC understand how pilots interact with the breathing systems of their high-performance aircraft. A combustion researcher by training, Dr. Dietrich is uniquely familiar with how oxygen (O_2) is consumed to produce carbon dioxide (CO_2), which is also important to human physiology. He helped develop a portable monitor to measure human metabolic function in ground and spaceflight environments using O_2 and CO_2 sensors he created. That technology was ultimately used in several high-visibility breathing studies the NESC performed to assist the U.S. Navy and Air Force understand the cause of physiologic episodes in pilots of their F/A-18 and F-35 aircraft fleets.

"For the first time we could instrument a pilot to measure physiologic states in flight and the impacts of the flight environment on the pilot," he said. "The O_2 and CO_2 sensors evolved from an effort to understand whether a candle could burn in a purely buoyant-free (microgravity) environment, and from there we thought we could develop an instrument that could measure metabolic function. What started as a study in understanding whether a steady candle flame could exist in the absence of gravity ends up examining how fighter pilots breath in tactical aircraft. It was rewarding to bring technology we've developed at Glenn to a practical implementation."



Dr. Josh Stuckner

Dr. Josh Stuckner applied data analytics and machine learning to assist the NESC in finding the root cause of friction stir weld anomalies on fuel tanks. "We had a team of excellent subject matter experts and managers working as a whole to figure out the issue and recommend solutions," he said. As part of his role to design the set of experiments, he employed a space-filling design that required fewer tests but provided more valuable information on a much wider range of settings. This let the team identify how best to control the weld parameters, like spin and speed, that were needed to generate better friction stir welds.

"What I really enjoyed about this project was being part of an investigation that affects the NASA mission now. My typical work is long-term materials research and developing tools to speed up materials research, which takes a while to have an impact. Even now it can take up to 20 years for a new material to go from being discovered in the lab to having commercial viability. So, it was great to apply all these techniques I've been learning and developing to a project that impacts NASA now, and then get really good results with them. I felt I was part of the NASA you hear about when you're a kid."

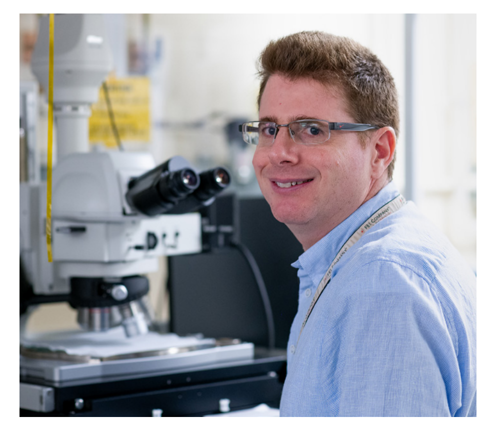
Goddard Space Flight Center

Carmel A. Conaty, NESC Chief Engineer
103 GSFC employees supported NESC work in FY23

The Goddard Space Flight Center (GSFC) supported a wide range of NESC work including 57 assessments, numerous support activities, and 18 Technical Discipline Teams. Key activities included Mars Sample Return (MSR) Micrometeoroids and Orbital Debris Protection Review, MSR Orbiting Sample Models Review, MSR UV-C expert consulting, Galvanic Corrosion in Microfabricated Detectors and MEMs Devices, Avionics Packaging Engineering Processes and Best Practices, Psyche Independent Review Board and Psyche RAD750-V3, Use of Commercial-off-the-Shelf Guidance for NASA Missions, EEE Parts Copper Wire Bonds for Space Programs, and Verification of Testing Standard for CO_2 Partial Pressure in EVA Suits. NASA Technical Fellows for Systems Engineering and Mechanical Systems, and the NESC Integration Office liaison for SMD, STMD, and ARMD, reside at GSFC.

Jonathan Boblitt

Programmable logic devices (PLDs) have become commonplace in avionics, but no standard exists across NASA for their development. As the PLD community lead with expertise in field programmable gate arrays (FPGA), a type of PLD, Mr. Jonathan Boblitt has been working with the NESC to develop consistent guidance for their development. "An FPGA standard will go a long way in making sure that NASA and Goddard produce quality FPGA designs consistently across all the projects," he said. His work on this assessment also led to his involvement in an NESC investigation of an FPGA anomaly. "My team and I peer reviewed an extensive fault tree and analyzed several FPGA designs to find a cause and solution to the anomaly," said Mr. Boblitt. "When I am working with people across all the NASA centers, there's just always something new to learn. I love working the issues and being able to tackle these large problems."



Dr. Ari Brown

As part of the Detector Systems Branch at GSFC, Dr. Ari Brown has often observed degradation of the thin metallic films he uses to build microfabricated detectors and microelectromechanical systems devices. "These degradations usually reveal themselves in a discoloration of the metal, which can increase electrical resistance or other issues that make these components unusable for our applications," he said. Long thought to be the result of galvanic corrosion, Dr. Brown worked with the NESC to finally find the root cause of the problem as opposed to costly workarounds usually employed by projects. Their investigation revealed unwanted materials, which largely took the form of metal oxides, were causing the degradation issues, which could be solved with simple mitigations. "The NESC takes a scientific approach to understanding the problem and finding a mitigation strategy based on analytical evidence. They have an unbiased perspective of the issue, and that's invaluable, because even within projects there can be strong biases."

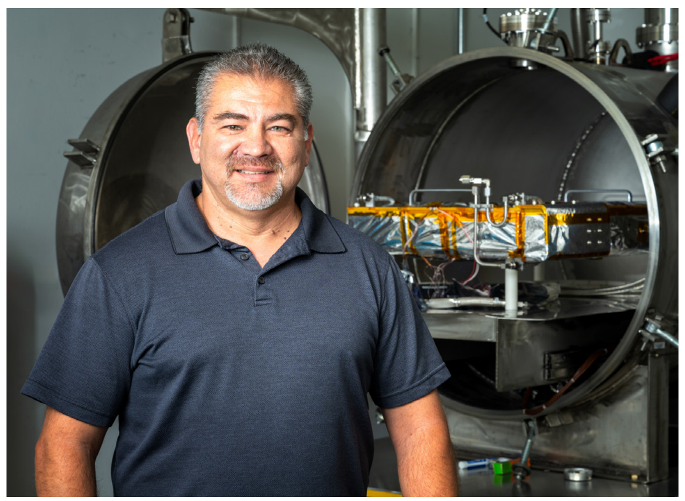
Beth Paquette

Ms. Beth Paquette is leading NESC efforts to gather avionics packaging best practices that will lead to the development of guidelines and processes for the Agency. She has been talking with packaging engineers across the centers. "The lessons learned we are collecting, especially from our more experienced engineers, is often knowledge that has never been written down," she said. "This also gives us a better understanding of what packaging looks like from center to center, because we all have different ways of operating based on the missions we support." Ms. Paquette also leads communities of practice including Avionics Packaging and Additive Manufacturing of Electronics. "For the last few years, my focus has been on research and development, like advanced packaging technologies and electronics additive manufacturing. We've been doing testing and working through the best practices for 3D printing, from the design phase to creating a tool path to the actual printing."

Jet Propulsion Laboratory

Kimberly A. Simpson, NESC Chief Engineer
98 JPL employees supported NESC work in FY23

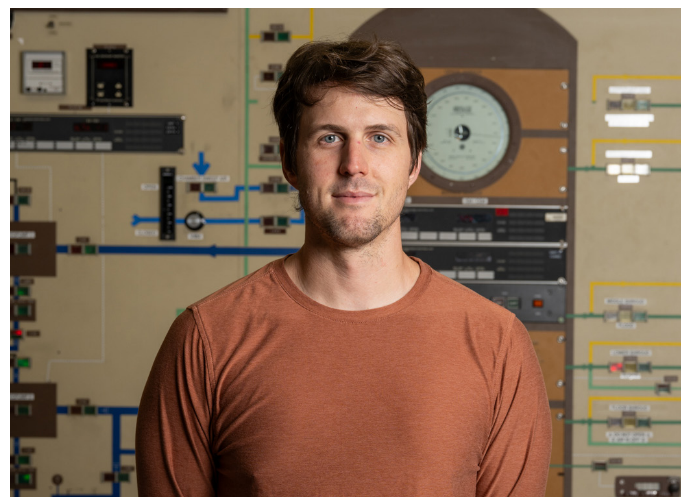
The Jet Propulsion Laboratory (JPL) provided technical leadership and engineering expertise to 27 new or ongoing NESC assessments and 19 Technical Discipline Teams (TDT) in 2023. JPL's expertise in composite overwrapped pressure vessels (COPV), avionics, software, environmental monitoring, additive manufacturing, mechanical structures, and thermal analysis supported assessments for a variety of NASA's Mission Directorates. Significant contributions included assessment of Electrical, Electronic, and Electromechanical Parts Copper Wire Bonds, wire and wire bundle ampacity testing and analysis, LOX-methane quick disconnect testing and analysis, and thermal testing in support of lunar glove analysis. Over 50 JPL employees served on TDTs working with NASA Technical Fellows on advancement of Agency engineering initiatives. JPL provides leadership for the COPV Working Group and the Space Environments, Electrical Power, and Mechanical Systems TDT deputies reside at JPL.



Raymond Higuera

Mr. Raymond Higuera is a Manufacturing Engineer/Lab Manager, a dual role that offers him the opportunity to oversee flight hardware builds and testing. "It's almost a hybrid position where I do both engineering and hands-on work," he said. This made him a good fit for the NESC's efforts to improve models and techniques for wire ampacity determination. "The primary objective is to develop a tool that will help determine ampacity limits based on wire lengths and sizes, power requirements, and environments. We are testing different wire configurations in various environments to develop the parameters that would be plugged into this tool."

The work has involved not only procuring and installing equipment and instrumentation into a test chamber, but also constructing several large wire bundles—up to 139 wires and 12 feet in length. The chamber provided both Earth- and space-like environments and temperature ranges from -50 to 70 °C. "Having all of these variables increases the accuracy of that tool." As his first experience working with the NESC, Mr. Higuera appreciated the collaboration with different NASA centers. "There are specialists everywhere you go, and talking to someone from another center gave me a different perception of how they work."



Wade Smith

Mr. Wade Smith is the testbed lead for the CITADEL (Cryogenic Ice Transfer, Acquisition Development, and Excavation Laboratory) at JPL. Mr. Smith manages multiple projects from conceptual design to test execution within CITADEL, a cryogenic testing chamber that can mimic icy moon environments with temperatures down to 50 K. and atmospheres at near-vacuum pressures. He is currently assisting the NESC with a durability analysis of astronaut gloves. "We're going to the dark side of the Moon for Artemis, and we need to understand the survivability of the glove materials and the material response to these extremely cold temperatures." He has designed the test that will include a specially designed mannequin hand that can mimic blood flow as well as an assembly system that will allow the hand and glove to flex. The data generated from the tests will help create the requirements for the development of new gloves.

The work he does is very hands on, which Mr. Smith enjoys. "As engineers, we can spend all of our time in front of a computer and forget what it's like to actually build things, put them together, and test them, which is the kind of work I like." He said working with the NESC "lets us work with other centers. At JPL, we can be physically isolated here on the West Coast. These projects help remind us that we're all a part of NASA."

Johnson Space Center

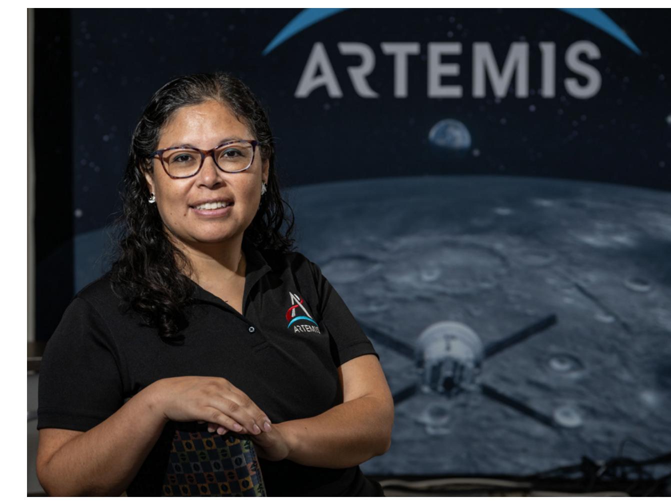
Joel W. Sills, NESC Chief Engineer
106 JSC employees supported NESC work in FY23

The year 2023 was an exciting and productive year at the Johnson Space Center (JSC) and the White Sands Test Facility (WSTF) as engineering, test, and operations personnel realized their contributions to the first successful Artemis I flight, including the Orion crew module landing and recovery. This past year, diverse engineering teams continued their support of multiple sustaining and new emerging programs including the ISS, Commercial Crew, Gateway, the Extravehicular Activity and Human Surface Mobility Program, and the Commercial Low Earth Orbit Destinations. The resident NASA Technical Fellows and engineering teams continue to investigate the Artemis I Orion heatshield char loss and the release and retention bolt erosion. Support continues for multiple propulsion and lunar material investigations and the Russian PrK crack investigation team. Resident NASA Technical Fellows continue their mission with Agency discipline leaders to strengthen technical community connections through joint sponsorship and participation in NASA, other governmental, and academia activities.

Erica Bruno

As the Loads and Dynamics (L&D) Section Manager for Jacobs Technology, Ms. Erica Bruno has spent much of her career supporting JSC engineering. A long-time member of the L&D Technical Discipline Team (TDT), she has worked on several NESC efforts including reviews of Space Launch System environments, Exploration Systems Development models, and Commercial Crew booster re-use. "L&D encompasses so much. Between low and high frequency, random vibration, shock, and acoustics, there's always something more to learn," said Ms. Bruno. "You are one of the first groups of a project paving the way because sizing of your hardware can't be done until you have loads."

In her work on assessments with the TDT or the Structures, Loads and Dynamics, Materials, and Mechanical Systems Early Career Community, Ms. Bruno appreciates the multidisciplined nature of NESC work. "I've been at JSC for most of my career, so I'm familiar with my Center's programs. But through the NESC, I get experience with other projects, analyses, and techniques that engineers across the Agency are working on. As part of these multidisciplined teams, you get other perspectives beyond just the JSC perspective. And if you have a question, you can reach out to others who have expertise in that area and not have to reinvent the wheel."



Dr. Jackelynne Silva-Martinez

As a member of the Systems Engineering TDT, Dr. Jackelynne Silva-Martinez led a study on Agile teams across the Agency to identify leadership outcomes that allow them to be more adaptable and flexible to change. She said Agile got its start in software development and has gradually broadened its impact. To gage NASA's incorporation of Agile principles, the Systems Engineering TDT paired with the Software and Human Factors TDTs to develop interview questions for Agile teams located at all 10 centers. "Using that feedback, we are formulating a NASA Agile Community of Practice (CoP) where Agilists can share their work, lessons learned, and best practices from their Agile transformations to help increase the workforce Agile capability across the centers."

Her work with the TDTs is also helping her shape the Agency's Agile CoP. "The TDTs help us provide ideas and collaborate across the entire Agency, and the accessibility to see what others are doing in their own centers helps us find solutions to problems." The same goes for Agile. "If leaders can empower their teams to deliver increasing value founded on open communication and frequent feedback within a transparent and collaborative environment, then a continuous learning mindset is developed in the organization's culture that allows them to be comfortable with uncertainty."

Kennedy Space Center

Stephen A. Minute, NESC Chief Engineer
49 KSC employees supported NESC work in FY23

Kennedy Space Center (KSC) personnel provided technical expertise to 41 NESC activities and Technical Discipline Teams (TDT) in 2023. They engaged in numerous NESC assessments including programmable logic device guidance and standard, spacesuit water membrane evaporator testing, galvanic corrosion and degradation of metallic films on circuit boards, and material sensitivity to hypergolic exposure. Likewise, the NESC supported KSC programs, providing parachute review and analyses and assessments of booster hot gas intrusion and tape flammability risk for the Commercial Crew Program and mobile launcher design and peer reviews for Exploration Ground Systems. The NESC also invested in KSC's laboratories to evaluate anaerobic hydrogen sensor development and perform spacesuit water membrane evaporator and commercial crew portable fire extinguisher testing. The NASA Technical Fellow for Electrical Power resides at KSC and relies on KSC expertise.

René Formoso

Following the Artemis II launch, Mr. René Formoso will be busy checking the results from the new microphone phased array (MPA) system that will be installed ~400 feet from the launch pad. "MPA will capture sounds coming off the mobile launcher platform from the vehicle to identify acoustic impingement zones during launch," he said. Mounted 132 feet up on a lighting tower, MPA will have 70 microphones, multiple cameras, and accelerometers to help NASA better understand how sounds translate as Artemis II lifts off. "The data we collect will help improve mobile launcher and sound suppression systems for future launches."

Mr. Formoso's years of experience in managing research and technology projects have been vital to the NESC's efforts to get MPA to the finish line with the design of mounting equipment as well as verifying and validating the system. He put MPA through its paces during engine hot fire tests at SSC as well as the NG-19 launch at the Wallops Flight Facility. "Every launch environment is different. So having this technology will help us understand how sound affects not only the ground systems but the rocket as well, which will help us keep the crew safe. The NESC is focused on reducing risk, and this MPA technology is reducing the risk of damaging hardware, the vehicle, or those on board." See MPA Innovative Technique on page 62.

Teresa Kinney

Ms. Teresa Kinney has spent more than 30 years performing dynamic analyses, including loads analysis and modal testing of large space structures that flew on Space Shuttle missions, including Spacelab and ISS. Today, as the acting Gateway Deep Space Logistics Chief Engineer and one of three deputies for the NESC Loads & Dynamics TDT, she has brought her expertise to several NESC assessments, including evaluating data from the Space Launch System modal and rollout tests and peer reviewing landing loads for the Commercial Crew Program. "Modal testing helps you understand how the hardware is going to behave and gives you confidence you will not fly outside of predictions," she said.

"There are only a few areas where you can't test like you fly, and loads is one of them. So you do your best to model and analyze the hardware as accurately as possible to predict the loads you could see in flight; then you reconcile those predictions with measured flight data. What I like most about this work is that you get smarter about testing from the analysis, and you get smarter about the analysis from testing. It's very interactive." In her work with the NESC, Ms. Kinney said she enjoys "the exposure to many different ways of doing things and to expertise across the Agency, which I find very exciting."

Langley Research Center

K. Elliott Cramer, NESC Chief Engineer
276 LaRC employees supported NESC work in FY23

The NESC continues to rely heavily on the unique expertise available in the Langley Research Center (LaRC) workforce. In FY23, 276 LaRC employees participated in more than 70 assessments, engaging in activities such as computational fluid dynamics analyses of the Mars Sample Return Earth Entry System; nondestructive evaluation and materials characterization to establish the bond verification process for the block Avcoat heatshield architecture used on the Orion spacecraft; modeling and simulation for Commercial Crew Program entry, descent, and landing; and quantitative material compatibility and environmentally assisted cracking data collection for propulsion system metals in the hypergolic propellant environment. Multiple LaRC facilities such as the Transonic Dynamics Tunnel, the Vertical Spin Tunnel, and the Light Alloy Laboratory were used in support of NESC activities. These efforts allow NASA to achieve its vision of exploring the secrets of the universe for the benefit of all.

Dr. Brett Hiller

Working for LaRC's Configuration Aerodynamics Branch, Dr. Brett Hiller's research focuses on aerodynamic design, analysis, and optimization for next generation vehicle concepts and technologies. This expertise made him a vital asset in the NESC's assessment of the Mars Sample Return (MSR) Earth Entry System's (EES) dynamic stability. "There was some uncertainty in the dynamic stability through the slower subsonic and transonic flight ranges," said Dr. Hiller. Wind tunnel test delays led the team to pursue complementary estimates for dynamic stability during reentry using computational fluid dynamics (CFD) simulations.

"We evaluated the static and dynamic aerodynamic performance of the flight-scale MSR-EES across its subsonic flight envelope, varying angle of attack and Mach number, and simulated two different wind tunnel configurations to provide test facilities with computational aerodynamic estimates for wind tunnel sting corrections." The year-long effort took place during the pandemic. "Thankfully, we effectively communicated across multiple centers and successfully completed the assessment. It was one of the first projects that exposed me to production-level CFD and estimating the performance of a model over a large portion of its flight range, so it has been an exciting and invaluable experience as an early-career engineer."

Dr. David Dawicke

A Senior Scientist for Analytical Services and Materials, Inc., Dr. David Dawicke has worked at LaRC for more than 30 years and has spent nearly 20 of them participating in NESC technical assessments. His expertise has proven invaluable on investigations into the Space Shuttle, ISS, Aries I-X, Mars 2020, CLARREO climate observatory, Orion, and Gateway Programs. As a member of the NESC Structures Technical Discipline Team, he has provided long-term support to NESC activities involving fatigue and fracture, composite overwrapped pressure vessels (COPV), frangible joints, specialized structural and material testing, and digital image correlation.

Recently he examined the standard that outlines the damage tolerance requirements for COPVs with metallic liners, helping the NESC team demonstrate experimentally and analytically that the approach allowed by the standard was unconservative. "We also came up with an approach that could be used to account for this unconservatism, and we're working to get that into the standard now," said Dr. Dawicke. "I have enjoyed working with the NESC on solving relevant, challenging problems with technical experts in many different fields. Each problem has been unique and required the implementation of existing skills and tools, the development of new skills, and collaboration with experts in fields outside of my experience."

Marshall Space Flight Center

Steven J. Gentz, NESC Chief Engineer
140 MSFC employees supported NESC work in FY23

The Marshall Space Flight Center (MSFC) continues to provide exceptional engineer, scientist, and technician subject matter expert support to 64 NESC technical activities involving exploration systems development, space operations and environmental effects, science, and crosscutting discipline activities. Some of the more significant efforts included mishap investigation, materials compatibility, model-based systems engineering, high-temperature insulation, advanced chemical propulsion, modeling and simulation of launch vehicle/spacecraft interfaces, and human factors task analyses. The NASA Technical Fellows for Propulsion, Space Environments, Environmental Control & Life Support (ECLS), Flight Mechanics, and Systems Engineering, and the Technical Discipline Team (TDT) Deputies for Propulsion, Nuclear Power & Propulsion, Materials, Space Environments, Loads & Dynamics, Nondestructive Evaluation, ECLS, Structures, Sensors & Instrumentation, and Software are resident at MSFC.

Amanda Drake

In her work managing NESC resources at MSFC, Resource Analyst Ms. Amanda Drake enjoys the opportunity to support the Agency and its mission. “I work across different areas of leadership, stakeholders, and managers, both inside and outside of NASA,” she said. “I also interface with vendors for the work and services we need to support the mission.” For the last 4 years, she has provided invaluable support at her Center. “I'm in charge of committing or reserving funds and getting them put on contract. That includes developing a realistic budget that matches NESC obligations, not just for the fiscal year, but looking 5 years ahead as well.” For more than 20 years, she has supported NASA projects as a contractor and civil servant, learning both the industry and government sides of the budget process. “I enjoy this type of work, especially the number crunching. I have always had a love for math, and that is why I enjoy the aspect of analyzing the data.”

Dr. Jessica Gaskin

As the Sensors & Instrumentation Deputy Technical Fellow, Dr. Jessica Gaskin supports the NASA Sensors & Instrumentation Technical Fellow in leading the TDT, coordinating monthly and yearly meetings, and supporting NESC assessments including workshopping quantum sensors. She specializes in science mission high-energy detector systems and X-ray optics. “It's such a brilliant philosophy—bringing together experts to solve a potential problem before it happens. It's that proactive engagement by the NESC that sets it apart from other organizations within NASA. Our TDT has members from every center, industry, academia, federally funded research and development centers, and other government agencies. It's a network of incredible experts who can put aside their organizations' politics to solve complex problems. It's a wonderful resource that science missions don't always know about.” Dr. Gaskin has made it her mission to let internal and external stakeholders know about the NESC.

Ilana Lu

Ms. Ilana Lu led weld characterization efforts to find the root cause of cryogenic tank self-reacting friction stir weld (FSW) anomalies. “FSW allows you to join materials like aluminum-lithium alloys that are difficult to fusion weld. Those materials are typically chosen for tanks because they perform well cryogenically and offer mass savings.” Ms. Lu, a welding engineer, managed the weld experiment preparation, specimen testing, and metallurgical evaluation of the hundreds of welds performed for this NESC assessment. “We gathered a lot of good data on what causes these anomalies, and we understand the welding process an order of magnitude better than we did previously. I think it's going to be really impactful for the friction stir welding community.” She credits the team for the successful outcome of the assessment. “Our team was the perfect combination of multidisciplinary experts in statistical analysis, machine learning, and metallurgy. That's been a real highlight of the work.”

Stennis Space Center

Michael D. Smiles, NESC Chief Engineer
33 SSC employees supported NESC work in FY23

Expert technical support was provided to the NESC by Stennis Space Center (SSC), including subject matter expertise in systems engineering, test operations, and data analysis and modeling. SSC also supplied technical expertise, labor, and facilities at the A-1 Test Stand for the NESC microphone phased-array system testing. The phased-array system was successfully operated during an engine firing and will eventually be utilized at KSC for the Artemis II launch. Additionally, SSC provided the data analysis and modeling technical lead for the NESC Liquid Oxygen-Methane Assessment. Several SSC engineers are valuable members of the NESC's Systems Engineering and Nondestructive Evaluation Technical Discipline Teams.

Dr. Daniel Allgood

Dr. Daniel Allgood is leading the data analysis and modeling of liquid oxygen (LOX) and liquid natural gas (methane) as part of an NESC assessment of the hazards and risks associated with these propellants. Detonation of these propellants is highly energetic and extremely hazardous if not controlled, said Dr. Allgood. “At Stennis, our focus is on rocket testing, so we generally don't look at the mixing dynamics of these cryogenic propellants in a launch vehicle failure scenario. We're diving into a whole new area of physics that has been exciting but quite challenging.” Dr. Allgood is leading a team of multi-center and multi-Agency modeling experts to inform the safe design and operation of launch vehicles using these propellants.

“The combustion modeling of LOX-methane as a condensed phase explosive is a new area no one has attempted. We've modeled much of the mixing dynamics so far and made progress in validating the combustion models. But we still have a long way to go to help the test teams understand the physics, the development of their tests, and how to interpret the data they collect.” He is enjoying the challenges this unique assessment offers. “This is the first chance I've had to work as the technical lead of a team. It has allowed me the great opportunity to view things from a leadership perspective versus just my own individual perspective.”

Lester Langford

At SSC for 33 years, Mr. Lester Langford is highly skilled in the logistics of his Center. “I've worked here a long time, and I can get things done,” said the electrical design engineer the NESC called on to coordinate the testing at SSC of a new microphone phased array (MPA). The ARC-built MPA will eventually be mounted ~460 feet away from KSC's Pad 39B to identify and pinpoint transient engine acoustic sources during the next Artemis launch. But first it was put through its paces during an RS-25 engine test at the SSC A-1 Test Stand. “It was a validation test on a stationary source before taking it to Wallops for testing during a launch,” Mr. Langford said.

In the more than a year it took to plan and coordinate the effort, Mr. Langford sited the MPA test area, had a large asphalt test pad built, and assisted in the assembly of the array when it arrived from ARC and construction of the more than 100-foot-tall scaffold to hold it. He also set up power, purge lines, and network connections to get the MPA data back to a control center. “When you look at the data, it is amazing,” he said of the test results, which will ultimately help improve sound suppression at the pad. “It will be an enhancement of the systems at KSC that help keep people and the launch area safe. It's going to be a good thing.”

NESC KNOWLEDGE PRODUCTS

Capturing & Preserving Critical Knowledge from NESC Assessments & Support Activities

The NESC is engaged in activities to identify, retain, and share critical knowledge in order to meet our future challenges. To disseminate that knowledge to engineers—within NASA, industry, and academia—the NESC develops a wide variety of knowledge products that can be readily accessed.

Explore these products at:
NASA.GOV/NESC

Documented results of independent testing and analysis delivered to the requesting stakeholders.

Useful knowledge gained from experience.

- *Lessons Learned Information System (LLIS)*
- *NESC Academy*

Critical engineering information or best practices captured in a one-page, quick-read format.

New and creative engineering approaches developed during NESC technical activities.

Citations for publications summarizing NESC technical activities for discipline-specific audiences.

Annual reports of NESC technical activities.

An online community where NASA employees can collaborate with peers and discipline experts.

NESC Academy
NASA Engineering & Safety Center

NESC Academy Enhancements

New Features Make It an Improved Resource for Career Development, Knowledge Transfer, and Training

Nearly two decades of NASA knowledge sits waiting to be learned—a wealth of information readily available to all employees and contractors—but it remains a largely untapped resource. The NESC is working to change that.

Since 2005, the NESC Academy has collected and housed more than 1,000 videos and webcasts from researchers, engineers, and field experts in 21 NASA technical disciplines. "I was blown away by the content available," said Ms. Carmel Conaty, the NESC Chief Engineer for GSFC. She led training and development programs at GSFC but until joining the NESC had never heard of the Academy.

"Many engineering supervisors have challenges finding training for employees, especially early-career engineers, because what NASA does is very niche oriented. And as budgets are cut for training and development, having this kind of specific discipline content is invaluable."

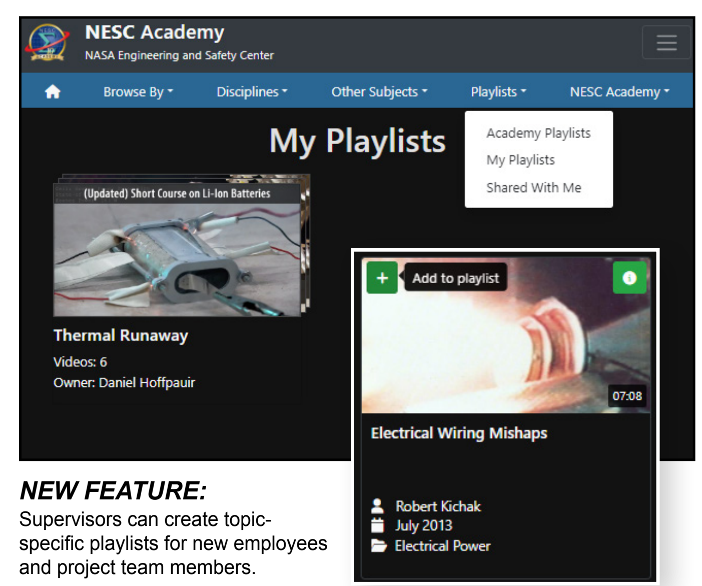
She worked with the NESC Academy developers to make its library of content more accessible and usable by the NASA workforce and increase content on discipline fundamentals. "We really want to augment this capability, especially for early careers. At Goddard, a large percentage of our engineering workforce is eligible to retire now or within the next five years. That will be a huge loss, so we want to continue to capture that knowledge, especially in our niche disciplined skills, and have state-of-the-art capabilities that allow the workforce to find and learn that knowledge. And we want to give supervisors the ability to assign just-in-time training to their employees."

Developers enhanced the site with a more user-friendly interface, better search capability, and the option to create playlists tailored to user interest. For supervisors, Ms. Conaty said they can create topic-specific video lists. "If employees will be supporting a thermal vacuum test, for example, the supervisor could create a playlist of videos on that topic to watch beforehand," she said.

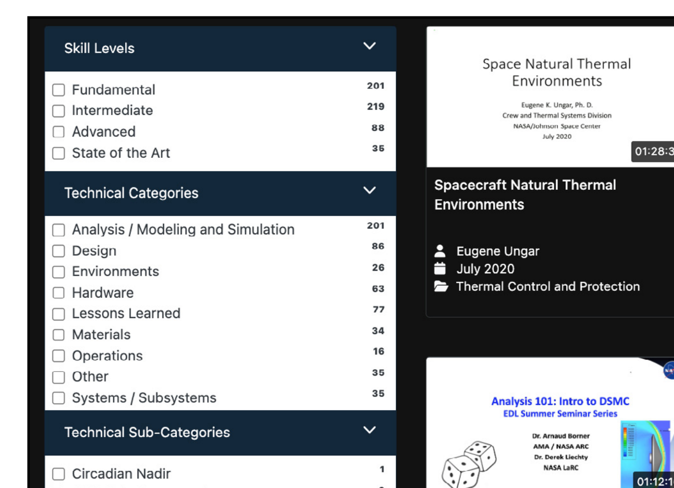
"It also exposes engineers to the broader NASA network, not just their own center or project. Often people can get siloed early in their careers, and this is a way for them to lift their heads up and see what's going on across the Agency."

Ms. Conaty adds that the NESC Academy is not meant to replace in-person training. "It's just one more thing we can do to help retain our engineers. I think it's everyone's responsibility within the NESC and the Agency to engage in the development of NASA engineers."

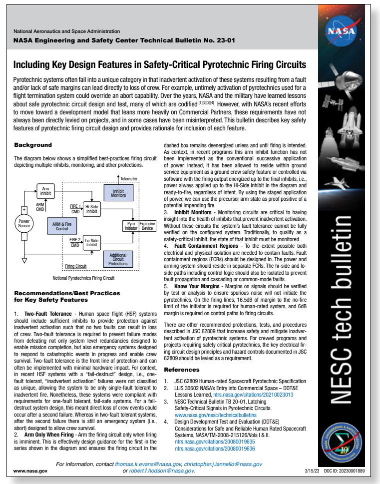
NESCACADEMY.NASA.GOV



NEW FEATURE:
Supervisors can create topic-specific playlists for new employees and project team members.



NEW FEATURE:
Videos are now rated by skill level and technical categories.



Technical Bulletin No. 23-01

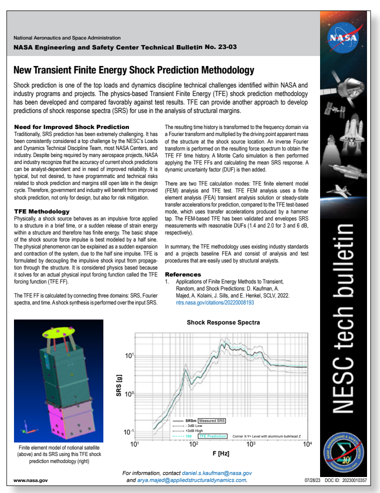
Including Key Design Features in Safety-Critical Pyrotechnic Firing Circuits

Pyrotechnic systems often fall into a unique category in that inadvertent activation of these systems resulting from a fault and/or lack of safe margins can lead directly to loss of crew. For example, untimely activation of pyrotechnics used for a flight termination system could override an abort capability. Over the years, NASA and the military have learned lessons about safe pyrotechnic circuit design and testing, many of which are codified. However, with NASA's recent efforts to move toward a development model that leans more heavily on commercial partners these requirements have not always been directly levied on projects, and in some cases have been misinterpreted. This bulletin describes key safety features of pyrotechnic firing circuit design and provides rationale for inclusion of each feature.

Technical Bulletin No. 23-02

Safety Considerations when Repurposing Commercially Available Flight Termination Systems from Uncrewed to Crewed Launch Vehicles

Both uncrewed and crewed launch vehicles (LV) require flight termination systems (FTS) for range safety to protect the public and ground assets in the event of an LV failure. Flight crew safety in this context is an added consideration for human spaceflight. The FTS is an electroexplosive system that activates destruct charges to rupture propellant tanks and shut down engines during flight termination. Commercially available FTS units have been developed for uncrewed applications and are now being repurposed to crewed applications. A consequence of using these systems is that they are designed for public and ground crew safety, though inadequate for flight crew safety. Missing are human spaceflight design controls for inadvertent activation during crewed ascent and protection for crew emergency aborts.



Technical Bulletin No. 23-03

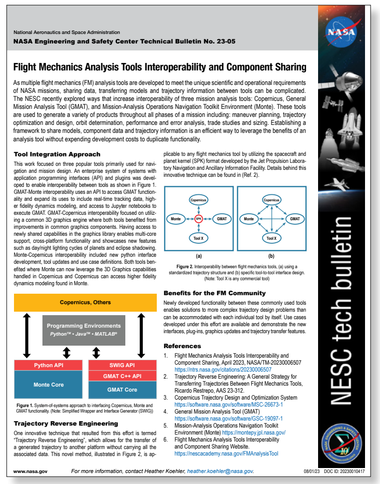
New Transient Finite Energy Shock Prediction Methodology

Shock prediction is one of the top loads and dynamics discipline technical challenges identified within NASA and industry programs and projects. The physics-based Transient Finite Energy (TFE) shock prediction methodology has been developed and compared favorably against test results. TFE can provide another approach to develop predictions of shock response spectra for use in the analysis of structural margins.

Technical Bulletin No. 23-04

Fast Coupled Loads Analysis Method: Norton-Thevenin Receptance Coupling

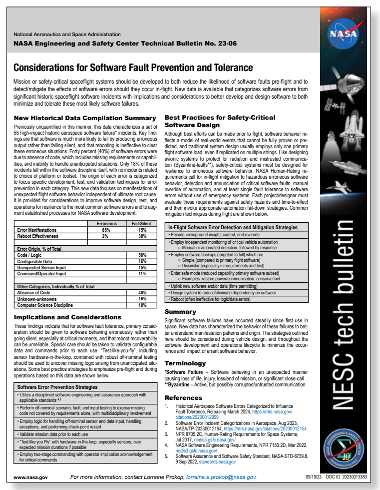
A new method called Norton-Thevenin Receptance Coupling (NTRC) has been developed to perform coupled loads analysis (CLA). NTRC provides a tool that payload developers can use to obtain launch loads at a fraction of the cost of a CLA any time it is required in the payload design cycle. NTRC combines the frequency domain component coupling method of receptance coupling with the Norton and Thevenin theory used in force limiting to derive an alternate method for performing CLA.



Technical Bulletin No. 23-05

Flight Mechanics Analysis Tools Interoperability and Component Sharing

As multiple flight mechanics analysis tools are developed to meet the unique scientific and operational requirements of NASA missions, sharing data and transferring models and trajectory information between tools can be complicated. The NESC recently explored ways that increase interoperability of three mission analysis tools: Copernicus, General Mission Analysis Tool, and Mission-Analysis Operations Navigation Toolkit Environment. These tools are used to generate a variety of products throughout all phases of a mission including: maneuver planning, trajectory optimization and design, orbit determination, performance and error analysis, trade studies, and sizing. Establishing a framework to share models, component data, and trajectory information is an efficient way to leverage the benefits of an analysis tool without expending development costs to duplicate functionality.



Technical Bulletin No. 23-06

Considerations for Software Fault Prevention and Tolerance

Mission or safety-critical spaceflight systems should be developed to both reduce the likelihood of software faults preflight and to detect/mitigate the effects of software errors should they occur in flight. New data are available that categorizes software errors from significant historic spaceflight software incidents with implications and considerations to better develop and design software to both minimize and tolerate these most likely software failures.

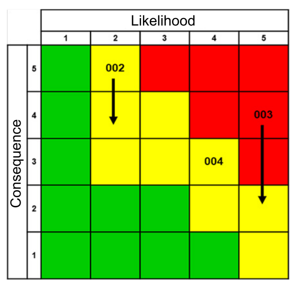
NESC Technical Bulletins FY23

Available at: NASA.GOV/NESC

Heather M. Koehler
NASA Technical Fellow for Flight Mechanics

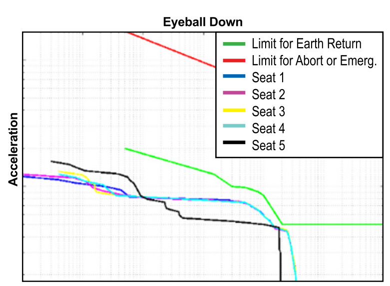
Reducing Risks Through Independent M&S

The NESC Flight Mechanics Technical Discipline Team (TDT) provides support to all NASA Mission Directorates and throughout all mission phases. Highlights from this past year include three critical program support assessments, new discipline-advancing capabilities in simulation tools, and a preview of future efforts by the TDT to capture knowledge and expertise to pass on to the next generation.



Notional risk scoring reduction through independent M&S

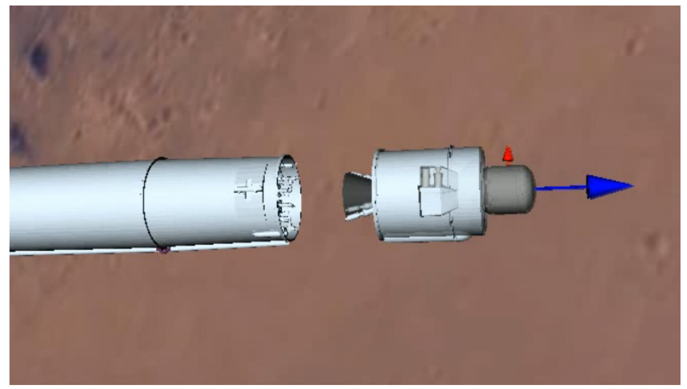
Independent modeling and simulation (M&S) enables new insights into critical subsystem designs and offers opportunities for analyses to reduce risk acceptance for programs. Several ongoing assessments have contributed to improved flight certification processes and risk reduction. The Flight Mechanics TDT sponsored improvements to simulation tools that enabled new solutions to complex problems, and recent NESC Academy recordings captured the latest advancements in the discipline.



Modeling of crew seat acceleration during entry, descent, and landing.

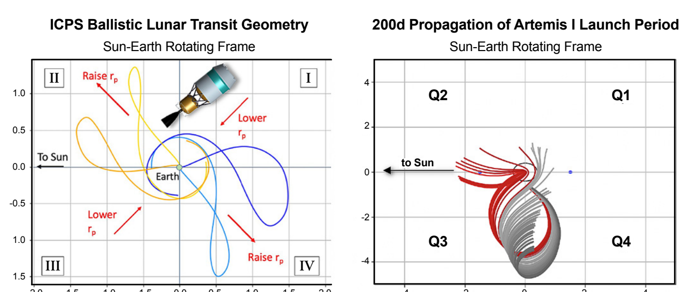
The TDT supported the Commercial Crew Program by independently modeling and simulating commercial providers' trajectory designs and on-board deorbit, entry, descent, and landing software. This past year, the team assessed the return of additional crew on commercial capsules for contingency scenarios and used independent simulation analyses to confirm this capability poses no significant changes in splashdown conditions, thus ensuring additional options for returning crew safely if the primary return vehicle is disabled. Additionally, the NESC is providing key assessments for manual control using a "paper pilot" based on actual pilot responses. This study enabled manual control as a viable survival scenario if the flight computer fails during deorbit, entry, descent, and landing phases of flight. These efforts contributed to an independent verification and validation of commercial providers' designs that supported certification of commercial flights to and from the ISS.

Standing up a new independent M&S effort in support of the Mars Ascent Vehicle, a critical element delivering Martian soil and atmosphere samples for eventual return to Earth, provides value and increases confidence in the design of this key element for the Mars Sample Return Campaign. The Flight Mechanics team is contributing unique methodologies for studying the challenging dynamics of this two-stage solid motor design where the second stage is unguided and spin-stabilized.



Frame of the Mars Ascent Vehicle second stage separation dynamics from an M&S animation.

Independent M&S of key staging and separation events for the SLS has resulted in affirmation of the SLS trajectory and guidance, navigation and control design. Flight Mechanics TDT members contributed analyses to evaluate the heliocentric disposal of the Interim Cyrogenic Propulsion Stage (ICPS).



Monte Carlo modeling of the Artemis I ICPS heliocentric disposal.

This past year, the TDT also completed an assessment that explored the interoperability between common mission analysis tools and enabled trajectory sharing between tools to solve more complex mission design problems (page 31). An NESC Technical Bulletin (page 47) and Innovative Technique (page 65) have been published on this topic.

New NESC Academy recordings on trajectory optimization tools and frameworks, electric aircraft sizing methodologies, system optimization, and aerodynamic decelerator systems were important knowledge capture and transfer initiatives. These recordings are available to help train and educate engineers on the tools and processes NESC teams will use for future independent M&S efforts.

Steven L. Rickman
NASA Technical Fellow for Thermal Control & Protection

Building a Community of Practice

The Thermal and Fluids Analysis Workshop (TFAWS) is an annual event cosponsored by the NESC's Thermal Control & Protection, Environmental Control & Life Support, Aerosciences, and Cryogenics Technical Discipline Teams in collaboration with the TFAWS Steering Committee. It is well known for a diverse set of events and remains a model for Community of Practice technical discipline workshops. Originally devised as an analysis tool training opportunity for new engineers, TFAWS has grown in scope over more than three decades to include a variety of activities including training, theory-based short courses, paper sessions, student posters, center tours, and vendor presentations. Most important though, it remains an excellent forum for technical interchange between thermal, fluids, cryogenics, and aerothermal professionals from across NASA, other U.S. government agencies, industry, and academia. After three virtual workshops due to the COVID pandemic, TFAWS resumed as an in-person event in 2023 under the planning leadership of GSFC, this year's host center.

TFAWS has become known as a forum to train the next generation of engineers. A poster session gave students an opportunity to showcase their work and build connections with engineers in government and industry. A "speed mentoring" event was initiated this year and gave many early career engineers and students an opportunity to benefit from the experience of senior engineers and leaders.

This year's event drew a total of 350 attendees representing NASA, the aerospace industry, academia, and international participants from 23 countries. The 4-day workshop consisted of 80 paper presentations, 16 short courses and panel discussions, 7 analysis tool and hardware hands-on short courses, 14 vendor participants, and 13 hardware and analysis tool vendor presentations. Tours highlighting GSFC facilities were provided the day after the workshop adjourned.

Top Left: GSFC's Jordan Effron builds a multi-layer insulation blanket during a hands-on short course.

Top Right: Dr. Bhanu Sood discusses GSFC technology development strategy and technical thrusts during a lunchtime talk.

Bottom: Students and early career engineers meet with senior NASA engineers during the inaugural "speed mentoring" session.

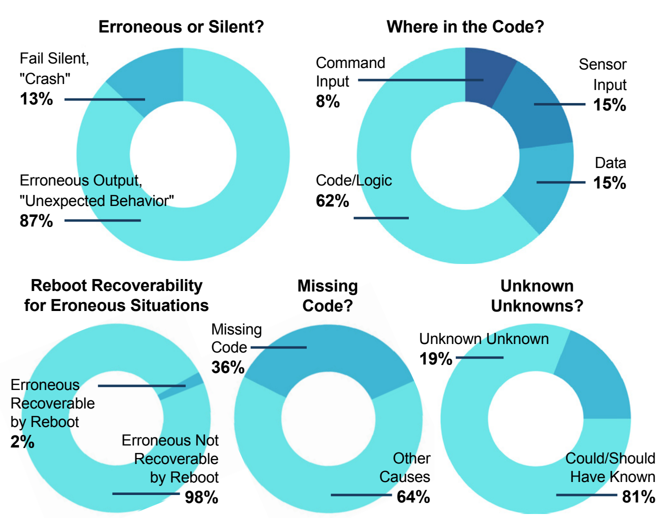
Dr. Lorraine E. Prokop
NASA Technical Fellow for Software

Understanding Risk, Artificial Intelligence, and Improving Software Quality

The software discipline has broad involvement across each of the NASA Mission Directorates. Some recent discipline focus and development areas are highlighted below, along with a look at the Software Technical Discipline Team's (TDT) approach to evolving discipline best practices toward the future.

Understanding Automation Risk

Software creates automation. Reliance on that automation is increasing the amount of software in NASA programs.This year, the software team examined historical software incidents in aerospace to characterize how, why, and where software or automation is mostly likely to fail. The goal is to better engineer software to minimize the risk of errors, improve software processes, and better architect software for resilience to errors (or improve fault-tolerance should errors occur).



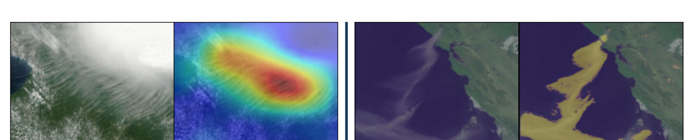
Some key findings shown in the above charts, indicate that software more often does the wrong thing rather than just crash. Rebooting was found to be ineffective when software behaves erroneously. Unexpected behavior was mostly attributed to the code or logic itself, and about half of those instances were the result of missing software—software not present due to unanticipated situations or missing requirements. This may indicate that even fully tested software is exposed to this significant class of error. Data misconfiguration was a sizeable factor that continues to grow with the advent of more modern data-driven systems. A final subjective category assessed was "unknown unknowns"—things that could not have been reasonably anticipated. These accounted for 19% of software incidents studied.

The software team is using and sharing these findings to improve best practices. More emphasis is being placed on the importance of complete requirements, off-nominal test campaigns, and "test as you fly" using real hardware in the loop. When designing systems for fault tolerance, more consideration should be given to detecting and correcting for erroneous behavior versus just checking for a crash. Less confidence should be placed on rebooting as an effective recovery strategy. Backup strategies for automations should be employed for critical applications—considering the historic prevalence of absent software and unknown unknowns. More information can be found in NASA/TP-20230012154, *Software Error Incident Categorizations in Aerospace*.

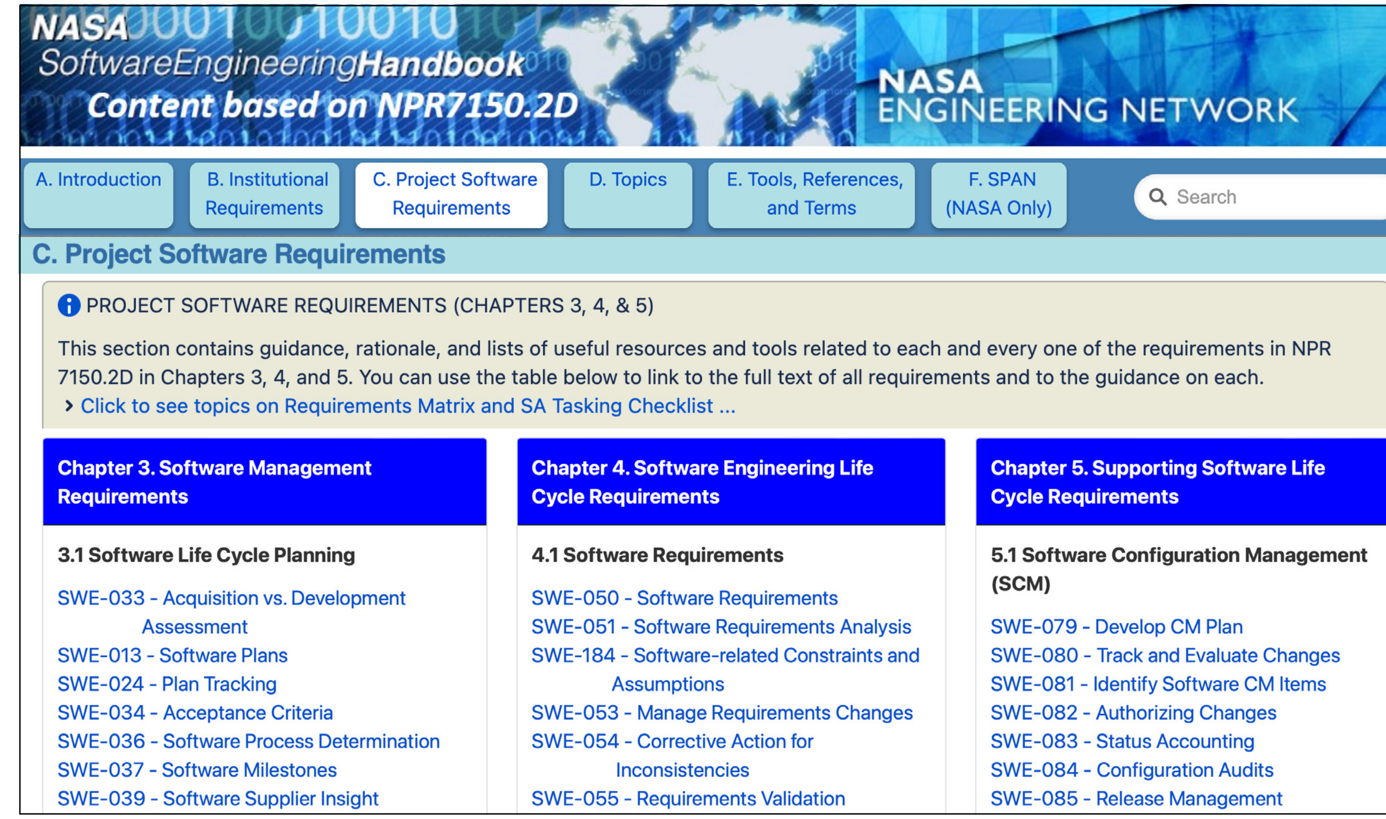
Employing AI and Machine Learning Techniques

The rise of artificial intelligence (AI) and machine learning (ML) techniques has allowed NASA to examine data in new ways that were not previously possible. While NASA has been employing autonomy since its inception, AI/ML techniques provide teams the ability to expand the use of autonomy outside of previous bounds. The Agency has been working on AI ethics frameworks and examining standards, procedures, and practices, taking security implications into account. While AI/ML generally uses nondeterministic statistical algorithms that currently limit its use in safety-critical flight applications, it is used by NASA in more than 400 AI/ML projects aiding research and science. The Agency also uses AI/ML Communities of Practice for sharing knowledge across the centers. The TDT surveyed AI/ML work across the Agency and summarized it for trends and lessons.

Common usages of AI/ML include image recognition and identification. NASA Earth science missions use AI/ML to identify marine debris, measure cloud thickness, and identify wildfire smoke (examples are shown in the satellite images below). This reduces the workload on personnel. There are many applications of AI/ML being used to predict atmospheric physics. One example is hurricane track and intensity prediction. Another example is predicting planetary boundary layer thickness and comparing it against measurements, and those predictions are being fused with live data to improve the performance over previous boundary layer models.



Examples of how NASA uses AI/ML. Satellite images of clouds with estimation of cloud thickness (left) and wildfire detection (right).



NASA-HDBK-2203, *NASA Software Engineering and Assurance Handbook* (https://swehb.nasa.gov)

The Code Analysis Pipeline: Static Analysis Tool for IV&V and Software Quality Improvement

The Code Analysis Pipeline (CAP) is an open-source tool architecture that supports software development and assurance activities, improving overall software quality. The Independent Verification and Validation (IV&V) Program is using CAP to support software asurance on the Human Landing System, Gateway, Exploration Ground Systems, Orion, and Roman. CAP supports the configuration and automated execution of multiple static code analysis tools to identify potential code defects, generate code metrics that indicate potential areas of quality concern (e.g., cyclomatic complexity), and execute any other tool that analyzes or processes source code. The TDT is focused on integrating Modified Condition/Decision Coverage analysis support for coverage testing. Results from tools are consolidated into a central database and presented in context through a user interface that supports review, query, reporting, and analysis of results as the code matures.

The tool architecture is based on an industry standard DevOps approach for continuous building of source code and running of tools. CAP integrates with GitHub for source code control, uses Jenkins to support automation of analysis builds, and leverages Docker to create standard and custom build environments that support unique mission needs and use cases.

Improving Software Process & Sharing Best Practices

The TDT has captured the best practice knowledge from across the centers in NPR 7150.2, *NASA Software Engineering Requirements*, and NASA-HDBK-2203, *NASA Software Engineering and Assurance Handbook* (https://swehb.nasa.gov.) Two APPEL training classes have been developed and shared with several organizations to give them the foundations in the NPR and software engineering management. The TDT established several subteams to help programs/projects as they tackle software architecture, project management, requirements, cybersecurity, testing and verification, and programmable logic controllers. Many of these teams have developed guidance and best practices, which are documented in NASA-HDBK-2203 and on the NASA Engineering Network.

NPR 7150.2 and the handbook outline best practices over the full lifecycle for all NASA software. This includes requirements development, architecture, design, implementation, and verification. Also covered, and equally important, are the supporting activities/functions that improve quality, including software assurance, safety configuration management, reuse, and software acquisition. Rationale and guidance for the requirements are addressed in the handbook that is internally and externally accessible and regularly updated as new information, tools, and techniques are found and used.

The Software TDT deputies train software engineers, systems engineers, chief engineers, and project managers on the NPR requirements and their role in ensuring these requirements are implemented across NASA centers. Additionally, the TDT deputies train software technical leads on many of the advanced management aspects of a software engineering effort, including planning, cost estimating, negotiating, and handling change management.

Dr. Dexter Johnson
NASA Technical Fellow for Loads & Dynamics

Mentoring the Next Generation of Engineers and Improving Shock Testing Standards

The year 2023 was productive for the Loads & Dynamics (L&D) Technical Discipline Team (TDT). New shock and modal analysis techniques were developed and mentoring the next generation of NASA discipline experts continued. Additionally, NESC Technical Bulletin No. 23-3, *New Transient Finite Energy Shock Prediction Methodology*, was released.

Early Career Community Nurtures Development of NASA's Future Discipline Leaders

NASA has acknowledged the need for "attracting and advancing a highly skilled, competent, and diverse workforce in order to cultivate an innovative work environment..." as stated in Objective 3.1 of the 2014 NASA Strategic Plan.

A survey conducted in 2014 by Emerge, the early-career professional group at JSC, showed that recent hires believe that "communication and collaboration amongst organizations" is a key area of improvement, while "lack of opportunities for professional growth" is the top reason why they would consider leaving the Agency. This, when coupled with NASA's aging workforce (the average age as of 2016 was 49), stresses the importance of capturing knowledge to pass along to the next generation of NASA engineers.

The Structures, Loads and Dynamics, Mechanical Systems, and Materials (SLAMMS) disciplines have also been identified as critical fields for the advancement of NASA's strategic vision, which emphasizes the importance of developing and retaining engineers in those areas. Consequently, the SLAM(M)S Steering Committee (Materials was not initially included), comprising center SLAMS Division/Branch Chiefs and NASA Technical Fellows, formed the Young Professionals Forum in 2012, which evolved into the current Early Career Forum (ECF) in 2017, and was expanded to provide year-round activities (e.g., monthly meetings, training opportunities) for the Early Career Community (ECC).

Over the lifetime of the ECC, the SLAMS Steering Committee was dissolved, and the stewardship of the ECC relied on the Technical Fellows, who empowered ECC leaders to take on the primary responsibility of planning and running the ECC and ECF events.

Today's SLAMMS Early Career Community

Within the past few years, a new SLAMMS Division/Branch Chief collaboration group was formed, called the SLAMMS Leadership Working Group (LWG), and is led by James Loughlin, GSFC Mechanical Systems Division Chief, with co-lead Elonso Rayos, JSC Structures Engineering Assistant Division Chief. The LWG is a forum focused on capability sustainment, discipline technical challenges, and workforce concerns. For example, disparate Agency technical resource access is discussed, collaboration is coordinated, and critical gaps in expertise are filled using cross-Agency cooperation.

The current SLAMMS ECE leadership team includes Khadijah Shariff (JSC-Structures), Dr. Matthew Chamberlain (LaRC-Loads & Dynamics), Dr. Jonathan Sauder (JPL-Mechanical Systems), and Cassie Smith (JPL-Mechanical Systems). NASA Technical Fellows supporting SLAMMS are Deneen Taylor (Structures), Dr. Dexter Johnson (Loads & Dynamics), Dr. Michael Dube (Mechanical Systems), and Dr. Bryan McEnerney (Materials).

The SLAMMS Early Career Forum

The ECF is the annual "face-to-face" workshop for the community. The ECF is held at a different NASA center each year and features technical presentations by early career engineers (ECE), splinter sessions with NASA Technical Fellows, mentor presentations, facility tours, networking events, design challenges, and evening social activities to advance the SLAMMS disciplines and develop NASA's future workforce. The ECF features technical presentations given by the ECEs to their peers, senior engineers, and Technical Fellows.

The 12th Annual SLAMMS ECF was held at MSFC and virtually. Sixty-six ECEs, Technical Fellows, TDT mentors, and discipline managers from the SLAMMS LWG were in attendance. ECEs from 8 centers made 16 technical presentations and 18 posters, which were ranked by mentors for the top awards. Multiple splinter sessions provided ECEs with opportunities to ask career-related advice from Technical Fellows, project and systems management, and individuals experienced in design, analysis, and testing. In addition, there was a detailed discussion for each of the technical disciplines represented at the forum, and multiple site tours were provided.

Attendees of the 12th annual SLAMMS EFC at MSFC 2023.

The Future of the SLAMMS ECC

The SLAMMS ECC will continue to evolve as discussions with the ECE leadership team and Technical Fellows continue towards mapping its future. SLAMMS is igniting cross-Agency collaboration for future generations. Its current goals include communication and collaboration among organizations, professional growth of early career engineers, knowledge capturing for the next generation of NASA engineers, and developing and retaining engineers in the specific SLAMMS disciplines. It will nurture the technical, professional, and personal development of NASA's next generation of SLAMMS discipline leaders.

Awards presented by Dr. Dexter Johnson. Left: "Best Presentation" (Mitchell Haglund-GSFC) Right: "Best Poster" (Tessa Fedotowsky-MSFC).

Updating Guidance on Shock Qualification and Acceptance Test Requirements

The L&D TDT has completed work that will have a positive impact on shock testing of NASA flight hardware. Pyroshock is the transient response of a structure to loading induced by activation of attached or incorporated pyrotechnic devices. Typical pyrotechnic devices include frangible bolts, separation nuts, and pin pullers that are used to assemble, separate, and reconfigure spaceflight hardware during a mission. Shocks can easily propagate through structure and damage sensitive components. Thus, successful pyroshock testing is considered essential to mission success. At the request of the Gateway Program Chief Engineer, the NASA Chief Engineer initiated an inquiry to reevaluate shock testing approaches for both unit and major assembly flight hardware and requested recommendations for potential revisions to NASA-STD-7003B, *Pyroshock Test Criteria*, that would clarify the guidance and applicability to new programs. The work delves into topics of shock acceptance and qualification testing for unit and major assemblies, shock test tolerances, shaker shock testing, and the distinction between mechanical shock and pyroshock testing. It also provides recommendations for their inclusion in the next Agency-wide revision of NASA-STD-7003B.

Current NASA-STD-7003B Requirements

Unit and major assembly flight hardware acceptance and qualification testing are discussed in NASA-STD-7003B. It requires that all units go through shock qualification testing, with few exceptions. The purpose of a qualification test is to verify the design integrity of the flight hardware. The standard calls for pyroshock qualification testing of nonflight hardware for externally induced environments to be performed with a 3 dB margin added to the maximum predicted environment (MPE), with two shocks per each orthogonal axis. Qualification tests are performed on hardware that will not be flown but is manufactured using the same drawings, materials, tooling, processes, inspection methods, and personnel competency as used for the flight hardware. The flight hardware is not recommended to go through shock test, therefore, it lacks workmanship screening testing. The required random vibration (RV) test is considered to be a partial workmanship screening, covering only up to 2000 Hz. A full workmanship screening test for unique and sensitive hardware that may have modes above 2000 Hz needs to be evaluated on a case-by-case basis by an expert in pyroshock dynamics and approved within a program's risk management system and/or governing board.

The major assembly acceptance and qualification testing are not recommended, considering that the MPE and design margin cannot be demonstrated at the system-level tests. The major assembly unmargined testing, however, may achieve three objectives. First, the functional demonstration of shock separation devices—probably the most important part of the major assembly level testing—demonstrates the source electrical and mechanical hardware functions as expected, and the interface separates without any issues. Second, the major assembly testing provides the validation of the unit shock environments.

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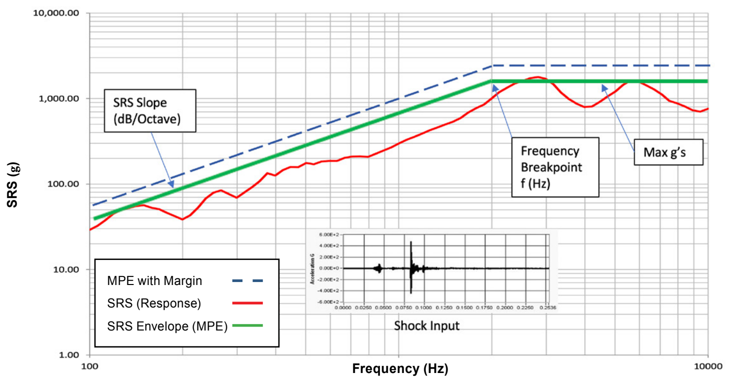


An example shock response spectrum (SRS) obtained from a mechanical shock separation system, indicating a broad signature is produced by pyro devices.

Third, the major assembly testing provides transfer functions (TF) that may help to estimate the attenuation—and in some cases structural amplifications—throughout the system with all assemblies in flight configuration. NASA-STD-7003B contains discussions for the first two major assembly test objectives. However, there are no discussions on the third test objective related to the TFs. The TFs provide qualitative assessment of shock propagation paths and attenuations at joints and interfaces. The TFs may be used qualitatively as attenuation is highly dependent on the materials and joint construction and may be different if there are changes in the system configuration.

Suggestions for Improving NASA-STD-7003B

The shock tolerance specified in NASA-STD-7003B is ±6 dB from 100 Hz to 3 kHz and +9/-6 dB above 3 kHz. The constant ±6 dB tolerance bandwidths across all frequencies are possible, as many existing shock simulation systems are able to simulate shock signatures that fall within these tolerances without difficulty. These tolerances are based on practical test implementation and shock simulation equipment consideration. The tolerance tightening should be considered at the flight hardware resonant frequencies to avoid over/under testing. However, if detonator or explosive shock simulation systems are used to qualify flight hardware, the shock tolerances above 3 kHz may be kept at +9/-6 dB.

Measurements from many different pyro/non-pyro separation systems have been shown to have broader shock signatures and do not support the mechanical shock as being applicable to low- and mid-frequency shocks only. The standard discusses this topic and has an example of far field SRS indicating shock energy above 2 kHz. The future revision should clarify the applicability of the mechanical shocks to be broader and not to be limited to 2 kHz and below (see figure at left).

Even though shaker shock testing has been used in the past and is still used by some NASA organizations and contractors, there are multiple technical issues with this type of testing. The shaker-generated shock signatures in the low- and mid-frequency range (typically up to ~2 kHz) provide severe shock environments that may lead to structural failures. Most shakers are also not able to generate SRS above ~2 kHz, therefore, shaker shock test is deficient in meeting the shock requirement up to 10 kHz frequency. NASA-STD-7003B does not recommend the shaker method of shock testing due to the above limitations. This should be emphasized more in the standard. The shaker shock simulation test may be used if it is able to generate time histories that resemble signatures generated by space separation devices, and SRS levels meet the entire frequency range requirements.

For the next NASA-STD-7003B revision, recommendations are being made to include acceptance RV testing for partial workmanship screening testing, add the TFs to be used as qualitative information in assessing the attenuation in the structural shock paths, change the shock tolerance to ±6 dB across all frequencies, and consider mechanical shocks to be broader and not limited to low- and mid-frequency SRSs.

In summary, the updated guidance provides clarification to the question/uncertainty of the applicability of historical guidance to current programs, while ensuring proper applicability to future programs. This work directly benefitted the Gateway Program, and could potentially benefit the Human Lander System (HLS).

References:

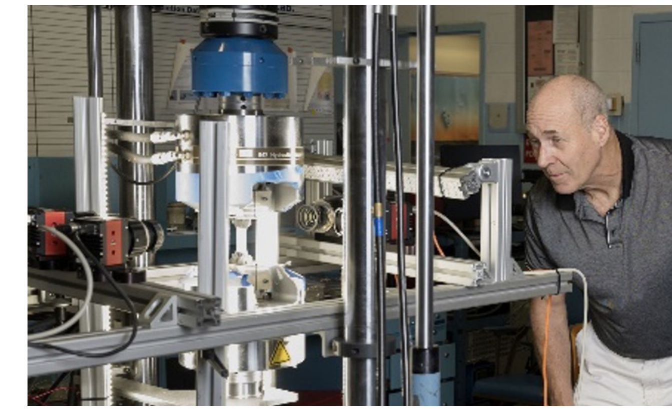
1. *Kolaini, A.R., Kinney, T., and Johnson, D.: Guidance on Shock Qualification and Acceptance Test Requirements. SCLV, June 27-29, 2023, El Segundo, CA. Available from: https://ntrs.nasa.gov/citations/20230009008*
2. *NASA-STD-7003B, "Pyroshock Test Criteria," June 11, 2020.*

The Gateway Program has benefitted from the updated guidance recommended for NASA-STD-7003B.

HLS could benefit from the updated guidance recommended for NASA-STD-7003B. Credit: Blue Origin

Deneen M. Taylor
NASA Technical Fellow for Structures

Advances in Understanding COPV Structural Life



Dr. David Dawicki employs digital image correlation to evaluate strain in metallic coupons.

The Structures Technical Discipline Team (TDT) was involved in numerous investigations this past year, but composites, fracture mechanics, and pressure vessels dominate the list. All three of these specialties are important to composite overwrapped pressure vessels (COPV). One of the TDT's most important findings this year was the exposure of an inherent vulnerability that underpredicts structural life, driven by current specifications and testing standards for COPVs. This NESC work and its recommendations will significantly improve safety and mission success for all current and future COPV operations throughout the aerospace community.

Damage Tolerance Analysis Standard Can Be Unconservative for COPVs

COPVs consist of a metallic liner that contains the fluid or gas and a composite overwrap that provides strength (Figure 1). The operational pressure cycles for a spaceflight COPV generally starts with an initial overpressure, called an autofrettage cycle, that yields the metallic liner, while the stronger composite overwrap remains elastic. Liner yielding during autofrettage results in a small amount of liner growth, resulting in liner compression when the COPV is depressurized after autofrettage. The subsequent operational cycles can be either elastic (elastically responding COPV) or elastic-plastic (plastically responding COPV).

The damage tolerance life evaluation of spaceflight COPVs is governed by the ANSI/AIAA-S-081B, *Space Systems–Composite Overwrapped Pressure Vessels*. This standard provides the baseline requirements for damage tolerance analyses (DTA) of COPVs with elastically responding liners. The standard allows the DTA to consider the influence of the elastic-plastic autofrettage cycle independently of the elastically responding cycles. The elastically responding cycles are permitted to be analyzed using linear elastic fracture mechanics (LEFM) tools like the NASGRO crack-growth analysis software. The standard states that the DTA must not consider any beneficial influences of the autofrettage cycle on the subse-

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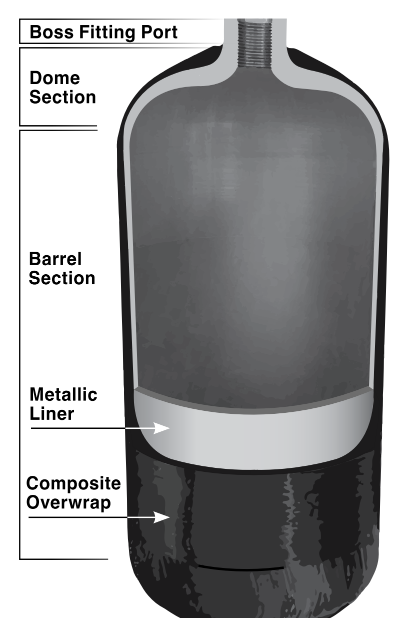

Figure 1. Illustration of COPV major components.

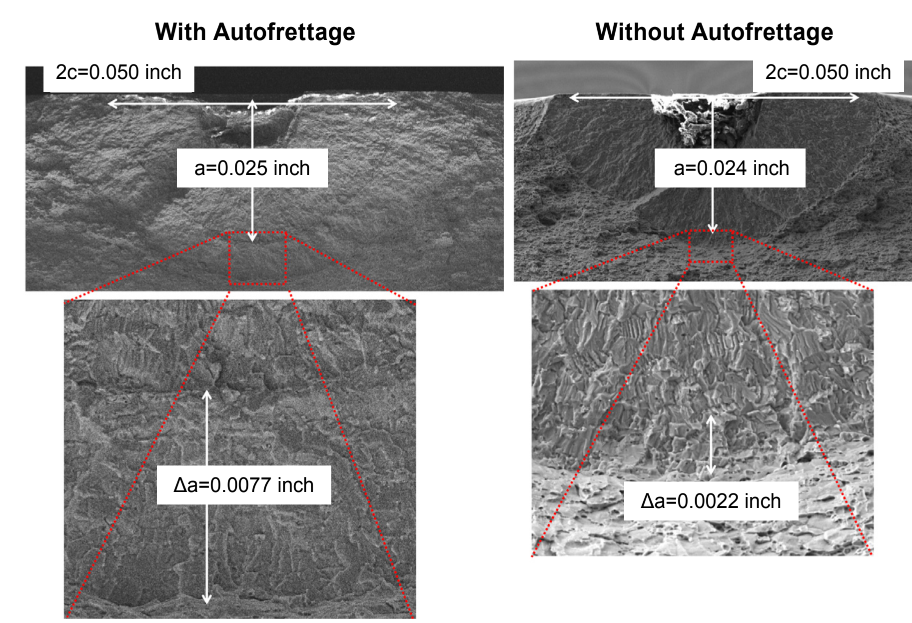

Figure 2. Fracture surfaces from two identical tests showing crack growth (Δa), with and without an initial autofrettage cycle.

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quent elastically responding cycles but does not consider the possibility of detrimental influences of the autofrettage cycle.

In the study, Unconservatism of Linear-Elastic Fracture Mechanics Analysis Post Autofrettage (NASA/TM-20230013348), an NESC team conducted a combined experimental and analytical investigation into the influence of the autofrettage cycle on subsequent elastic cycles. Tests were conducted on coupons with part-through surface cracks that were subjected to cyclic loading that was representative of the operational cycles of a COPV liner. Half of the tests were conducted with the full loading history (including the autofrettage cycle) and the other half were identical except that the autofrettage cycle was omitted. Cracks in the tests with the autofrettage cycle grew faster than cracks in the identical tests that excluded the autofrettage cycle, as shown by the fracture surfaces in the photomicrographs (Figure 2). The distance between the mark left by the autofrettage cycle and the ductile fracture region was the amount of crack growth (Δa=0.0077 inch) due to the LEFM cycles. Crack growth due to the LEFM cycles in the LEFM-only test was Δa=0.0022 inch, more than three times slower than that in the identical autofrettage plus LEFM test.

A validated finite element analysis and experimental measurements were used to evaluate the influence of the autofrettage cycle. The elastic-plastic autofrettage cycle was found to create a large region of plastic deformation ahead of the crack and blunted the crack tip. Previous fracture mechanics tests and analytical studies in the literature examined elastic overloads and found that plastic deformation ahead of the crack developed residual stresses that closed the crack surfaces, reducing the subsequent crack growth rate. However, the crack blunting allowed the crack to remain open for the entire loading, as illustrated by the finite element simulations of the crack surfaces at peak and minimum stress (Figure 3). The differences between the tests with and without the autofrettage cycle that were observed experimentally and simulated with a validated finite element analysis indicate that the damage tolerance analysis approach allowed by the standard can be unconservative. The NESC proposed an alternative damage tolerance analysis approach and recommended that the AIAA Aerospace Pressure Vessel Committee on standards update the ANSI/AIAA S-081B standard to address COPV liners with compressive stresses following the peak autofrettage stress.

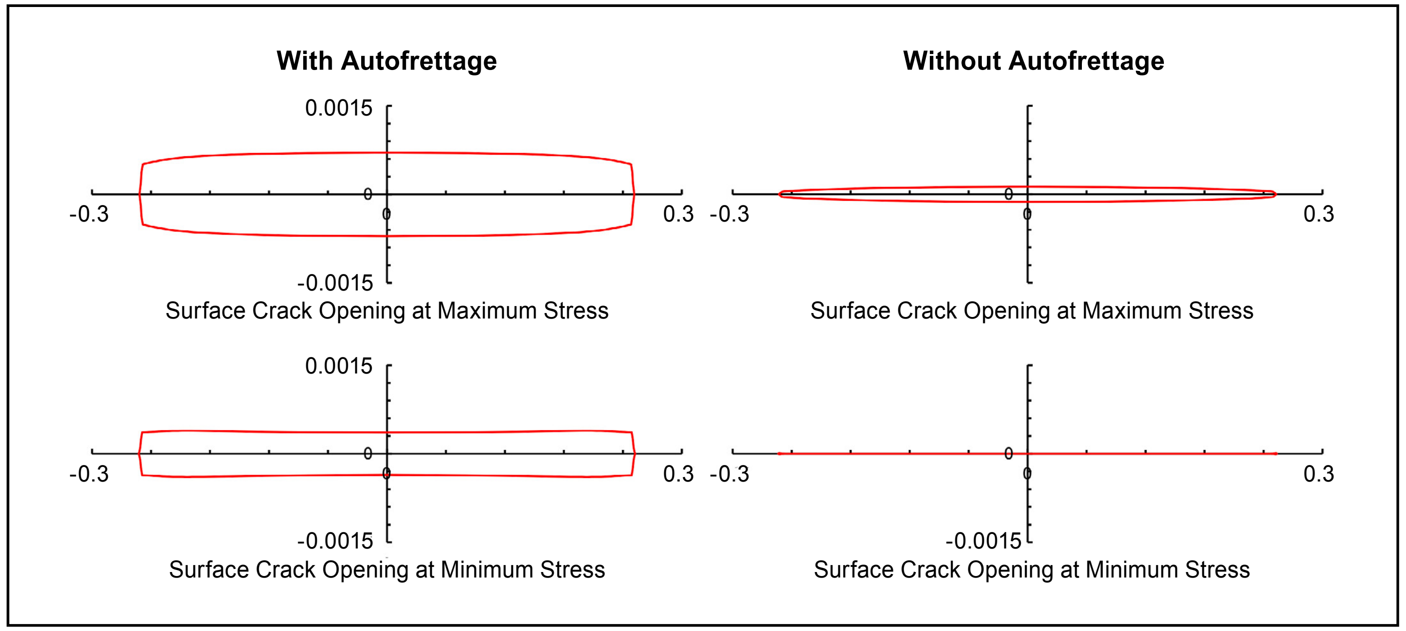


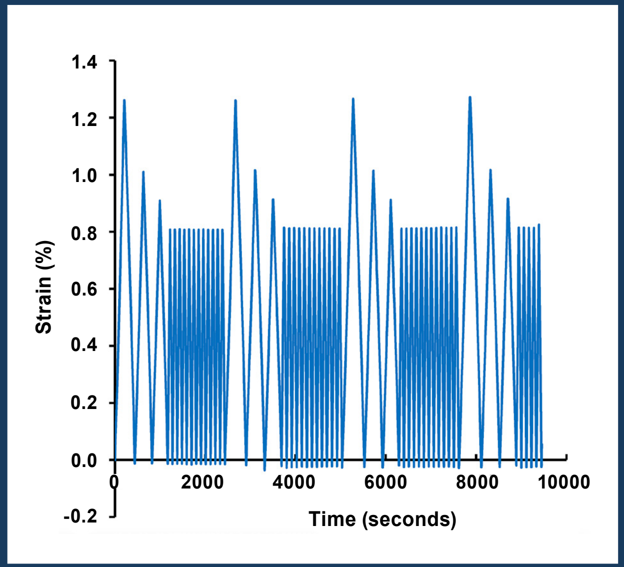
Figure 3. Abaqus finite element analysis of crack growth with and without an autofrettage cycle. Y-axis indicates crack opening displacement and x-axis indicates crack length.

A Brief Introduction to Damage Tolerance for COPVs

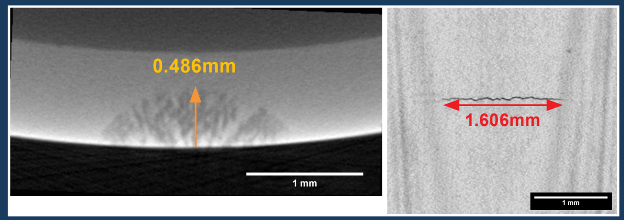
ANSI/AIAA S-081B standard, *Space Systems–Composite Overwrapped Pressure Vessels,* is a compilation of accepted practices for COPVs used in space applications developed as a collaboration of industry, government, and universities. The standard covers many aspects of COPVs including damage tolerance life analyses that are used for flight qualification overseen by fracture control boards. The standard for damage tolerance requires that the COPV "...survive four operational lifetimes with the largest crack in the metallic liner that can be missed by a nondestructive evaluation (NDE) subjected to bounding stresses representative of what the COPV experiences in its life (manufacturing, integration, operational including thermal and residual)." The operational life of a COPV liner typically includes an initial elastic-plastic cycle (autofrettage or proof) followed by other cycles that may be elastic (elastically responding liners) or elastic-plastic (plastically responding liners). A representative load spectrum is shown at right. During autofrettage, the COPV is pressurized to at least proof pressure to compress the liner inner surface, making it less susceptible to operational stresses. COPVs with elastically responding liners may be damage-tolerance qualified using LEFM analysis tools, but plastically responding liners must be damage-tolerance qualified by testing. Guidance on evaluating the appropriateness of LEFM tools for COPV damage tolerance was provided in NESC Technical Bulletin No. 21-04, *Evaluating Appropriateness of LEFM Tools for COPV and Metal Pressure Vessel Damage Tolerance Life Verification Tolerance Life Verification and NASA/TM-2020-5006765/Volumes 1/2.*

A COPV consists of a metallic liner with an exterior composite wrap. The composite provides strength, and the liner contains the compressed fluid or gas.

Results of a failure test. COPVs contain high pressure gases or fluids that can have tremendous explosive energy.



Representative loading spectrum for an elastically responding COPV liner with an initial elastic-plastic cycle.



Computed tomography scan of a metallic liner detecting a part-through crack.

Future of the Structures Discipline

As the Agency moves more toward forming strategic industry partnerships with commercial contracts for new programs, the Structures TDT has highlighted the need for proper focus on appropriate requirements as the Team's strategic vector. Although NASA Standards are often provided for reference, their prescriptive nature is not necessarily appropriate for use with commercial contracts. Industry partners and/or NASA team members create alternative standards, unique for each program, but there is inconsistency across different programs with respect to detailed requirements in these standards. Emerging technologies such as soft goods, large-scale deployable structures, inflatables, probabilistic analysis techniques, and additive manufactured hardware all drive unique requirements. The TDT identified the need for a tailoring guide, tied to mission priorities and risk postures, to assist with insight/oversight strategies for NASA programs. Using industry partners also means less NASA-owned hardware, which can lead to a loss of institutional knowledge.

Its imperative that Engineering Directorates at each center proactively look for in-house projects so the next generation of engineers have opportunities for hands-on experience developing, designing, and testing (DDT) flight hardware. This experience is the foundation necessary for NASA engineers to guide the commercial partners through their own DDT processes and to be able to provide appropriate verification and validation of NASA requirements. Structures TDT members form a diverse team crossing all centers and programs, facilitating good collaboration on requirement interpretation, which ultimately ensures safety of NASA crew and mission success of operations in these new commercial programs.

Dr. Morgan B. Abney
NASA Technical Fellow for Environmental Control & Life Support

Advancing Human Spaceflight Safety

As NASA continues to pursue new human missions to low Earth orbit, lunar orbit, the lunar surface, and on to Mars, the NESC continues to provide a robust technical resource to address critical challenges.

The NESC Environmental Control and Life Support Systems (ECLSS), Crew Systems, and Extravehicular Activity (EVA) discipline is led by the NASA Technical Fellow for ECLS, Dr. Morgan Abney, ECLSS & Crew Systems Deputy Dave Williams, Extravehicular & Human Surface Mobility Deputy Danielle Morris, and EVA Deputy Colin Campbell. In 2023, this team led assessments and provided support to the Commercial Crew Program, ISS, Orion Multi-Purpose Crew Vehicle, Extravehicular and Human Mobility Program, Gateway International Habitat, and Moon-to-Mars Program. Three of the most notable activities in 2023 are briefly described below.

Mitigation for Water in the Helmet During EVA

During EVA22 in 2013, water was observed in the helmet and assumed to be the result of a "burp" from the drink bag. No further investigation was pursued because water had been observed to some degree (water on visor, wet hair, etc.) on eight previous occasions. The result was a nearly catastrophic event during EVA23, where astronaut Luca Parmitano experienced dangerous quantities of water in his helmet. Both EVA23 and EVA35 in 2016 contributed to identification of drowning as a key risk, which resulted in several water mitigation approaches. Based on these approaches, the program determined the risk level to be acceptable for nominal EVA. However, in March 2022, a crewmember returning from EVA80 noticed water accumulated on the visor of his helmet obstructing ~30-50% of his field of view. Due to the increasing complexity of EVA objectives on EVA80 and forward, the ISS Program identified loss or reduction of visibility as a greater risk than previously recognized and sought to identify methods to prevent even small quantities of liquid water from forming in the helmet during EVA. The NESC was asked to provide support to the activity through modeling of the helmet and two-phase (water and oxygen) flow behavior in microgravity, through model validation testing, and through testing of mitigation hardware identified by the larger team. The model predictions provided a map (Figure 1) of anticipated liquid water formations based on the contact angle between the face or head and the helmet surface. Based on the ISS helmet with no water mitigations, the model predicted that large blobs would most likely form bridges between the helmet and face and that rupture of those bridges would result in the majority of liquid transferring to the face. To mitigate this risk, the ISS EVA80 team devised a solution to add absorbent materials in the path of the oxygen and water entering the helmet. Following EVA23, the helmet absorption pad (HAP) was added for bulk water collection. The improved mitigation strategy based on EVA80 included a HAP extender (HAP-E) and a helmet absorption band (HAB) (Figure 2). The NESC provided modeling of the mitigation hardware and validation testing of the HAB configuration using flow conditions anticipated in ISS operation (Figure 3). The testing provided ground validation of the HAB performance. The HAB and HAP-E have both been implemented in flight.

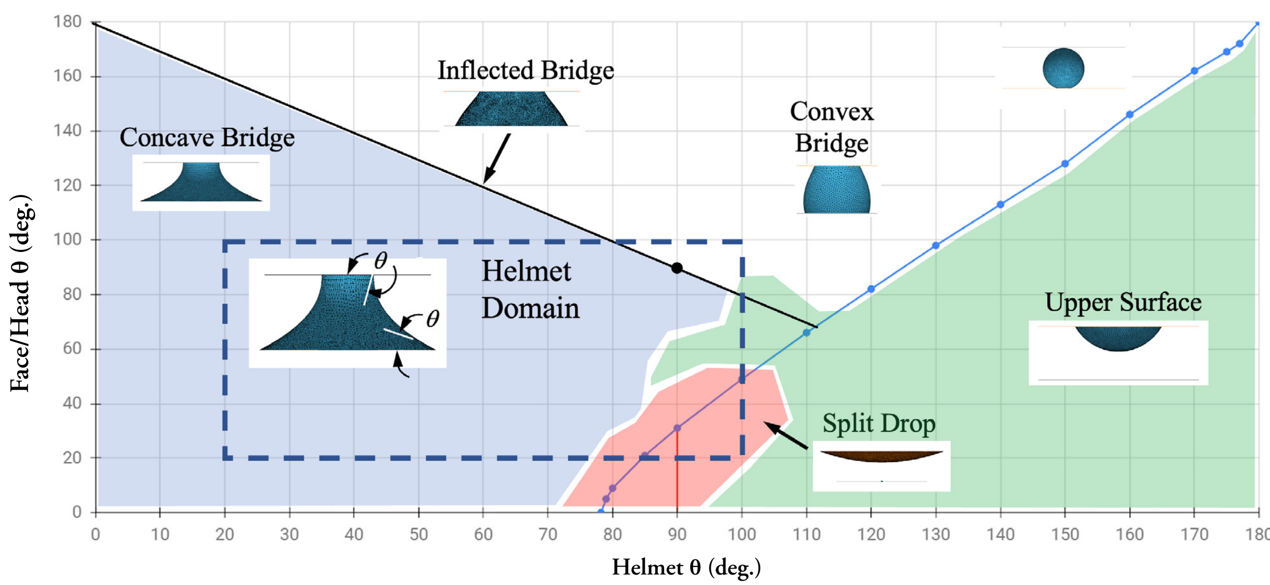


Figure 1. Map of predicted water formations within a helmet as a function of face/head and helmet contact angles. Dashed rectangle indicates the expected domain of the ISS helmet with no water mitigations.

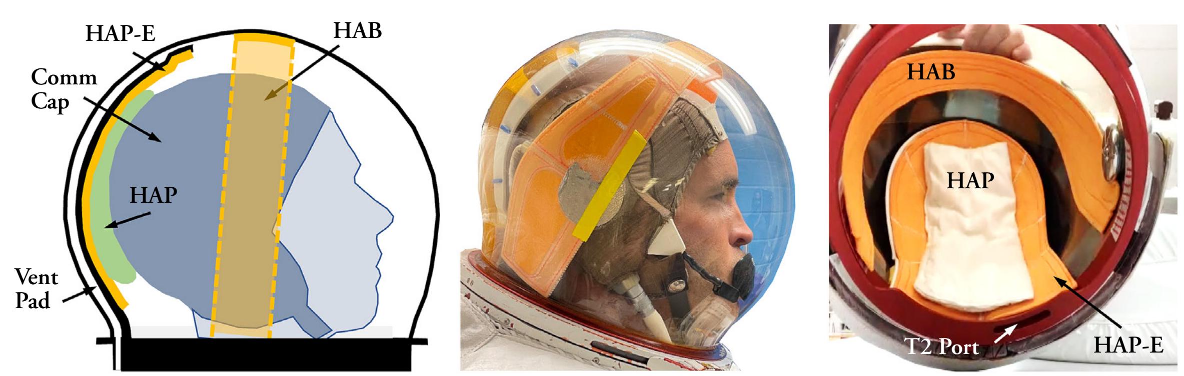


Figure 2. Water mitigation strategy for the ISS helmet: a) sketch of HAP, HAP-E, and HAB, b) side view of early prototype, c) bottom view of early prototype.

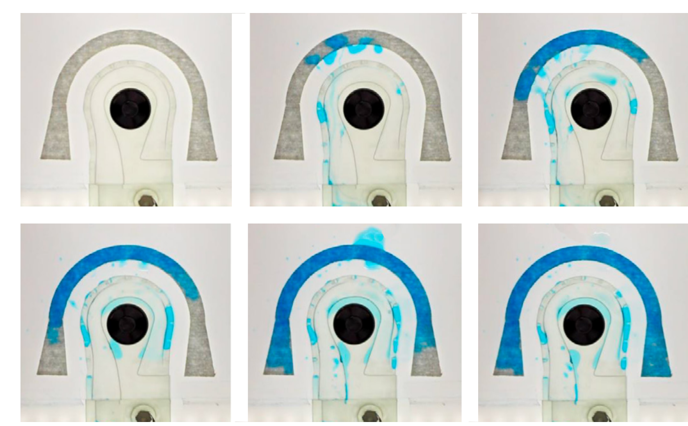


Figure 3. HAB ground validation testing under trickle water flow conditions.

Evaluation of Terrestrial Portable Fire Extinguishers for Microgravity Applications

The tragic fire of Apollo 1 has, of necessity, instilled in NASA an enduring respect for the risk of fire in spacecraft. As such, robust fire detection and response systems have been a cornerstone of NASA-designed vehicles. Portable fire extinguishers (PFE) are a fundamental fire response capability of spacecraft and both carbon dioxide and water-based PFEs have been used by NASA historically. However, terrestrial-based PFEs, particularly those using new halon-based suppressants, may provide improved capability beyond the NASA state-of-the-art. In 2023, the NESC sought to evaluate the effectiveness of commercial-off-the-shelf (COTS) PFEs in microgravity. The team developed an analytical model to predict the discharge rate of three terrestrial COTS PFEs containing CO2, HFC-227ea, and Novec 1230. The model considered the internal geometry of the PFEs, the material properties of the suppressants and their corresponding PFE tanks, and the effects of microgravity and in-flight perturbations. The results predicted that for PFE tanks containing dip tubes, like those for HFC-227ea and Novec 1230 where nitrogen gas is used as a pressurant, microgravity plays a significant role in the discharge performance due to two-phase flow. Figure 4 shows the various equilibrium configurations based on gravity and perturbations. As a comparison, the analysis predicts >80% discharge of the HFC-227ea in the COTS PFE within ~30 seconds with the remainder discharging over ~0.5-1 hours when discharged in a terrestrial fire (Figure 4A), while only 60-80% discharges in 30 seconds with the remainder discharging over 1-2 hours in microgravity (Figure 4C).

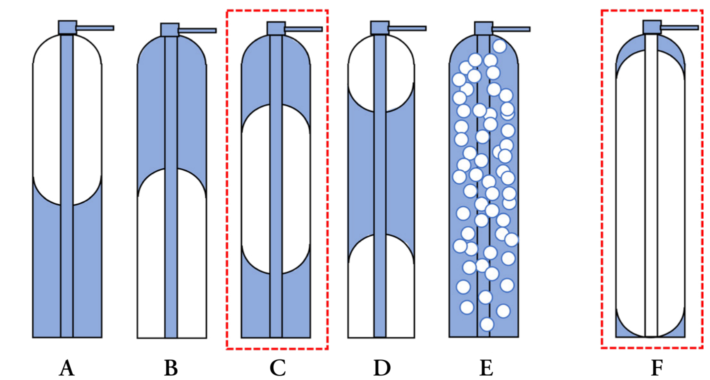


Figure 4. Equilibrium two-phase configurations of nitrogen (white)-pressurized liquid suppressant (blue). A) PFE held nominally with nozzle up in 1-g with no perturbations, B) PFE held inverted in 1-g or in 0-g where liquid preferentially accumulates away from the dip tube entrance with no perturbations, C) PFE in 0-g at the statistically most probable state with no perturbations, D) PFE in 0-g where nitrogen preferentially accumulates at ends of the PFE with no perturbations, E) PFE in any level gravity with significant perturbations (shaken up), and F) statistically most probable state in 0-g following complete discharge.

Based on this analysis, the use of terrestrially designed PFEs containing gaseous pressurant over a liquid suppressant will likely result in decreased initial discharge of the suppressant and significantly longer total discharge times in microgravity as compared to terrestrial discharge performance. Testing is ongoing to validate the models using a custom-designed PFE test stand (Figures 5 and 6) that enables multi-configuration testing of COTS PFEs.

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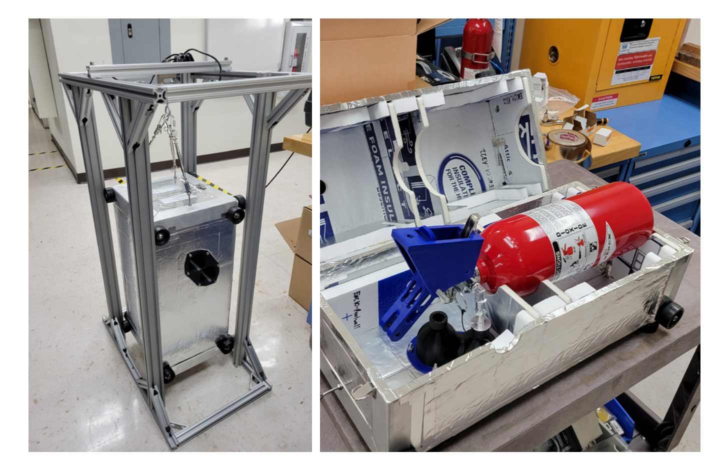

Figure 5. (left) PFE test stand for model validation. Design prevents directional load effects to enable accurate mass measurement during PFE discharge.
Figure 6. (right) Insulated PFE housing and remote discharge control allows for accurate, real-time thermal measurements during validation testing.

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Standardized Abrasion, Cut, and Thermal Testing for Spacesuit Gloves and Materials

State-of-the-art spacesuit gloves have been optimized for the challenges of ISS. Artemis missions call for high-frequency EVAs at the lunar south pole, where temperatures in the permanently shadowed region (PSR) will expose crew gloves to temperatures lower than ever previously experienced and where frequent and repeated exposure to regolith dust and rocks will present significantly increased risk for abrasion and cuts. With the development of new spacesuits by commercial partners, inexpensive and repeatable test methods are needed to characterize, evaluate, and compare gloves and glove materials for their thermal performance at PSR temperatures and for their resistance to lunar regolith abrasion and cuts. To address these needs, the NESC is leading a team to develop standardized test methods in coordination with ASTM International Committee F47 on Commercial Spaceflight.

Three standardized methods are currently in development. The first method seeks to standardize lunar dust abrasion testing of glove (and suit) materials based on adapted "tumble testing" first proposed at NASA in 1990. The NASA-designed tumbler (Figure 7) enables testing of six samples per run and compares pre- and post-tumbled tensile strength of materials to compare abrasion resistance. The method is highly controlled using a commercially available tumble medium and lunar regolith simulant.

Because material properties change with temperature, the second method seeks to develop a standardized approach to evaluate the cut resistance of glove materials at relevant cryogenic temperatures. The method is an adaptation of ASTM F2992 *Standard Test Method for Measuring Cut Resistance of Materials Used in Protective Clothing with Tomodynamometer (TDM-100) Test Equipment.* In order to allow for cut evaluation at cryogenic temperatures, the TDM-100 cut fixture was modified to include channels for liquid nitrogen flow (Figure 8A), thereby cooling the test material to 77 K.

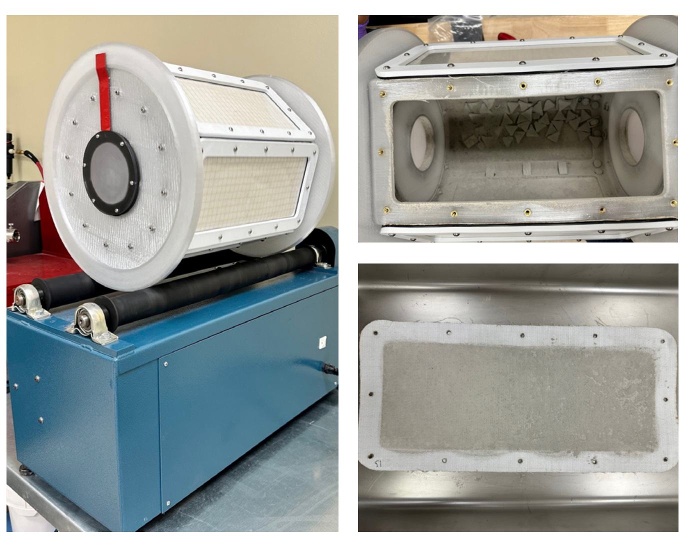

Figure 7. Hardware used in the tumble test method. Tumbler apparatus (left). Tumbler with panel removed to show lunar regolith simulant and commercially available tumbler media (top right). Tumbler panel showing lunar regolith simulant (bottom right).

The third method seeks to evaluate the thermal performance of gloves down to PSR requirement temperature of 48 K. Historical thermal testing of gloves was conducted with human-in-the-loop (HITL) testing for both radiative and conductive cooling. Conductive cooling was accomplished by having the test subject grab thermally controlled "grasp objects" and maintain contact until their skin temperature reached 283 K (50 °F) or until they felt sufficient discomfort to end the test themselves. While HITL testing is critical for final certification of gloves, iterative design and development testing would benefit from a faster, less expensive test. To meet this need, the NESC is developing a glove thermal test that uses a custom manikin hand designed by Thermetrics, LLC (Figure 8B).

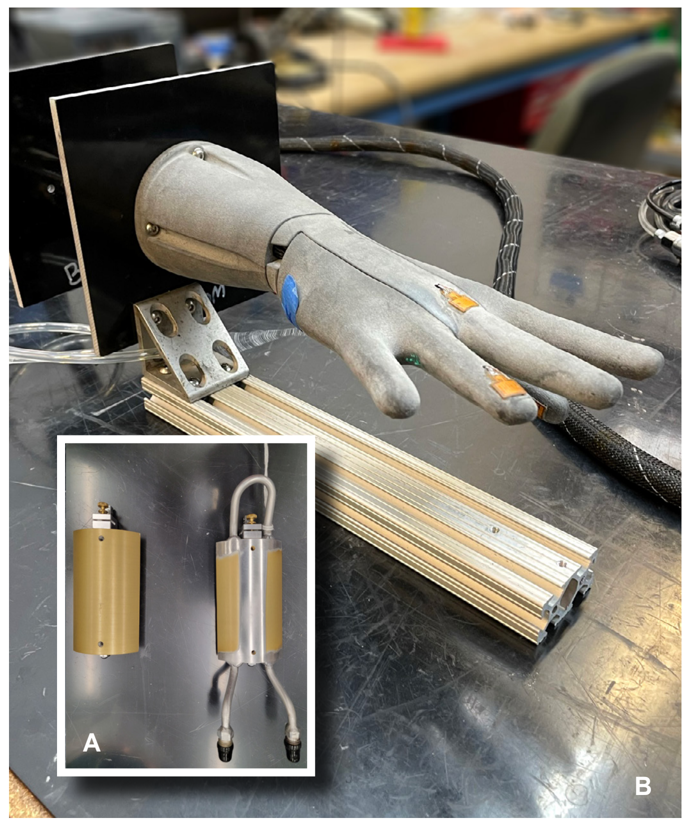

Figure 8. A) Mandrel used in cut testing as designed for ambient testing (left) and cryogenic testing (right). Flow channels allow for liquid nitrogen flow to cool the material sample to cryogenic temperatures. B) Prototype of Thermetrics, LLC custom manikin hand for spacesuit glove thermal testing.

The manikin hand is outfitted with temperature and heat flux sensors to monitor heat transfer to the hand. The hand is placed within a spacesuit glove and thermally controlled with internal water flow to simulate human heat generation. The Cryogenic Ice Transfer, Acquisition, Development, and Excavation Laboratory (CITADEL) chamber at JPL is then used to test the glove thermal performance at a range of temperatures from 200 K down to 48 K. Thermal performance is evaluated to mimic historical HITL testing under both radiative and conductive cooling. Conductive cooling is accomplished through a temperature-controlled touch object and is evaluated using two touch pressures. All three methods will be incorporated as ASTM F47 standard test procedures following NASA and ASTM committee review and approvals (targeting 2024).

ASA astronaut and Expedition 68 Flight Engineer Nicole Mann is pictured in her Extravehicular Mobility Unit (EMU) during an EVA. The NESC has recently contributed to astronaut safety investigations of water accumulating in EMU helmets during EVAs, and developing EMU gloves for use in the harsh conditions of the lunar south pole.

Identification of Noise Sources During Launch Using Phased Array Microphone Systems

Every part of a launch vehicle, launch pad, and ground operation equipment is subjected to the high acoustic load generated during lift-off [1]. Therefore, many extreme measures are taken to try to suppress this acoustic environment by damping with a water deluge system and diverting engine plumes away from the vehicle via flame trenches. Even single decibel reductions of the acoustic levels can translate into a sizable reduction of acoustic loadings, certification needs, operational costs, and even vehicle weight. Therefore, lowering the acoustic level via various mitigation schemes is an important aspect of a launch pad design.

In 2011 and 2012, the NESC sponsored research into the effectiveness of a microphone phased array (MPA) to identify noise sources and tested the array during an Antares launch from the Wallops Flight Facility [2]. This simple prototype array was able to identify impingement-related noise sources during the launch.

Today, building on this previous work, a new open-space truss MPA architecture is in development and test for use during the Artemis II launch. This truss structure consists of an aluminum tubular frame holding 70 microphones mounted in optimized positions over a dome-shaped surface (Figure 1). The center canister structure holds visible and infrared cameras as well as the amplifier electronics that transfer and relay microphone signals out to data cables that send information to the ground-mounted data acquisition system. The collected data are postprocessed using a functional-orthogonal beamforming routine that minimizes the effects of side lobes and reflections on the acoustic signal [3]. This produces a much cleaner image of primary noise impingement sources emanating from the vehicle and launch pad structures.

Figure 1. Overall view of the MPA, cable bundle, and data acquisition cabinet.

The NESC activity is performing verification and validation tests to determine the MPA's environmental survivability and validate the beamforming capability. This is being done using a phased testing approach. Phase 1 testing performed at ARC elevated the MPA (Figure 2) and used horns and speakers of known intensity to ensure its ability to identify and separate noise sources (Figure 3).

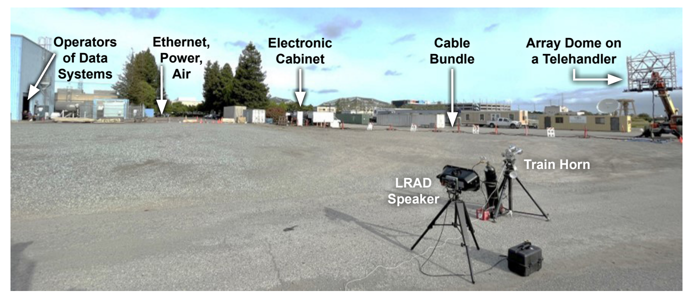

Figure 2. Setup for the outdoor test using a train horn and a long-range acoustic device (LRAD) speaker. The MPA was raised to test heights by a Telehandler.

In phase 2, the system was subjected to an actual engine noise environment during a static fire test at SSC. The MPA viewed the A-1 engine test stand during an RS-25 engine test from 460 feet, a similar distance from KSC Pad 39B to the lightning tower, where the MPA will be mounted for Artemis II (Figure 4). Results successfully identified and pinpointed the transient engine acoustic sources during the test (Figure 5).

The final test occurred during the NG-19 Antares launch from the Wallops Flight Facility in July 2023. The MPA tracked the plume and acoustic environment during the launch, showing transition from initial engine thrust to the overpressure environment flowing from the flame trench as the vehicle lifted off (Figure 6). The array was able to collect meaningful data while mounted outside, under acoustic conditions similar to those expected during the Artemis II launch and also subjected to heat, humidity, salt air, and extreme weather.

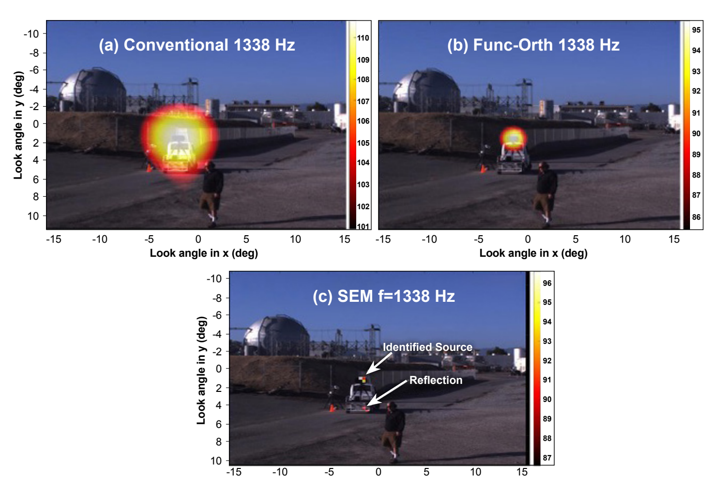

Figure 3. Comparison between different beamform schemes at a fixed f=1338 Hz with array center 100 ft. horizontal and 10 ft. above LRAD speaker.

Next, the MPA will be deployed at KSC for the Artemis II launch to measure the acoustic impingement and identify critical noise sources during that event. The data collected will help further refine and optimize the sound suppression systems for Artemis III and future launches.

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2. *Panda, J., Mosher, R. N. & Porter, B. J., "Noise Source Identification During Rocket Engine Test Firings and a Rocket Launch," Journal of Spacecraft and Rockets, Vol. 51, No. 4, July-Aug 2014. DOI: 10.2514/1.A32863*
3. *Dougherty, R.P., "Functional Beamforming for Aeroacoustic Source Distributions," 20th AIAA/CEAS Aeroacoustics Conference, 10.2514/6.2014-3066, 2014.*

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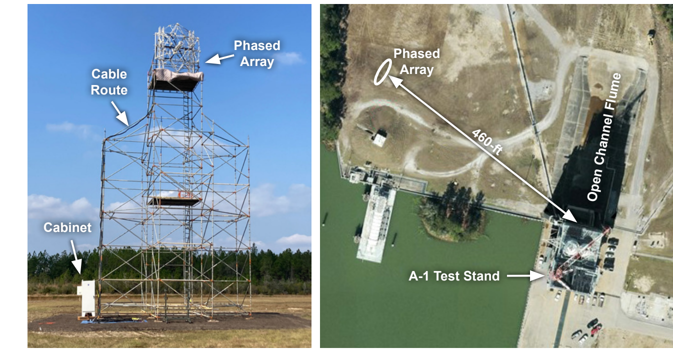

Figure 4. Scaffold system used to mount MPA and location of the array with respect to the SSC A-1 test stand. Right Image Credit: Google Maps

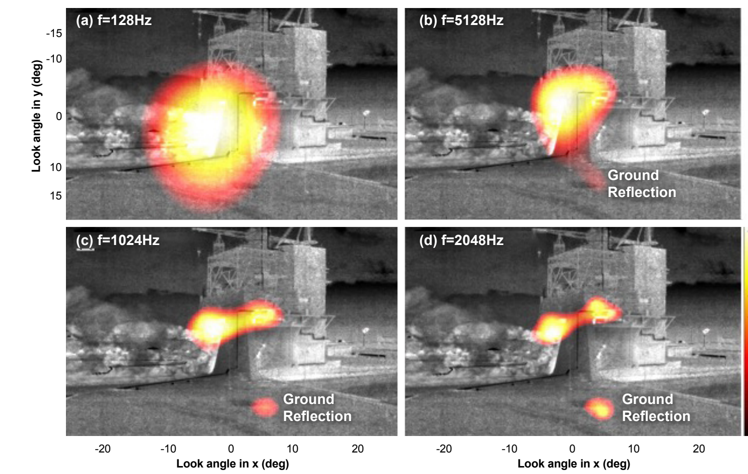

Figure 5. Noise sources identified at the indicated third-octave center frequencies using functional-orthogonal beamform.

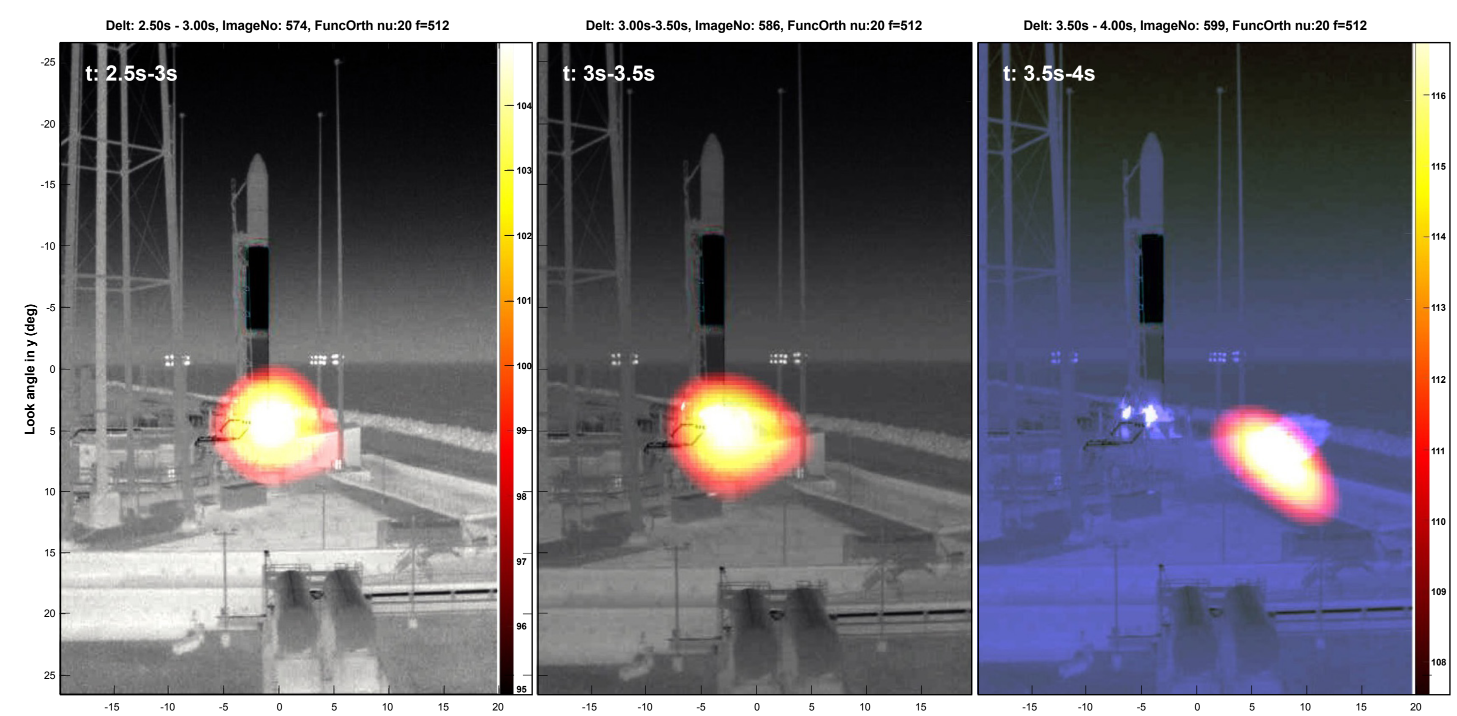

Figure 6. Time evolution of noise source generation during the NG-19 launch. The acoustic intensity of the redirected flow from the flame trench opening evolves to become a much stronger noise source, while acoustics from the plume are effectively mitigated by the sound suppression on the launch pad surface.

Operational Modal Analysis of the Artemis I Dynamic Rollout Test

Operational modal analysis (OMA) techniques have been used to identify the modal characteristics of the Artemis I launch vehicle during the Dynamic Rollout Test (DRT) and Wet Dress Rehearsal (WDR) configuration prior to launch. Forces induced during rollout and on the launch pad are not directly measurable, thus necessitating a unique approach.

NASA is developing the SLS to support lunar and deep space exploration. SLS is integrated inside the Vehicle Assembly Building (VAB) on the mobile launcher (ML), which supports the integrated SLS launch vehicle during transport to the pad through lift-off. The ML also provides the fuel, power, and data umbilicals running to the SLS and Orion Multi-Purpose Crew Vehicle (MPCV), as well as crew access to the MPCV crew module. The ML weighs ~10.6 million pounds and is over 380 feet tall. In the spring of 2022, the SLS was transported on the ML from the VAB to Launch Pad 39B (Figure 1) using the NASA crawler transporter (CT) to make this 4.2 mile trek, which takes ~8 hours. The CT alone weighs ~6.3 million pounds.

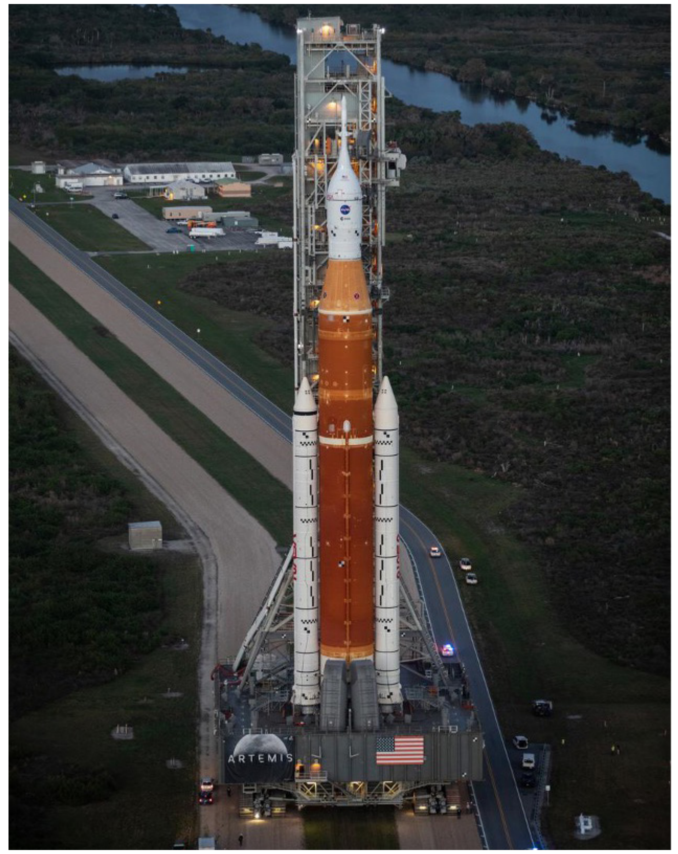

Figure 1. Artemis I Rollout to Launch Pad 39B.

Although the rollout environment produces relatively small launch vehicle structural loads in comparison to launch and ascent loads for most structures, the induced loads are fully representative of all loading across the entire vehicle, which is not feasible to replicate using localized shakers as was done in the Integrated Modal Test. As mentioned, forces induced during rollout and on the launch pad are not directly measurable, and OMA techniques were used to identify the modal characteristics of Artemis I in the DRT and WDR configurations. WDR, which typically includes vehicle fueling and other operations to demonstrate launch readiness, included several days of on-pad operations. Data collected for the WDR configuration, with partially filled core fuel tanks and without the CT under the ML, provided engineers another model configuration to check (Figure 2).

Figure 2. Artemis I at Launch Pad 39B.

Acquisition and processing the data from over 300 accelerometers located on Artemis I, ML, and CT was accomplished by a cross-program team of engineers and technicians from across the Agency, including from SLS, Exploration Ground Systems, and the NESC. Using analytical techniques developed from previous rollout tests combined with new data-processing methodologies, the team processed data from preselected CT speed increments during rollout and on-pad during WDR. By making the necessary modifications to the integrated models to match both the DRT and WDR configurations, the team was able to use those results to help make sense of what was being seen in the test data. This proved to be required for OMA testing on this structure, given the type of complex excitation that was being observed.

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Trajectory Reverse Engineering

A strategy for transferring spacecraft trajectories between flight mechanics tools, called Trajectory Reverse Engineering (TRE), has been developed[1]. This innovative technique has been designed to be generic, enabling its application between any pair of tools, and to be resilient to the differences found in the dynamical and numerical models unique to each tool. The TRE technique was developed as part of the NESC study, Flight Mechanics Analysis Tools Interoperability and Component Sharing, to develop interfaces to support interoperability between several of NASA's institutional flight mechanics tools.

The development of space missions involves multiple design tools, requiring the transfer of trajectories between them—a task that demands a large amount of trajectory data such as frames, states, state and time parametrizations, and dynamical and numerical models. This is a tedious and time-consuming task that is not always effective, particularly on complex dynamics where small variations in the models can cause trajectories to diverge in the reconstruction process.

The TRE strategy is a trajectory-sharing process that is agnostic to the models used and performed through a common object: the spacecraft and planet kernels (SPK), developed at JPL Navigation and Ancillary Information Facility. The use of this common object aims to lay the groundwork for a global flight mechanics tool interoperability system (Figure 1).

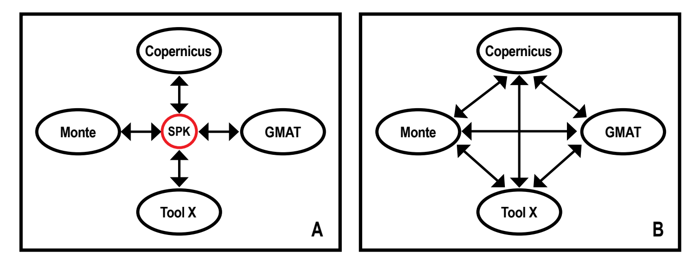

Figure 1. A) Interoperability between flight mechanics tools using standardized trajectory structures. B) Traditional specific tool-to-tool interface design.

An SPK file serves as a container object, representing a trajectory as a 6D invariant structure in phase-space, agnostic to gravitational environments, fidelity models, or numerical representation of the system. A judicious kernel scan is used to recover the trajectory in any new tool, with the minimum (or no) information from the generating source. Impulsive maneuvers can be extracted in the form of velocity discontinuities, finite burns can be detected as variations on the energy of the system, and natural bodies conforming the trajectory universe can be directly read from the kernel.

States or control points are found at predetermined time intervals or strategic points along the trajectory (e.g., periapsis, apoapsis, flybys closest approach), which are then used to reconstruct the trajectory timeline. The trajectory can be propagated forward in time using the selected set of control points. Due to the discrepancy between tool models, small or large discontinuities might appear between the integrated

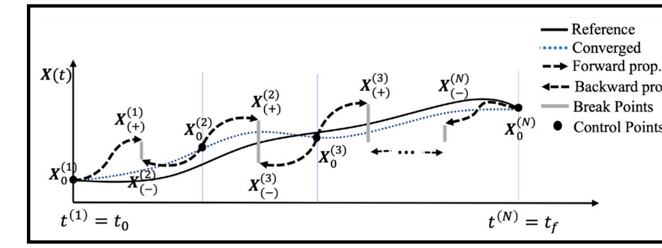

Figure 2. Multiple-shooting algorithm, utilizing strategic control points and a forward-backward propagation scheme.

legs, which can be smoothed by the implementation of a multiple-shooting algorithm (Figure 2).

The TRE strategy was successfully implemented for Monte and Copernicus in the form of Python scripts (examples of reconstructed trajectories from SPK for each of these tools are shown in Figure 3). Through an optional user input file, a user can configure their specific problem. User-defined constraints are also possible, but their implementation would depend on the specific tool. The benefits of this effort include cost reduction through the sharing of capabilities, acceleration of the turnaround process involving various analysis tools at different stages of mission development, improved design solutions through multi-tool mission designs, and a reduction in development redundancy.

Reference:

1. *Restrepo, R. L., "Trajectory Reverse Engineering: A General Strategy for Transferring Trajectories Between Flight Mechanics Tools" AAS 23-312, January 2023.*

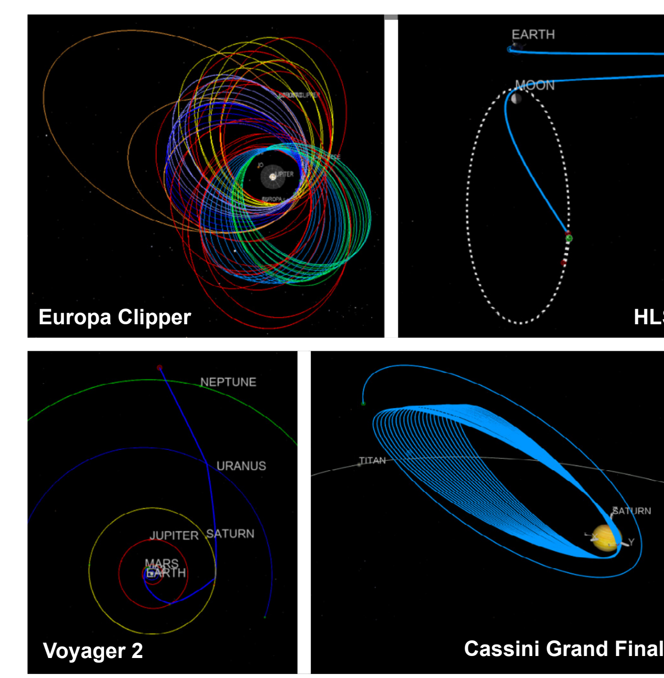

Figure 3. Future and flown missions reconstructions using Copernicus (Europa Clipper, Cassini) and Monte (HLS, Voyager 2) from SPK obtained from the Horizons System database at https://ssd.jpl.nasa.gov/horizons/.

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NESC Leadership

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Timmy R. Wilson *NESC Director* · **Michael T. Kirsch** *NESC Deputy Director* · **Mary Elizabeth Wusk** *NIO Manager* · **Lisa A. McAlhaney** *MTSO Manager* · **Peter Panetta** *NESC Technical Leader for Safety* · **Mark T. Vande Hei** *NESC Chief Astronaut*

NESC Principal Engineers

Clinton H. Cragg · **Jon P. Haas** · **Donald S. Parker** · **Michael D. Squire**

NESC Chief Engineers

Kenneth R. Hamm, Jr. *ARC* · **Dr. W. Lance Richards** *AFRC* · **Robert S. Jankovsky** *GRC* · **Carmel A. Conaty** *GSFC* · **Kimberly A. Simpson** *JPL* · **Joel W. Sills** *JSC* · **Stephen A. Minute** *KSC* · **K. Elliott Cramer** *LaRC* · **Steven J. Gentz** *MSFC* · **Michael D. Smiles** *SSC*

NASA Technical Fellows

Dr. Joseph Olejniczak *Aerosciences* · **Dr. Robert F. Hodson** *Avionics* · **Michael L. Meyer** *Cryogenics* · **Dr. Christopher J. Iannello** *Electrical Power* · **Dr. Morgan B. Abney** *ECLS* · **Heather M. Koehler** *Flight Mechanics* · **Dr. Christopher N. D'Souza** *GNC* · **Dr. Cynthia H. Null** *Human Factors* · **Dr. Dexter Johnson** *Loads & Dynamics* · **Dr. Bryan W. McEnerney** *Materials*

Dr. Michael J. Dube *Mechanical Systems* · **Dr. William H. Prosser** *Nondestructive Evaluation* · **Dr. Jonathan E. Jones** *Propulsion* · **Dr. Upendra N. Singh** *Sensors & Instrumentation* · **Dr. Lorraine E. Prokop** *Software* · **Dr. Joseph I. Minow** *Space Environments* · **Deneen M. Taylor** *Structures* · **Jon B. Holladay** *Systems Engineering* · **Steven L. Rickman** *Thermal Control & Protection*

Liaisons

Dr. Jonathan A. R. Rall, *Office of the Chief Scientist (OCS)*
David Francisco, *Office of the Chief Health and Medical Officer (OCHMO)*
Glen W. Lockwood, *Office of Safety and Mission Assurance (OSMA)*

Bios available at: NASA.GOV/NESC

NESC Alumni

Michael Aguilar *NASA Technical Fellow for Software (2005-19)*

Frank H. Bauer *NESC Discipline Expert for GNC (2003-04)*

Michael Blythe *NESC Deputy Director for Safety (2008-19)*

Dr. Thomas M. Brown *NASA Technical Fellow for Propulsion (2014-18)*

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

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

Steven F. Cash *MSFC NCE (2005)*

Derrick J. Cheston *GRC NCE (2003-07)*

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

Dr. Nancy Currie-Gregg *NESC PE (2011-17)*

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

Cornelius J. Dennehy *NASA Technical Fellow for GNC (2005-23)*

Dennis B. Dillman *NASA HQ NCE (2005-08)*

Dr. Daniel J. Dorney *NASA Technical Fellow for Propulsion (2018-22)*

Freddie Douglas, III *SSC NCE (2007-08)*

Patricia L. Dunnington *MTSO Mgr. (2006-08)*

Dawn C. Emerson *GRC NCE (2011-14)*

Walter C. Engelund *LaRC NCE (2009-13)*

Patrick G. Forrester *NESC Chief Astronaut (2009-16)*

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

Dr. Michael S. Freeman *ARC NCE (2003-04)*

T. Randy Galloway *SSC NCE (2003-04)*

Roberto Garcia *NASA Technical Fellow for Propulsion (2007-13)*

Dr. Edward R. Generazio *NESC Discipline Expert for NDE (2003-05)*

Dr. Michael G. Gilbert *NESC PE (2008-21)*

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

Oscar Gonzalez *NASA Technical Fellow for Avionics (2010-18)*

Michael Hagopian *GSFC NCE (2003-07)*

David A. Hamilton *JSC NCE (2003-07)*

Dr. Charles E. Harris *NESC PE (2003-06)*

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

Marc S. Hollander *MTSO Mgr. (2005-06)*

Michael G. Hess *NESC Deputy Director for Safety (2021-22)*

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

Keith L. Hudkins *NASA HQ OCE Rep. (2003-07)*

Kauser S. Imtiaz *NASA Technical Fellow for Structures (2017-23)*

George L. Jackson *GSFC NCE (2015-18)*

Danny D. Johnston *MSFC NCE (2003-04)*

Michael W. Kehoe *DFRC NCE (2003-05)*

Dr. Justin H. Kerr *JSC NCE (2021-22)*

R. Lloyd Keith *JPL NCE (2007-16)*

Denney J. Keys *NASA Technical Fellow for Electrical Power (2009-12)*

Dr. Dean A. Kontinos *ARC NCE (2006-07)*

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

Nans Kunz *ARC NCE (2009-15)*

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

Matthew R. Landano *JPL NCE (2003-04)*

Dr. Curtis E. Larsen *NASA Technical Fellow for Loads & Dynamics (2005-17)*

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

Richard T. Manella *GRC NCE (2009-10)*

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

Brian K. Muirhead *JPL NCE (2005-07)*

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

Daniel G. Murri *NASA Technical Fellow for Flight Mechanics (2008-22)*

Stan C. Newberry *MTSO Manager (2003-04)*

Dr. Tina L. Panontin *ARC NCE (2008-09)*

Fernando A. Pellerano *GSFC NCE (2018-21)*

Joseph W. Pellicciotti *NASA Technical Fellow for Mechanical Systems (2008-13) and GSFC NCE (2013-15)*

Dr. Robert S. Piascik *NASA Technical Fellow for Materials (2003-16)*

Jill L. Prince *NIO Manager (2013-22)*

Dr. Shamim A. Rahman *SSC NCE (2005-06)*

Dr. Ivatury S. Raju *NASA Technical Fellow for Structures (2003-17)*

Paul W. Roberts *LaRC NCE (2016-19)*

Ralph R. Roe, Jr. *NESC Director (2003-14)*

Jerry L. Ross *NESC Chief Astronaut (2004-06)*

Henry A. Rotter, Jr. *NASA Technical Fellow for ECLS (2004-19)*

Richard W. Russell *NASA Technical Fellow for Materials (2016-22)*

Dr. Charles F. Schafer *MSFC NCE (2006-10)*

Dawn M. Schaible *Manager, Systems Engineering Office (2003-14)*

Dr. David M. Schuster *NASA Technical Fellow for Aerosciences (2007-23)*

Bryan K. Smith *GRC NCE (2008-10)*

Dr. James F. Stewart *AFRC NCE (2005-14)*

Daniel J. Tenney *MTSO Manager (2009-13)*

Scott D. Tingle *NESC Chief Astronaut (2020-22)*

John E. Tinsley *NASA HQ SMA Manager for NESC (2003-04)*

Timothy G. Trenkle *GSFC NCE (2009-13)*

Clayton P. Turner *LaRC NCE (2008-09)*

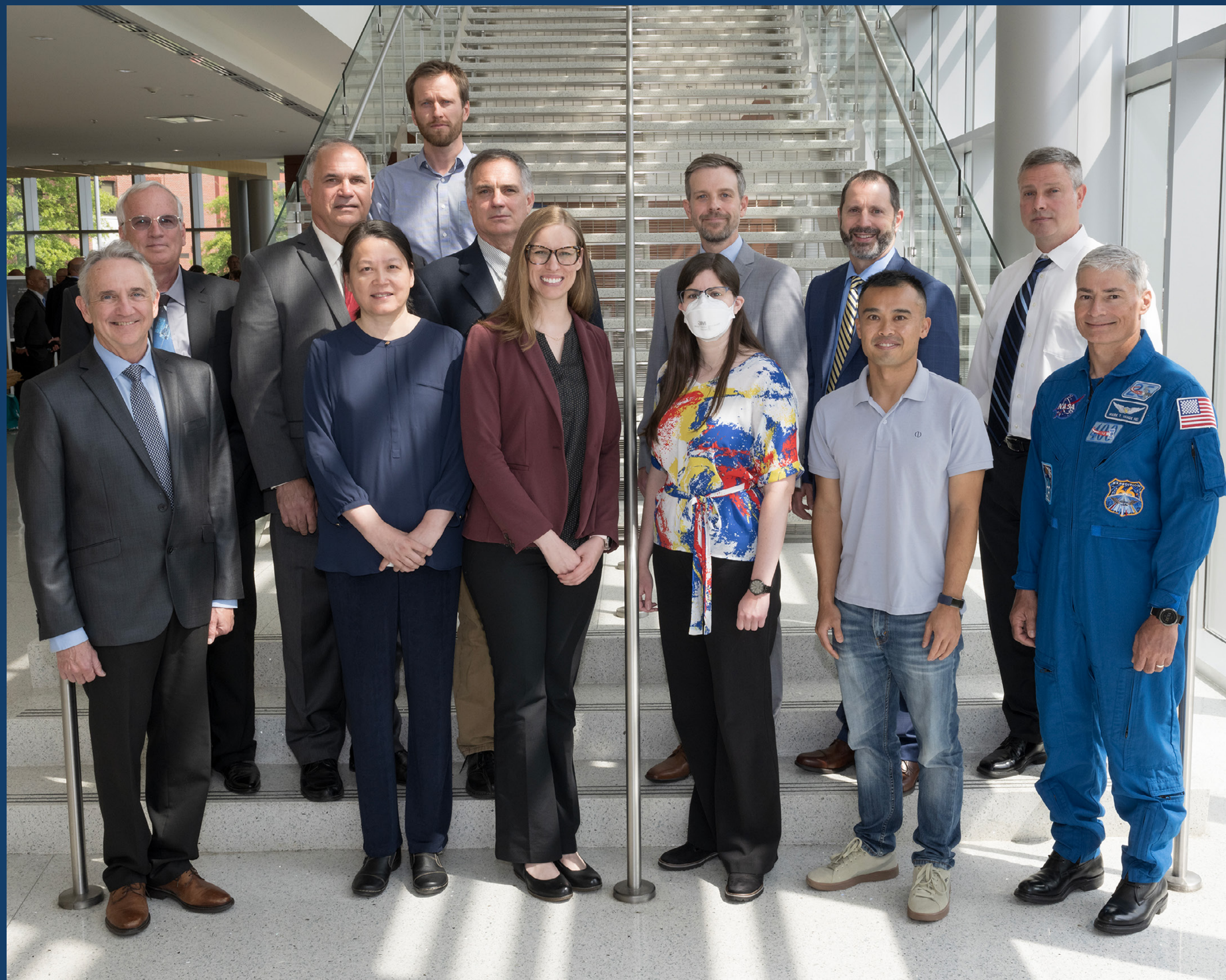
T. Scott West *JSC NCE (2012-20)*

Barry E. Wilmore *NESC Chief Astronaut (2005-20)*

Dr. Daniel Winterhalter *NESC Chief Scientist (2005-20)*

In Memory of Dr. Henning Leidecker

Dr. Henning Leidecker, a failure analysis expert with the Goddard Space Flight Center, passed away peacefully on October 30, 2023, surrounded by family and loved ones. Dr. Leidecker served on countless projects and anomaly investigations over his extraordinary 39-year NASA career. He passionately applied his vast wealth of knowledge to solve NASA's most challenging problems, including on Shuttle, ISS, Commercial Crew, Hubble and Webb telescopes, and more. Our colleague, friend, and mentor will be greatly missed.



Left to right: (Front Row) Tim Wilson (LaRC); Yuan Chen (LaRC), Elspeth Peterson (KSC), Grace Belancik (ARC), Jing Pei (LaRC), Mark Vande Hei (NESC Chief Astronaut); (Second row) James Walker (MSFC), Carlton Faller (JSC), Jason Vaughn (MSFC), Shane Cravens (Syncom Space Services, SSC), Shawn Brechbill (MSFC), Kevin Dickens (GRC); (Third row) Christopher Johnston (LaRC)

NESC HONOR AWARDS

NESC Honor Awards are given each year to NASA employees, industry representatives, and other stakeholders for their efforts and achievements in engineering, leadership, teamwork, and communication. These awards formally recognize those who have made outstanding contributions to the NESC mission, demonstrate engineering and technical excellence, and foster an open environment.

NESC Director's Award

Honors individuals for defending a technical position that conflicts with a program or organization's initial or prevailing engineering perspectives and for taking personal initiative to foster clear and open communication and resolve controversial issues.

DANIEL L. DIETRICH - In recognition of the development and advocacy of the technical rationale to assess the safety and effectiveness of breathing systems for pilots of tactical aircraft.

NESC Leadership Award

Honors individuals for sustained leadership excellence demonstrated by establishing a vision, developing and managing a plan, and building consensus to proactively resolve conflicts and achieve results.

YUAN CHEN - In recognition of outstanding leadership in the electrical, electronic, electromechanical parts' community and the development of recommendations on the use of commercial parts in NASA missions.

NIKOLAUS GRAVENSTEIN - In recognition of outstanding technical leadership in support of Verification of Testing Standard for Carbon Dioxide (CO_2) Partial Pressure in Extravehicular Activity Suits.

ELSPETH M. PETERSEN - In recognition of outstanding leadership to the Spacesuit Water Membrane Evaporator Assessment Team in negotiating creative solutions and facility challenges.

PATRICK A. SIMPKINS - In recognition of outstanding technical leadership in support of numerous NESC assessments to reduce risk to NASA's most critical human and robotic spaceflight programs.

NESC Engineering Excellence Award

Honors individuals for making significant engineering contributions, developing innovative approaches, and ensuring appropriate levels of engineering rigor are applied to the resolution of technical issues in support of the NESC mission.

KEVIN W. DICKENS - In recognition of engineering excellence and sustained commitment to the NESC Propulsion Technical Discipline Team and NASA missions.

DAVID S. HAFERMALZ - In recognition of engineering excellence and technical insight in the Orion digital acquisition unit testing in support of the Thermocouple Interference During High-speed Entry Assessment.

CHRISTOPHER O. JOHNSTON - In recognition of engineering excellence for developing the electromagnetic mechanism for the anomalous temperature behavior during the Thermocouple Interference During High-speed Entry Assessment.

JING LI - In recognition of engineering excellence in support of the Verification of Testing Standard for Carbon Dioxide (CO_2) Partial Pressure in Extravehicular Activity Suits.

RAY P. PITTS - In recognition of engineering excellence in evaluating material defects in spacesuit water membrane evaporator modules and ensuring engineering rigor during failure mitigation testing.

JASON A. VAUGHN - In recognition of engineering excellence in Kevlar lanyard testing in support of the Lucy Project Solar Array Anomaly Team.

JAMES L. WALKER - In recognition of engineering excellence in the development of new statistical methodologies for nondestructive evaluation of fracture critical flight hardware and the incorporation into NASA standards.

NESC Group Achievement Award

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

COMMERCIAL ECLSS DESIGN DEEP-DIVE ASSESSMENT TEAM - In recognition of significant contributions to the safety of life support, emergency, active thermal, and crew systems in preparation of Boeing CST-100's first crewed flight.

FILTRATION OF SPACEFLIGHT PROPULSION AND PRESSURANT SYSTEM ASSESSMENT TEAM - In recognition of outstanding dedication and engineering excellence in the development of a unified guide to spaceflight propulsion filtration.

COMMERCIAL CREW PROGRAM ASCENT STABILITY ASSESSMENT TEAM - In recognition of outstanding technical achievement in establishing rigorous best practices for justifying deviations from Commercial Crew Program control system stability robustness margin guidelines.

NASA COTS GUIDANCE ASSESSMENT TEAM - For outstanding technical contributions to advance EEE parts engineering through the development of practices for the use of COTS parts in NASA missions.

THRUSTER ADVANCEMENT FOR LOW-TEMPERATURE OPERATION IN SPACE (TALOS) PROJECT - In recognition of outstanding technical achievement in the evaluation of the TALOS Project's LabVIEW code used for ground tests of hypergolic thrusters.

NASA Technical Memorandums (TM), NASA Technical Publications (TP), and NASA Contractor Reports (CR)

1. NASA/TP-20220015152 Optimization Approach for Wind Tunnel Fan Blade Strain Gage Correlation with Test Fixture Unknowns.
2. NASA/TM-20220015363 Technology Maturation Report for Damage Arresting Composites under the Environmentally Responsible Aviation Project.
3. NASA/TM-20220017053 Unique Science from the Moon in the Artemis Era
4. NASA/TM-20220018183 Recommendations on Use of Commercial-Off-The-Shelf (COTS) Guidance for all Mission Risk Classifications - Phase II
5. NASA/CR-20230002635 Assessment of Coated Particle Fuels for Space Nuclear Power and Propulsion Systems; A Report for the NESC Nuclear Power & Propulsion Technical Discipline Team
6. NASA/TM-20230004147 Ceramic Capacitor Grain Size Analysis Using Electron Backscatter Diffraction (EBSD)
7. NASA/TM-20230004154 Multi-Purpose Crew Vehicle (MPCV) Crew Module (CM) Side Hatch Dynamic Analysis
8. NASA/TP-20230005922 Best Practices for the Design, Development, and Operation of Robust and Reliable Space Vehicle Guidance, Navigation, and Control Systems
9. NASA/TM-20230006220 Metallurgical Factors that Govern ST Properties in Commercial 2219-T87 Thick Plate
10. NASA/TP-20230006226 Evaluation of Through-thickness Microtextural Characteristics in 2219-T87 Thick Plate
11. NASA/TM-20230006507 Flight Mechanics Analysis Tools Interoperability and Component Sharing
12. NASA/TM-20230006648 Verification of Testing Standard for Carbon Dioxide (CO2) Partial Pressure in Extravehicular Activity (EVA) Suits
13. NASA/TM-20230007658 ISS Universal Waste Management System (UWMS) Optical Sensor: Phase 1-Feasibility
14. NASA/CR-20230010099 NASCAP Surface Charging Tool Development; Nascap-2k Additional Examples
15. NASA/TM-20230010624 Self Reacting-Friction Stir Weld (SR-FSW) Anomalies
16. NASA/TM-20230010640 Space-Shielding Radiation Dosage Code Evaluation; Phase 1: SHIELDOSE-2 Radiation-Assessment Code
17. NASA/TM-20230010680 Shock Prediction Advancement: Transient Finite Energy (TFE) Shock Predictor
18. NASA/TM-20230011306 NASA Exploration Systems Maintainability Standards for Artemis and Beyond
19. NASA/CR-20230012105 A Compilation of Composite Overwrapped Pressure Vessel Research (2015–2021)
20. NASA/TP-20230012154 Software Error Incident Categorizations in Aerospace
21. NASA/TM-20230013348 Unconservatism of Linear-Elastic Fracture Mechanics (LEFM)Analysis Post Autofrettage
22. NASA/TM-20230013386 Floating Potential Measurement Unit (FPMU) Data Processing Algorithm Development and Analysis Assessment

Technical Papers, Conference Proceedings, and Technical Presentations

AVIONICS

1. Chen, Y.: Statistical Interpretation of Life Test - Comparison between MIL and JEDEC requirements. NASA Electronic Parts and Packaging Program's Electronic Technology Workshop, June 12-15, 2023.
2. Franconi, N., Cook, T., Wilson, C., and George, A.: Comparison of Multi-Phase Power Converters and Power Delivery Networks for Next-Generation Space Architectures. 2023 IEEE Aerospace Conference, Big Sky, MT. pp. 1-15, DOI: 10.1109/AERO55745.2023.10115579.
3. Green, C.; Haghani, N.; Hernandez-Pellerano, A.; Gheen, B.; Lanham, A.; Fraction, J.: MUSTANG: A Workhorse for NASA Spaceflight Avionics. IEEE Space Mission Challenges for Information Technology - IEEE Space Computing Conference Caltech (SMC-IT/SCC), Pasadena, CA.
4. Hodson, R., Chen, Y., and Douglas, S.: NESC Recommendations on Use of COTS Parts for NASA Missions (Phase II) & The ILPM Pathfinder. NASA Electronic Parts and Packaging Program's Electronic Technology Workshop, June 12-15, 2023.
5. Hodson, R., Chen, Y., and Douglas, S.: Recommendations on Use of COTS Parts for NASA Missions. 2023 Space Computing Conference (SCC) Closed Session, El Segundo, CA, July 21, 2023.
6. Powell, W.: SpaceVPX Interoperability Study Briefing. SOSA Architecture Meeting, November 1, 2022.
7. Powell, W. and Hodson, R.: Advancing SpaceVPX Interoperability – Embedded Tech Trends, Chandler, AZ, January 23, 2023.
8. Powell, W.: NASA's Vision for Spaceflight Avionics. 2023 Space Computing Conference (SCC) Closed Session, El Segundo, CA, July 21, 2023.
9. Rutishauser, D.; Prothro, J.; and Fail, J.: A System to Provide Deterministic Flight Software Operation and Maximize Multicore Processing Performance: The Safe and Precise Landing – Integrated Capabilities Evolution (SPLICE) Datapath. IEEE Space Mission Challenges for Information Technology - IEEE Space Computing Conference, Caltech, Pasadena, CA, July 18-21, 2023.
10. Some, R.; Collier, P.; Hodson, R.; and Powell W.: SpaceVPX Interoperability. IEEE Space Computing Conference, Caltech, Pasadena, CA, USA - 18-21 July 2023.

FLIGHT MECHANICS

1. Restrepo, R. L.: Trajectory Reverse Engineering: A General Strategy for Transferring Trajectories Between Flight Mechanics Tools, AAS 23-312. 33rd AAS/AIAA Space Flight Mechanics Meeting, Austin, TX, January 15-19, 2023.

LOADS AND DYNAMICS

1. Allgood, J. and Decker, A.: Space Launch System Day of Launch Loads for Artemis I. Spacecraft and Launch Vehicle (SCLV) Dynamic Environments Workshop, El Segundo, CA, June 27-29, 2023.
2. Bell, J.; Armand, S.; and Samareh, J.: Structural Evaluation and Optimization of Aeroshell Design Properties for Launch and Reentry Load Cases for Future AI-Informed Design Leveraging Large Datasets. Spacecraft and Launch Vehicle Dynamic Environments Workshop, El Segundo, CA, June 27-29, 2023.
3. Blelloch, P.: Efficient Calculation of Random Stress Results. Spacecraft and Launch Vehicle Dynamic Environments Workshop, El Segundo, CA, June 27-29, 2023.
4. Gardner, B.; Parrinello, A.; and Musser, C.: An Isogrid Panel Model for SEA. Spacecraft and Launch Vehicle Dynamic Environments Workshop, El Segundo, CA, June 27-29, 2023.
5. Griggs, L.; Allgood, J.; Swatzell, S.; Moseley, J.; Oliver, N.; and Decker, A.: Space Launch System Artemis 1 Ascent Loads Reconstruction. Spacecraft and Launch Vehicle (SCLV) Dynamic Environments Workshop, El Segundo, CA, June 27-29, 2023.
6. Hahn, S.; Lunetta, N.; Weathers, J.; Zuo, K.; and Decker, A.: Space Launch System Artemis 1 Rollout Loads Monitoring and Reconstruction. Spacecraft and Launch Vehicle (SCLV) Dynamic Environments Workshop, El Segundo, CA, June 27-29, 2023.
7. Kennedy, M. and Blough, J.: Shocksat Testing and Analysis Results. Spacecraft and Launch Vehicle Dynamic Environments Workshop, El Segundo, CA, June 27-29, 2023.
8. Kolaini, A.; Kinney, T.; and Johnson, D.: Guidance on Shock Qualification and Acceptance Test Requirements. Spacecraft and Launch Vehicle Dynamic Environments Workshop, El Segundo, CA, June 27-29, 2023.
9. Patel, H. and Parsons, D.: Pressure Transducer Shock Testing. Spacecraft and Launch Vehicle Dynamic Environments Workshop, El Segundo, CA, June 27-29, 2023.

SOFTWARE

1. Prokop, L.: A Study of Historical Flight Software Error Incidents to Influence Fault-Tolerant Design. 2023 Flight Software Workshop, March 20-23, 2023, Pasadena, CA.

SPACE ENVIRONMENTS

1. Barrie, J.; Gouzman, I.; Hoffman, R.; Tighe, A.; Tagawa, M.; Miller, S.K.R.; de Groh, K.K.; Minow, J.I.; and Lao, Y.Y.: In-Situ Sensors for Monitoring the Space Environment and Its Effect Upon Satellite Materials [White paper]. Space Materials Workshop, July 24-28, 2023, virtual.
2. Davis, V.A.; and Mandell, M.J.: NASCAP Surface Charging Tool Development, Nascap-2k Additional Examples. NASA CR-20230010099, Langley Research Center, Hampton, VA, July 2023.
3. Dawkins, E.C.M.; Stober, G.; Janches, D.; Carrillo-Sánchez, J.D.; Lieberman, R.S.; Jacobi, C.; Moffat-Griffin, T.; Mitchell, N.J.; Cobbett, N.; Batista, P.P.; Andrioli, V.F.; Buriti, R.A.; Murphy, D.J.; Kero, J.; Gulbrandsen, N.; Tsutsumi, M.; Kozlovsky, A.; Kim, J.H.; Lee, C.; and Lester, M.: Solar Cycle and Long-term Trends in the Observed Peak of the Meteor Altitude Distributions by Meteor Radars. Geophysical Research Letters, 50, e2022GL101953. https://doi.org/10.1029/2022GL101953, 2023.
4. Debchoudhury, S.; Lin, D.; Coffey, V.N.; Barjatya, A.; Minow, J.I.; and Parker, L.N.: Plasma Irregularities Observed by ISS FPMU: Multi-instrument Case-study and Modeling Results. Abstract SA52A-24, AGU Fall Meeting 2022, December 12-16, 2022, Chicago, IL.
5. Debchoudhury, S.; Karan, D.; Barjatya, A.; Coffey, V.N.; and Minow, J.I.: Multi-layer Observations of Plasma Blobs and Bubbles using ICON, GOLD, and ISS FPMU. 2023 Coupling, Energetics, and Dynamics of Atmospheric Regions (CEDAR) Workshop, June 25-30, 2023, San Diego, CA.
6. de Groh, K.; Stanton, J.S.; Minow, J.I.; Kimoto, Y.; Lord, E.M.; and Lao, Y.Y.: Space Materials Center [White paper]. Space Materials Workshop, July 24-28, 2023, virtual.
7. Janches, D.; Bruzonne, J.S.; Weryk, R.J.; Hormaechea, J.L.; and Brunini, C.: Radar Observations of the Arid Meteor Shower Outburst from Comet 15P/Finlay. Planetary Science Journal, 4, 165, 2023, https://dx.doi.org/10.3847/PSJ/ace82a.
8. Levine, J.S.: The Impact of Lunar Dust and Mars Dust on Human Exploration: Summary of the NASA Engineering and Safety Center (NESC) Workshop. Lunar Science Innovation Consortium Dust Mitigation Focus Group Meeting, January 19, 2023, virtual.
9. Mertens, C.J.; Gronoff, G.; Zheng, Y.; Buhler, J.; Willis, E.M.; Petrenko, M.; Phoenix, D.; Jun, I.; and Minow, J.I.: NAIRAS Model Updates and Improvements to the Prediction of the Ionizing Radiation Environment from the Earth's Surface to Geospace. Abstract SM35C-1769, AGU Fall Meeting 2022, December 12-16, 2022, Chicago, IL.
10. Mertens, C.J.; Gronoff, G.; Phoenix, D.; Paul, S.N.; Mehta, P.M.; Zheng, Y.; and Nunez, M.: NAIRAS Model Nowcasting and Forecasting of the Aviation Radiation Environment. 20th Conference on Space Weather, American Meteorological Society, 103rd Annual Meeting, January 8-12, 2023, Denver, CO.
11. Mertens, C.J.; Gronoff, G.; Zheng, Y.; Buhler, J.; Willis, E.M.; Petrenko, M.; Phoenix, D.; Jun, I.; and Minow, J.: NAIRAS Model Updates and Improvements to the Prediction of Ionizing Radiation from Earth's Surface to Cislunar Environment. NOAA Space Weather Workshop, April 17-21, 2023, Boulder, CO.
12. Mertens, C.J.; Gronoff, G.P.; Phoenix, D.; Zheng, Y.; Petrenko, M.; Buhler, J.; Jun, I.; Minow, J.I.; and Willis E.: NAIRAS Ionizing Radiation Model: Extension from Atmosphere to Space. NASA/TP-20230006306, May 2023.
13. Mertens, C.J.; Gronoff, G.; Zheng, Y.; Buhler, J.; Willis, E.M.; Petrenko, M.; Phoenix, D.; Jun, I.; and Minow, J.I.: NAIRAS Atmospheric and Space Radiation Environment Model. IEEE Nuclear and Space Radiation Effects Conference, July 24-28, 2023, Kansas City, MO.
14. Mertens, C.J.; Gronoff, G.P.; Zheng, Y.; Petrenko, M.; Buhler, J.; Phoenix, D.; Willis, E.; Jun, I.; and Minow, J.: NAIRAS model run- on-request service at CCMC. Space Weather, 21, e2023SW003473. https://doi.org/10.1029/2023SW003473, 2023.
15. Minow, J.I.; Meloy, R.; Parker, L.N.; and Collado-Vega, Y.: JWST Space Environments Launch Constraints. Fall 2022 Natural Environments Day-of-Launch Working Group, December 7, 2022, virtual.
16. Minow, J.I.: Impacts of the Space Environment on Lunar Exploration. AIAA-2023-2467, AIAA SciTech Forum and Exposition, January 23-27, 2023, National Harbor, MD (invited).
17. Minow, J.I.: Spacecraft Anomalies and Failures Workshop 2023: NASA Introductory Comments. Spacecraft Anomalies and Failures 2023 Workshop, March 29, 2023, Goddard Space Flight Center, Greenbelt, MD, and March 30, 2023, NRO HQ Westfields (invited).
18. Minow, J.I.: SCAF Workshop 2023: Day 1 Final Comments and Wrap-up. Spacecraft Anomalies and Failures 2023 Workshop, March 29, 2023, Goddard Space Flight Center, Greenbelt, MD and March 30, 2023, NRO HQ Westfields (invited).
19. Minow, J.I.: Low Energy Ionizing Radiation and Plasma Contributions to Radiation Dose in Materials at Sun-Earth Lagrange Points. 2023 Materials Research Society Spring Meeting and Exhibit, Symposium SF02: Materials in Space—Design and Testing, April 10-14, 2023, San Francisco, CA (invited).
20. Minow, J.I.; Debchoudhury, S.; Barjatya, A.; Coffey, V.; and Parker, L.N.: Floating Potential Measurement Unit (FPMU) Data Processing Algorithm and Analysis Assessment. NASA/TM-20230013386, NESC-RP-19-01434, September 2023.
21. Minow, J.I.: Surface Charging to High Voltages in the Space Environment. High Voltage Aerospace Systems Workshop, Energy & Mobility Technology, Systems, and Value Chain Conference and Expo, September 12-15, 2023, Cleveland, OH (invited).
22. Minow, J.I.; Diekmann, A.M.; Willis, E.M.; and Coffey, V.N.: L2-Charged Particle Environment (L2-CPE) Low Energy Radiation Fluence Model. Radiation and its Effects on Components and Systems Conference (RADECS) 2023, September 25-29, 2023, Toulouse, France.
23. Newheart, A.M.; Sazykin, S.; Coffey, V.N.; Chandler, M.O.; Coster, A. J.; Fejer, B.G.; Minow, J.I.; and Swenson, C.M.: Observations of Night-Time Equatorial Ionosphere Structure with the FPMU on board the International Space Station. Journal of Geophysical Research: Space Physics, 127, e2022JA030373. https://doi. org/10.1029/2022JA030373 2022.
24. Parker, L.N.; Jun, I.; and Minow, J.I.: Introduction to the Virtual Collection on the Applied Space Environments Conference 2021. Journal of Spacecraft and Rockets, Vol. 60, No. 2, pp. 374-374, doi/abs/10.2514/1.A35728, 2023.
25. Schonberg, W. and Squire, M: Predicting High-speed Particle Impact Damage in Spacecraft Thermal Protection Systems. Journal of Space Safety Engineering. Accepted for publication.
26. Schonberg, W. and Squire, M.: Toward a More Generalized Ballistic Limit Equation for Multi-Shock Shield. Acta Astronautica. Accepted for publication.
27. Stober, G.; Weryk, R.; Janches, D.; Dawkins, E.C.M.; Günzkofer, F.; Hormaechea, J.L.; and Pokhotelov, D.: Polarization Dependency of Transverse Scattering and Collisional Coupling to the Ambient Atmosphere from Meteor Trails - Theory and Observations. Planetary and Space Science, 105768, ISSN 0032-0633, https://doi.org/10.1016/j.pss.2023.105768, 2023.
28. Thomsen, D.L.; Jordan, T.M.; Milic, L.; and Girard, W.: Decreasing Proton Single Event Effects in CubeSats with Shielding. 2023 Single Event Effects (SEE) Symposium and Military and Aerospace Programmable Logic Devices (MAPLD) Workshop, May 15-19, 2023, La Jolla, CA.
29. Valinia, A.; and Minow, J.: Required Space Weather Reconnaissance in the Artemis Era. 54th Lunar and Planetary Science Conference, March 13-17, 2023, The Woodlands, TX.
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STRUCTURES

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The Origin of the NESC Insignia

“I named my spacecraft Sigma Seven. Sigma, a Greek symbol for the sum of the elements of an equation, stands for engineering excellence. That was my goal, engineering excellence.” - Wally Schirra

The NESC’s unique insignia has its roots in the early Mercury program. For the NESC, the sigma also represents engineering excellence. While the Sigma Seven represented the seven Mercury astronauts, the "10" in the NESC insignia represents the 10 NASA centers. The NESC draws upon resources from the entire Agency to ensure engineering excellence.

Artist Cece Bibby painting Sigma Seven logo on Mercury spacecraft with astronaut Wally Schirra in 1962.

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