National Aeronautics and Space Administration

NASA ENGINEERING & SAFETY CENTER

NESC TECHNICAL UPDATE

Annual Summary of NESC 2021 Technical Activities

www.nasa.gov

NASA/TM-20210024654

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

Once again, the NASA team has excelled in the face of a global pandemic with the NESC providing the critical support and expertise to ensure our success. This year, Artemis I made significant progress toward the maiden flight of the Space Launch System as we completed stacking of the vehicle in the Vehicle Assembly Building and had a successful umbilical retract and release test, as well as integrated modal test. The fully integrated stack looks absolutely amazing in preparation for its first uncrewed trip around the Moon early next year. Also nearing its launch date was the James Webb Space Telescope, and we continued to work with our Human Landing System and Commercial Crew partners to ensure safe travel of our astronauts to ISS and the Moon. We even watched as Perseverance collected samples from Mars and witnessed the Ingenuity robotic helicopter's take offs and landings on the planet's surface. During this challenging year, programs and projects relied on the NESC when complex, technical questions needed quick resolutions. This organization has proven its value as an Agency resource for expertise and independent, discipline-wide perspectives to problem solving. The guidance and engineering rigor provided by its technical assessments was critical to the success of NASA's significant accomplishments in 2021.

Robert D. Cabana

NASA Associate Administrator

NASA's programs and missions made significant progress in 2021, even while many of us, again, orchestrated that progress from virtual or distanced work environments. It was a challenge we did not anticipate but have successfully managed and navigated despite the uncertainty and unknowns. But this is where the Agency excels. This 2021 Technical Update illustrates NASA's tenacity to solve the technical challenges that are inherent in spaceflight, to mitigate uncertainties, and identify the unknown risks that come with it. Now in its 18th year, the NESC was once again an integral part of that process. With an ability to adapt to the changing needs of the Agency, the NESC has moved seamlessly from supporting projects and programs in the design and development phase to those in the final test and flight stages. In the more than 75 assessment and support activities undertaken this year, the NESC provided expertise, developed unique tools, methodologies and approaches, and fostered collaborative and multidisciplinary teams to help solve an array of complex technical challenges across NASA programs and projects. The knowledge captured and shared during these activities serves to enhance the safety of the Agency's current and future exploration missions.

Ralph R. Roe, Jr.

NASA Chief Engineer

NASA ENGINEERING & SAFETY CENTER

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 engages proactively to help NASA avoid future problems.

Independence & Objectivity - The NESC performs technical assessments and provides recommendations based on independent testing and analysis. An independent reporting path and independent funding from the Office of the Chief Engineer help ensure objective technical results for NASA.

Engineering Excellence - The NESC draws on the knowledge base of technical experts from across 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.

Photos: NESC Testing 2004-2021

NESC Chief Engineers

Each NASA **Center** has a local NESC representative who serves as a **point-of-contact** for Center-based technical issues.

Ames Research Center, *Kenneth R. Hamm, Jr.*

Armstrong Flight Research Center, *Dr. W. Lance Richards*

Glenn Research Center, *Robert S. Jankovsky*

Goddard Space Flight Center, *Carmel A. Conaty*

Jet Propulsion Laboratory, *Kimberly A. Simpson*

Johnson Space Center, *Dr. Justin H. Kerr*

Kennedy Space Center, *Stephen A. Minute*

Langley Research Center, *Mary Elizabeth Wusk*

Marshall Space Flight Center, *Steven J. Gentz*

Stennis Space Center, *Michael D. Smiles*

Find your local NESC contact through the NASA Enterprise Directory.

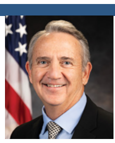
Artist Cece Bibby painting Sigma Seven logo on Mercury spacecraft with astronaut Wally Schirra in 1962

Did You Know?

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.



TIMMY R. WILSON
NESC Director

NESC Continues to Evolve to Meet NASA's Changing Priorities and Capabilities

The advances made in science and technology during the past 18 years have been remarkable, and there have been major changes in both how space is being used and the technologies available to use it. In 2003, NASA was recovering from the Columbia accident and working to put the Space Shuttle back into operation. The rovers Spirit and Opportunity were on their way Mars. Today, the Shuttle has been retired, commercial spacecraft providers are flying astronauts to the International Space Station (ISS), and Perseverance has begun collecting samples of the Martian soil to send back to Earth while the Ingenuity helicopter surveys from above. The Hubble Space Telescope is set to pass the baton to the James Webb Space Telescope. And constellations of satellites are adding challenges to managing space traffic as we figure out how to share the sky.

The NESC has witnessed and participated in the accomplishments and changes during that time. But the NESC, formed in 2003, has also had to evolve to meet NASA's changing priorities and capabilities. Just like NASA's overall goals to explore, discover, and expand knowledge for the benefit of humanity haven't changed, neither has the NESC's guiding mission to promote safety through engineering excellence and independent analysis.

One thing that has remained the same is the basic NESC structure, designed to respond quickly to NASA's toughest technical problems. When the NESC began, the focus was supporting operational programs like the Space Shuttle and ISS, and the assessment team was the most common method of engagement with the programs. An assessment team is like the classic tiger team: independent, temporary, and dedicated to addressing a specific issue. Today, while ISS is still an important aspect of the NASA mission, the current environment has shifted toward new mission development. Programs like Commercial Crew, Artemis, Orion, and the Space Launch System have different types of problems and need different ways to solve them. The NESC has adapted its model to accommodate, building not only assessment teams, but also collaborative relationships between NESC team members and the programs. In many cases, this arrangement has proven more effective in meeting needs of the stakeholders by providing real-time, on-the-scene technical help.

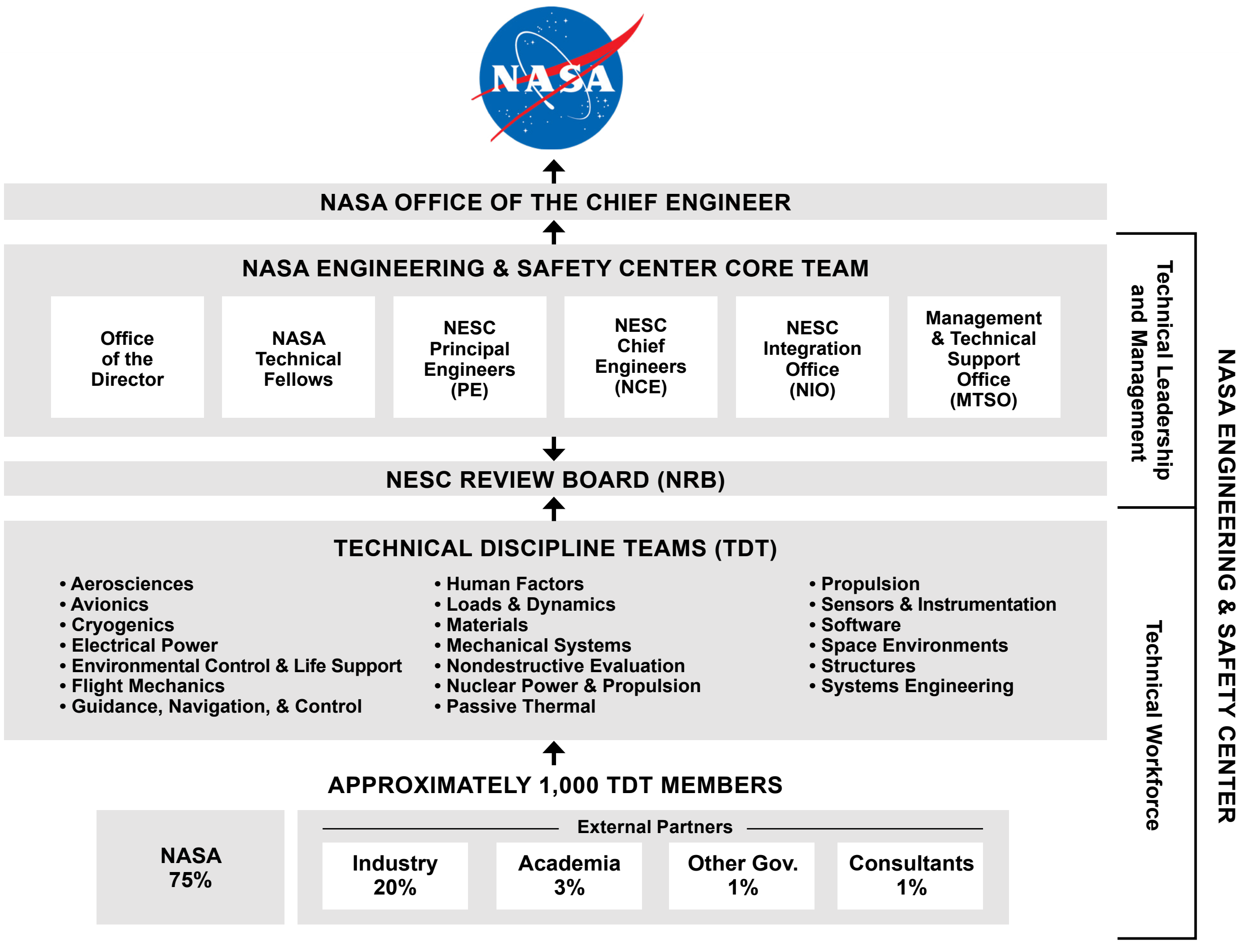
Whether for an assessment, support activity, or other type of technical assistance, the NESC Technical Discipline Teams (TDT) provide that expertise. TDTs are ready teams of engineers and scientists representing 20 different engineering disciplines. The TDTs are led by the NASA Technical Fellows for their respective disciplines. The Technical Fellows work directly for the NESC, but the members of their TDT, representing the highest level of expertise available, come from across NASA, other government agencies, academia, and private industry.

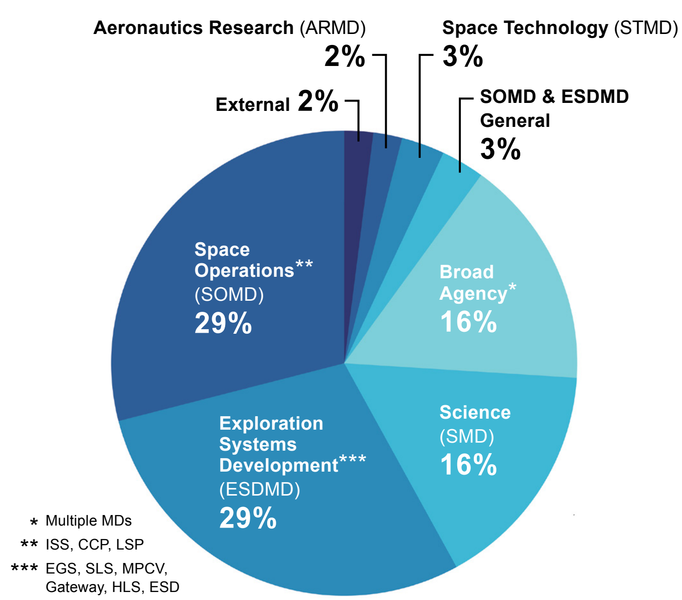
The Technical Fellows are considered part of the NESC core team, which also includes the Principal Engineers, NESC Integration Office, NESC Chief Engineers, and the Management and Technical Support Office. The Office of the Director provides overall guidance and leadership for the NESC. Members of these six NESC offices debate and approve every NESC product during NESC Review Board (NRB) sessions. The NRB is a critical element of the NESC because the diversity in experience and technical backgrounds, as well as the rigor of a peer-review process, produce well-rounded and robust solutions and documentation.

As NASA's priorities have evolved, the NESC has responded. The NESC has the flexibility to direct and redirect its focus to the Agency's highest risks and biggest technical challenges. As Artemis and other programs in development mature into operational phases, the focus may shift again, as we seek even better methods for the NESC to continue to pursue its ultimate goal: safety through engineering excellence.

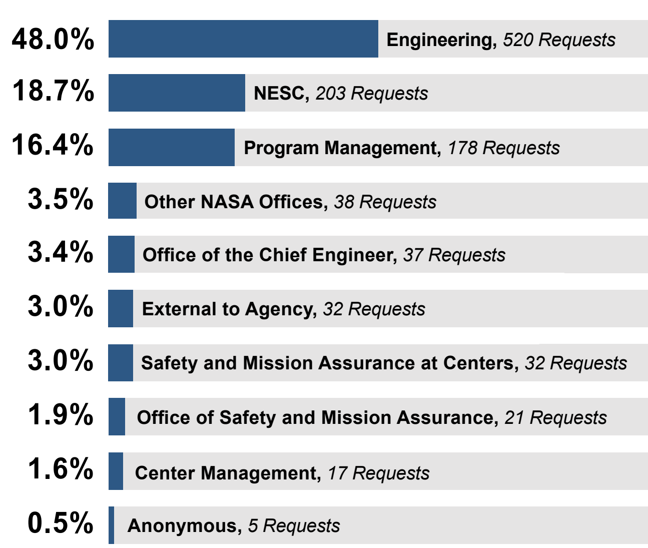
1,083 Accepted
Requests
Since 2003,
75 in FY21

Data as of September 30, 2021





Accepted Requests by Mission Directorate
FY14 - FY21



Sources of Accepted Requests Since 2003
1,083 Total Requests

OFFICE OF THE DIRECTOR


Timmy R. Wilson
NESC
Director


Michael T. Kirsch
NESC Deputy
Director


Michael G. Hess
NESC Deputy Director
for Safety


Jill L. Prince
NESC Integration
Office Manager


Dr. Azita Valinia
NESC Chief
Scientist

NA
In

NESC PRINCIPAL ENGINEERS


Clinton H.
Cragg
LaRC


Dr. Michael G.
Gilbert
LaRC


Donald S.
Parker
KSC


Michael D.
Squire
LaRC

NESC CHIEF ENGINEERS


Carmel A.
Conaty
GSFC


Steven J.
Gentz
MSFC


Kenneth R.
Hamm, Jr.
ARC


Robert S.
Jankovsky
GRC


Dr. Justin H.
Kerr
JSC


Stephen A.
Minute
KSC

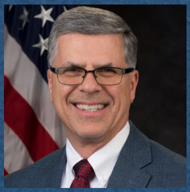

Dr. W. Lance
Richards
AFRC

NASA TECHNICAL FELLOWS


Dr. Morgan B. Abney
Environmental Control
& Life Support


Cornelius J.
Dennehy
GNC


Dr. Michael J.
Dube
Mechanical Systems

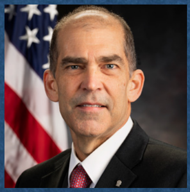

Dr. Daniel J.
Dorney
Propulsion


Dr. Robert F.
Hodson
Avionics


Jon B.
Holladay
Systems Engineering


Dr. Christopher J.
Iannello
Electrical Power


Dr. Joseph I.
Minow
Space Environments


Daniel G.
Murri
Flight Mechanics


Dr. Cynthia H.
Null
Human Factors


Dr. Lorraine E.
Prokop
Software


Dr. William H.
Prosser
Nondestructive Evaluation


Steven L.
Rickman
Passive Thermal


Richard W.
Russell
Materials

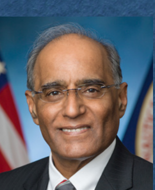
Patrick A. Martin
ASA HQ Senior SMA
ntegration Manager

Scott D. Tingle
NESC Chief
Astronaut

Kimberly A.
Simpson
JPL

Michael D.
Smiles
SSC

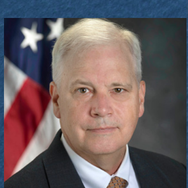
Mary Elizabeth
Wusk
LaRC



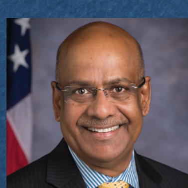
Kauser S.
Imtiaz
Structures

Dr. Dexter
Johnson
Loads & Dynamics

Michael L.
Meyer
Cryogenics



Dr. David M.
Schuster
Aerosciences



Dr. Upendra N.
Singh
Sensors & Instrumentation

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
PE (2011-17)

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

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

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

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

Oscar Gonzalez
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Michael Hagopian
GSFC NCE (2003-07)

David A. Hamilton
JSC NCE (2003-07)

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

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

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

George D. Hopson
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for Propulsion (2003-07)

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

George L. Jackson
GSFC NCE (2015-18)

Danny D. Johnston
MSFC NCE (2003-04)

Michael W. Kehoe
DFRC NCE (2003-05)

R. Lloyd Keith
JPL NCE (2007-16)

Denney J. Keys
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Electrical Power (2009-12)

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

Julie A. Kramer-White
NESC Discipline Expert
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)

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)

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 Rotter
NASA Technical Fellow
for ECLS (2004-19)

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

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

Bryan K. Smith
GRC NCE (2008-10)

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

Daniel J. Tenney
MTSO Manager (2009-13)

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)

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

Daniel Winterhalter
NESC Chief Scientist
(2005-20)

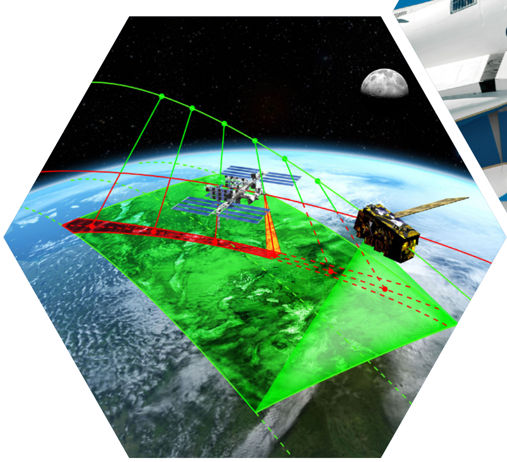
In Memory of T. SCOTT WEST

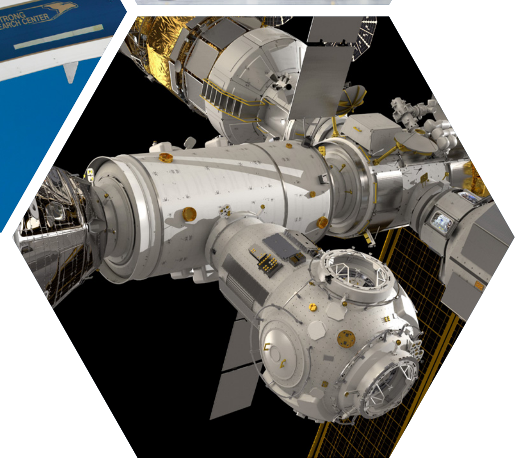
NESC Tenure: 3/11/2013 – 12/9/2020

Timothy "Scott" West, NESC Chief Engineer at JSC, passed away in December 2020. As a valued member of our team, he made many contributions to the NESC, JSC, and NASA. He was extremely proud of his involvement with the ISS, Orion, and Commercial Crew Programs. NASA's human spaceflight programs and the NESC owe much to Scott and his sustained contributions to their success. Our colleague and friend will be greatly missed.

OVERVIEW: *The Assessment Process*

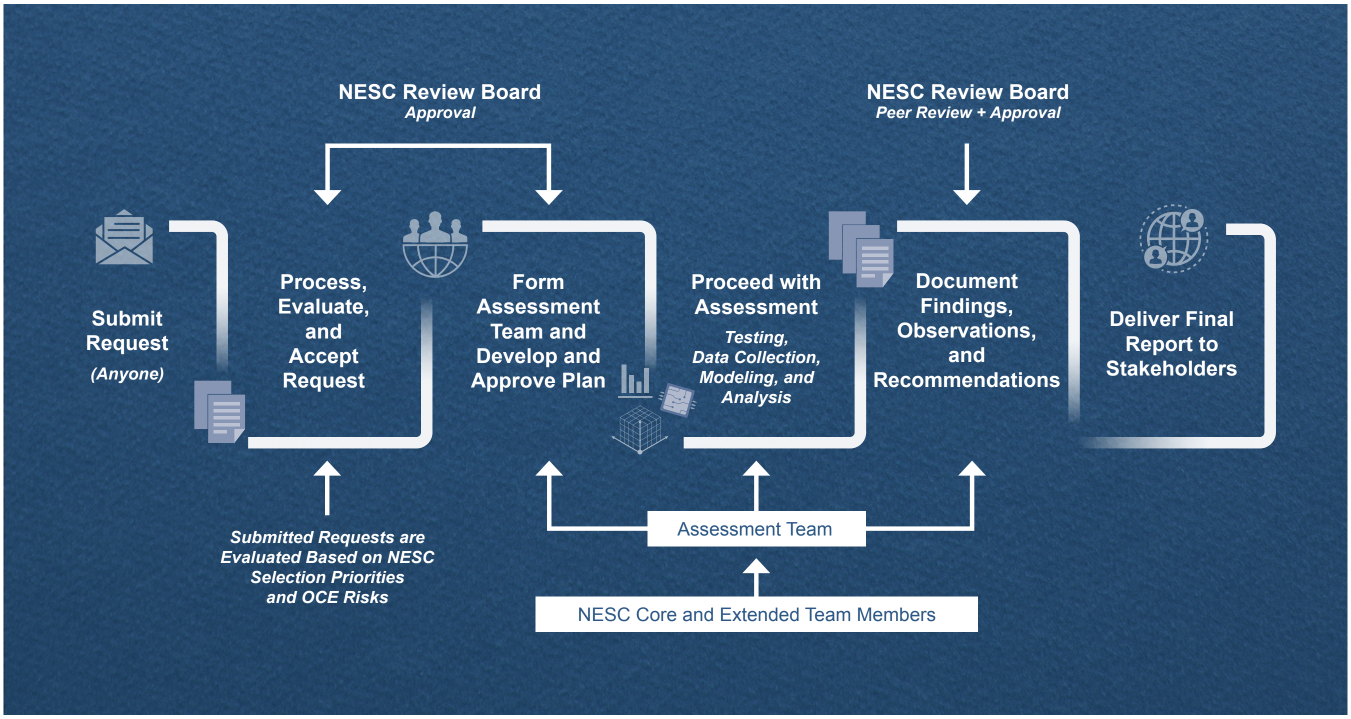
ASSESSMENT AND SUPPORT ACTIVITIES





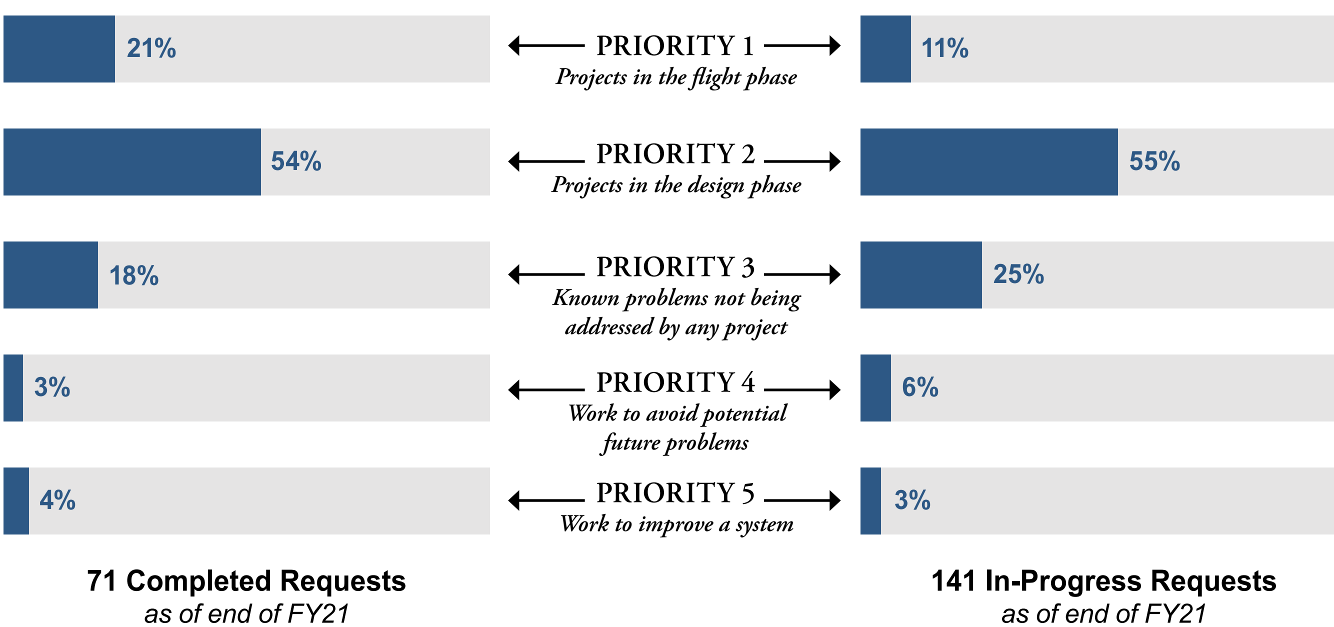
Assessments typically include independent testing and/or analyses, the results of which are peer reviewed by the NESC Review Board and documented in engineering reports. **Support activities** typically include providing technical expertise for consulting on program/project issues, supporting design reviews, and other short-term technical activities.

OVERVIEW: *The Assessment Process*



NESC ASSESSMENT PROCESS

The NESC assessment process is key to developing peer-reviewed engineering reports for stakeholders. Requests for 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 original request. An NESC team's findings, observations, and recommendations are rigorously documented within an engineering report and are peer reviewed and approved by the NRB prior to release to the stakeholder.



PRIORITY 1

COMPLETED ASSESSMENTS

PRIORITY 1: *Projects in the Flight Phase*

Pilot Breathing Assessment

The NESC has released its engineering report for the Pilot Breathing Assessment (PBA). The three-year study addressed human physiology and breathing behaviors in high-performance aircraft during operation. The study began in 2017 when the Navy requested an independent review of its efforts to address an increased occurrence of physiological episodes across their F/A-18 fleet. The PBA team designed novel instrumentation and used advanced analysis to examine pilot physiological state and interaction with the 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 equipment augmented with an advanced sensor system. Data streams were aligned and examined to identify pilot/aircraft interactions with potential for negative cognitive and physiological impact.

Analysts investigated the underlying interactions between pilots and aircraft life-support systems that cause Breathing Sequence Disruptions (BSD), a temporal or volumetric mismatch between pilot breathing demand and air flow delivered, which may lead to pilot physiological episodes causing mission aborts. After more than 100 scripted flights and processing of more than 250 million data points, it was determined that breathing pressures and airflows were often mismatched, resulting in increased effort by the pilot in maintaining sufficient ventilation. Although humans are quite adaptable to such breathing stress, repeated hysteresis in pressure/flow parameters adds to the burden of flying. The PBA study is the first to document such BSDs within the context of using on-demand mask/regulator systems with a liquid oxygen supply. The report presents the findings in detail and provides a Pilot Breathing Almanac, which documents the breadth and variety of pilot breathing metrics under various flight conditions as well as new insights into pilot physiology. The team also wrote a case-study to demonstrate the value of systems engineering and inclusion of the human element over the system development and operational lifecycle. *This work was performed by LaRC, AFRC, ARC, GRC, GSFC, JPL, JSC, WSTF, and also the EPA, UF, USN, and USAF.* NASA/TM-20210018900

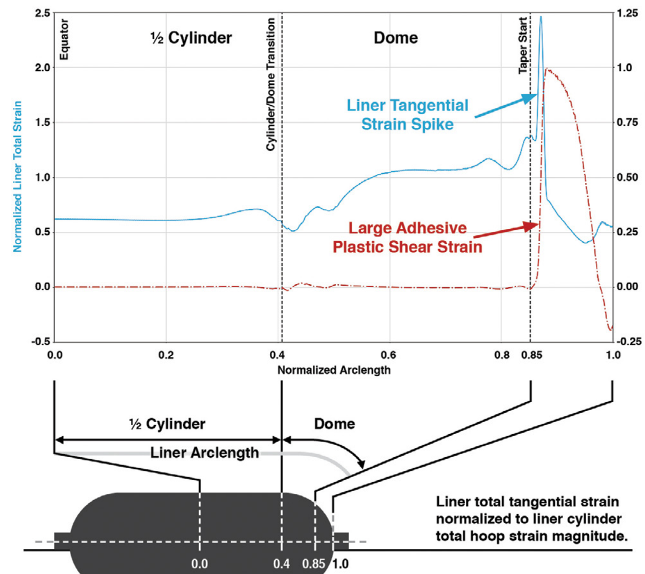
ARFC F-15 high-performance aircraft were used in the PBA.

PRIORITY 1

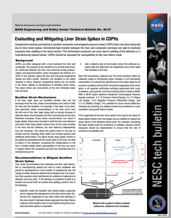
Mitigating Liner Strain Spikes in COPVs

In its ongoing work to ensure the safety of composite overwrapped pressure vessels (COPV) used in spaceflight, the NESC learned of unexpected cracking and leaking in bonded COPV liners occurring in recent test programs. COPVs are often designed with a bond between the liner and composite overwrap. The purpose of the bondline is to provide load transfer continuity between the liner and overwrap during pressurization and depressurization cycles throughout the lifetime of a COPV. Shear stress can concentrate in the liner at geometric transitions such as at a liner thickness taper near the boss fitting. If the liner taper does not smoothly transfer load into the overwrap from the liner, stress concentrations can result in both the liner and the bondline.

The NESC performed finite element analysis of COPV designs to evaluate margins and any design risks. The unexpected cracking and leaking have been attributed to liner strain spikes observed through measurement and predicted by analysis. Liner strain concentrations from adhesive and liner yield interaction or manufacturing defects can lead to crack nucleation and growth or development of a liner buckle. Diminished load transfer between the liner and composite overwrap can lead to localized excessive liner yielding in the dome section. This diminished constraint can occur due to yielding of the adhesive or a manufacturing unbond defect. COPVs should be assessed for susceptibility to this new failure mode. Recommendations to mitigate bondline strain spikes were documented in NESC Technical Bulletin 20-07 *Evaluating and Mitigating Liner Strain Spikes in COPVs. This work was performed by KSC, JPL, GRC, LaRC, JSC, MSFC, AFRC, GSFC, and WSTF.*



Analytical results: explicitly modeled elastic-plastic adhesive, not including disbond



Refer to NESC Technical Bulletin 20-07:
Evaluating and Mitigating Liner Strain Spikes in COPVs

PRIORITY 1: *Projects in the Flight Phase*

In-Progress Assessments

- ECLSS-ATCS Review
- Cross-Program Exposure Testing Review
- CCP Fracture Control Risk Reduction
- Hot-Gas Intrusion in Engine Bays
- Effects of Pressure Spikes on Material in a Hypergolic Engine
- Ablative Thermal Protection System Reuse Study
- Extravehicular Mobility Unit Sublimator Corrosion
- Orion Frangible Joint Threshold and Margin Analysis
- Ti-NTO Compatibility Cross-Program Impact and Lessons Learned
- Validation of ISS Lithium-Ion Main Battery's Thermal Runaway Mitigation Analysis and Design Features

Completed Support Activities

- Anomalous False Carriers on Ethernet Buses
- Technical Support for Reaction Wheel Assembly Anomaly
- Drogue and Main Impact Damage Tolerance Evaluation Phase 2
- CCP Mass Properties Evaluation
- Corrosion Mitigation Strategy for Reuse
- Hardware Development for COVID Applications
- Materials Support to Aircraft Type A Mishap
- NESC Support of CCP Anomaly
- Rapid Slews for Lunar Reconnaissance Orbiter

In-Progress Support Activities

- LF Regulator Debris Catcher Development
- Parachute Impact Damage Tolerance Evaluation - Phase 3
- ISS FGB Air Leak
- CCP Launch Vehicle Orbital Tube Welding POD Study Samples
- Support for Fire Cartridge Failure Investigation, Manufacturing and Hardware Verification
- Battery Charge Discharge Unit Flight Anomaly Investigation Support

PRIORITY 2

COMPLETED ASSESSMENTS

PRIORITY 2: *Projects in the Design Phase*

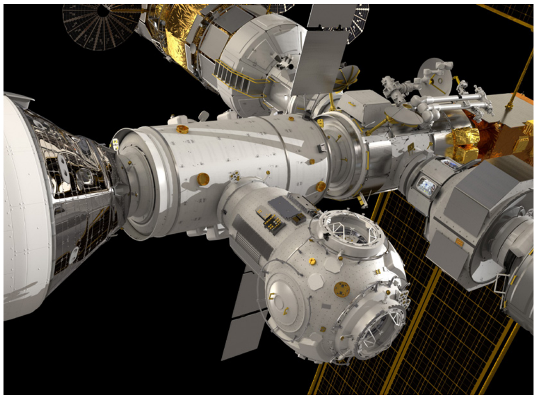
Evaluating Biocides for Exploration Missions

Water system interfaces require architecture-level consideration when selecting a biocide. NASA has used iodine as a biocide to successfully control microbial growth in life support systems since the Apollo era. Exploration missions, however, will involve longer periods of dormancy during which water will remain stagnant and prone to microbial growth, and mass and cost constraints will limit the ability to carry filtering or replacement hardware. There also is interest in establishing international interoperability standards for exploration systems, including biocide compatibility. To help identify and prioritize biocide solutions for near- and long-term mission goals, the NESC was asked to evaluate the impacts of multiple biocide solutions on life support, extravehicular activity systems, and crew health at both system and subsystem levels. Assessing the trade space of various life support system water biocides such as silver, bromide, and chloride compounds, the NESC identified several viable architectures and a prioritized list of development activities that should be undertaken to address knowledge gaps before an architecture is down-selected. *This work was performed by MSFC, JSC, JPL, ARC, and KSC.* NASA/TM-20210013644

Future life support systems will be critical components of long-duration missions. Concept of Orion approaching Gateway.

Gauging Propellant in Zero-g

In a low-gravity environment, liquid fuel can slosh or accumulate on tank surfaces rather than settle, which makes the gauging of remaining fuel in the tank challenging. NASA has invested in new technologies to directly measure tank propellant mass in microgravity. To aid future investment decisions, the NESC completed an assessment of their technical maturity and potential effectiveness to gauge cryogenic propellant in the reduced gravity environment of space. The assessment team provided subject matter advice on how the respective technology has addressed, or may be impacted by, varying operating conditions that can arise in a cryogenic system. Multiple areas were identified for consideration in engineering development, and the assessment team findings highlighted the technology strengths, limitations, and areas with potential for complex development. *This work was performed by GRC, KSC, MSFC, SSC, GSFC, and LaRC.*

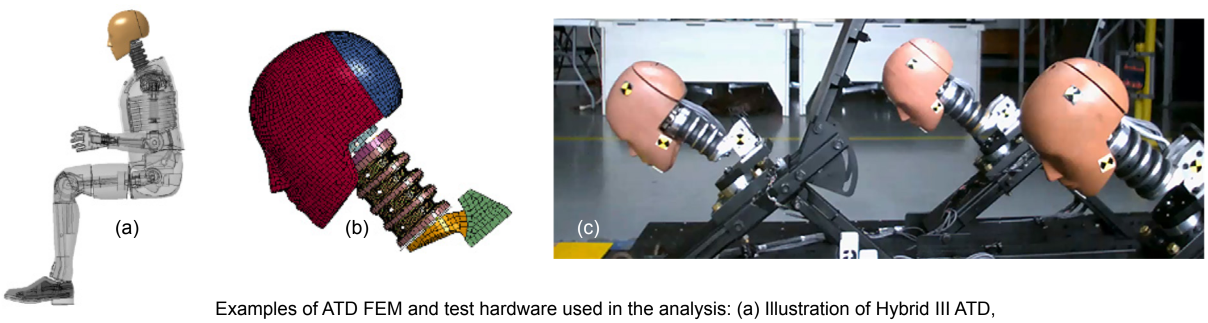


Reliable sensing of cryogenic fuel mass is required for zero-g environments. Concept of visiting vehicles at Gateway.

PRIORITY 2

Leveraging Occupant Protection Expertise to Aid in Certification

NASA developed occupant protection (OP) requirements for the Multi-Purpose Crew Vehicle (MPCV) and Commercial Crew Programs (CCP) to ensure crew safety and mitigate occupant injuries during dynamic phases of spaceflight. As expertise in OP and biodynamics across NASA is extremely limited, the Health and Human Performance Directorate/Health and Medical Technical Authority community requested NESC assistance to support OP testing/analysis, loads and dynamics, and systems engineering to aid CCP and its partners in their pursuit of OP certification. An NESC team was able to leverage past assessments involving the development of anthropomorphic test devices (ATD) models and verification methodologies, the improvement of ATD modeling and test methodologies, and the development of techniques to assess ATD model uncertainties. The team applied these techniques to aid CCP partners in their OP model development testing, model calibration, full-vehicle testing, and model validation efforts to ensure the occupant finite element models (FEM) used in OP certification analysis provide an accurate prediction of forces experienced during dynamic phases of flight. The team also worked to ensure water landing testing was performed in a manner adequate to fully validate the OP certification analysis methodology. *This work was performed by LaRC, JSC, and KSC.*

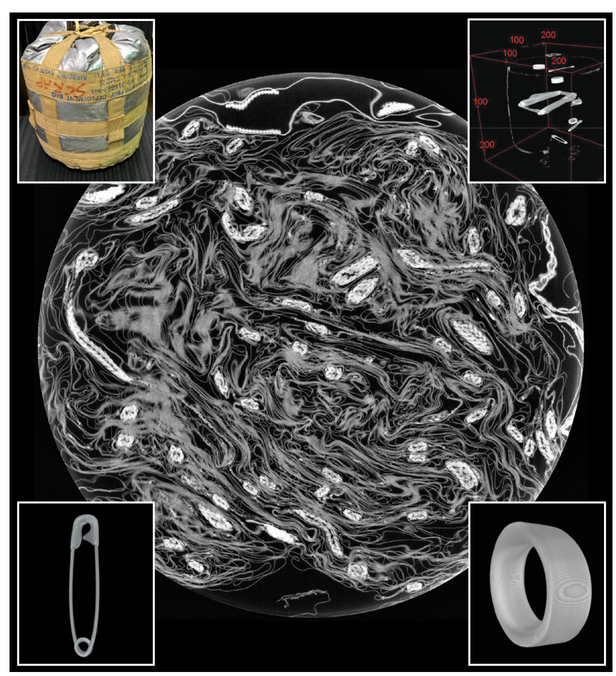


Examples of ATD FEM and test hardware used in the analysis: (a) Illustration of Hybrid III ATD, (b) LSTC ATD head-neck FEM, and (c) ATD isolated head-neck test configuration

Using X-ray Computed Tomography to Inspect Pressure-Packed Parachutes

Parachutes are designed and employed to stabilize and control a spacecraft's atmospheric descent to the surface. Individually pressure-packed into textile deployment bags, the parachutes must conform in volume and shape with available onboard vehicle stowage. Because the packing process can exert more than 400 pounds per square inch of pressure, it risks damaging the parachute's textiles and components. Currently, conventional two-dimensional X-ray nondestructive evaluation (NDE) technology is used to detect damaged reefing line cutters and reefing rings or to detect foreign object debris. This often requires time-consuming, multiple and/or repeat X-rays to resolve ambiguous findings and does not discern damage to textiles.

The NESC initiated a pathfinder evaluation of microfocus X-ray computed tomography (CT) NDE technology for identifying packing damage. Using the LaRC NDE facility, the team tested three small-to-medium sized cylindrical deployment bags, typical of ribbon drogue parachutes, pressure packed with parachute components at pack densities up to 25% greater than densities used by U.S. human spaceflight programs. Two- and three-dimensional X-ray CT images were produced for each pack configuration and were found to identify specific parachute-packing risks (e.g., foreign objects) more reliably compared to conventional X-ray NDE, but damage to textiles was difficult to discern. More rigorous investigation into the imaging of textiles would be necessary to confirm this finding and produce improved results. *This work was performed by LaRC and JSC.*



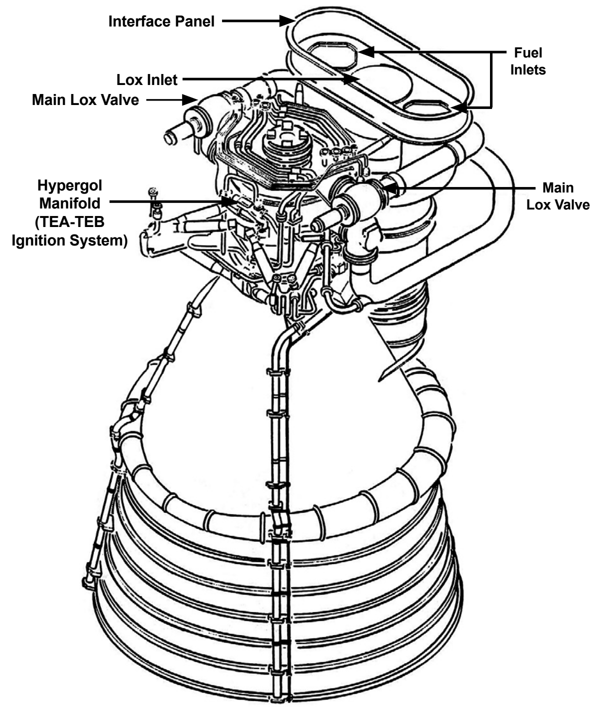
Clockwise from top left: Daylight image of parachute pack, frame from 3-D X-ray CT movie of pack contents, imaged reefing ring and safety pin, and actual textile parachute material (background)

PRIORITY 2

Start Sequences in TEA-TEB Ignition Systems

Many gas generator (GG)-cycle rocket engines use a pyrophoric mixture of triethylaluminum-triethylborane (TEA-TEB) to achieve ignition. The process involves pressurizing the TEA-TEB with helium to cause a burst disk to rupture and allow the TEA-TEB to flow into the GG. Once inside, the TEA-TEB mixture contacts the flowing liquid oxidizer (oxygen), combusts, and ignites the fuel. When the engine is restarted, residual helium in the TEA-TEB lines can mix with the TEA-TEB and act as a diluent as it flows into the GG chamber. The NESC initiated an assessment to experimentally determine the role of helium concentration in the combustion process with a goal of helping the start/restart sequences of engines and avoid unwanted hard starts.

Testing at the White Sands Test Facility (WSTF) used a Parr vessel contained in a chemical fume hood. TEA-TEB was injected by syringe into the vessel and pressure was recorded as function of time. A special tool was designed to load the syringe with TEA-TEB in a nitrogen-purged dry box and move it to the vessel for maximum safety. Results demonstrated that the TEA-TEB/O_2 reaction pressure increased while the combustion efficiency decreased with increasing amounts of diluent (helium and any excess O_2). The results can be used to help guide the formulation of start sequences in TEA-TEB ignition systems. See page 48 for an in-depth discussion. *This work was performed by MSFC, WSTF, and GRC. NASA/TM-20210018852*

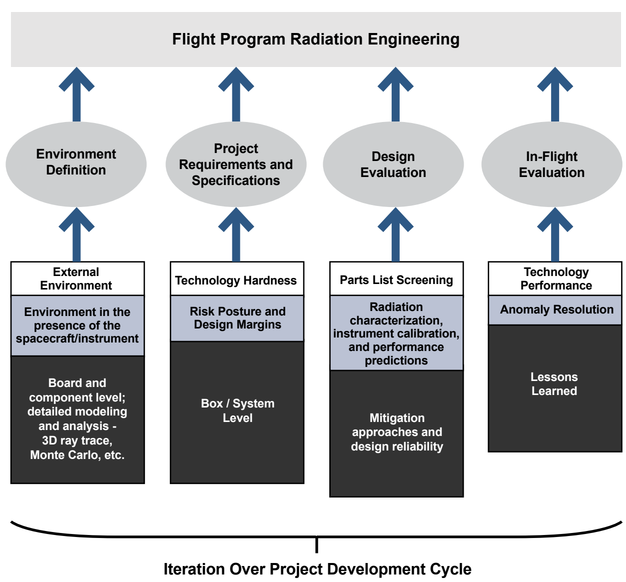


The Apollo F-1 engine is an example of a TEA-TEB ignition system.

Radiation-Hardness Assurance Guidance for NASA Avionics Systems

As human exploration embraces a broader range of missions in more severe radiation environments, it is crucial to ensure risks are understood and that natural space radiation environment threats do not compromise mission success. Toward that effort, the NESC formed a multi-Center team to develop and publish baseline radiation-hardness assurance (RHA) guidance for NASA avionics systems as well as guidance for a single-event effects (SEE) criticality analysis.

The team documented guidelines spanning the primary radiation effects (i.e., total ionizing dose, total non-ionizing dose, and SEE) and significant content on radiation shielding and transport, radiation effects testing and analysis, and operational monitoring for radiation effects. Additional appendices provided supporting information on ray-trace analysis, generation of radiation requirements, model-based mission assurance, proton testing at medical therapy facilities, and the impact of sample size on radiation testing and analysis. Continued progress is needed to develop a unified Agency approach to aerospace avionics RHA and approaches that promote model-based methods and experimental capabilities. See related RHA article, page 46. *This work was performed by LaRC, GSFC, JPL, JSC, MSFC, KSC, and WFF. NASA/TM-20210018053*

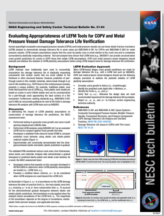


The RHA lifecycle process is laid out with interdependent activities that span assurance and engineering design.

PRIORITY 2

Understanding Autofrettage Crack Growth

After manufacturing, COPVs go through a process called autofrettage, where the tank is filled to high pressures to compress the inner surfaces, making them less susceptible to operational stresses later. Recently, the NESC supported the efforts of the Orion MPCV Program to measure the crack growth in selected materials during an autofrettage cycle. The process was to measure crack growth in precracked test coupons with specific crack geometries and strain levels similar to those associated with the autofrettage cycle of Orion COPVs. The team, leveraging knowledge gained during a previous COPV life test assessment (NASA/TM-20205006765), designed notch-test coupons, performed pre-cracking as well as cycle tests, and evaluated crack growth data. Results from the tests supported MPCV component damage tolerance verification and contributed to the NASA fracture community's understanding of autofrettage crack growth in single- and multiple-cycle applications. *This work was performed by GRC, LaRC, JSC, and WSTF.*



Refer to NESC Technical Bulletin 21-04:

Evaluating Appropriateness of LEFM Tools for COPV and Metal Pressure Vessel Damage Tolerance Life Verification

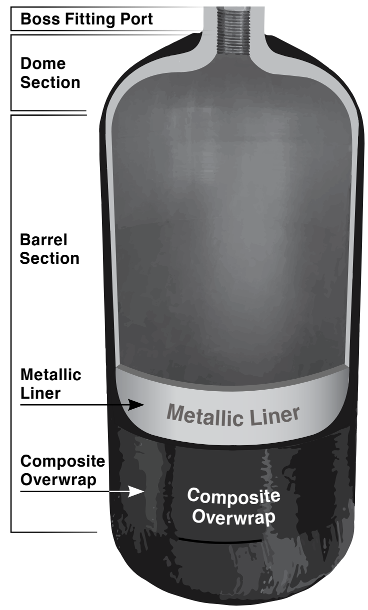


Illustration of COPV major components

Evaluating Laser Architecture for Laser Interferometer Space Antenna (LISA)

LISA is a European Space Agency (ESA)-led mission designed to search for gravitational wave signatures from massive black hole binary star systems. The on-orbit antenna consists of three satellites positioned in an equilateral triangle, each separated by over 1 million miles. With this configuration, the path between any two satellites is one of two arms that represent a Michelson-type interferometer. Multiple lasers will implement each arm of the interferometer. By measuring the minute distance changes in these arm lengths caused by passing gravitational waves, LISA will be able to measure their amplitude, direction, and polarization.

NASA is directly supporting the development of five key technologies for possible contribution to the mission, including the laser system, which will require simultaneous and stable in-orbit operation of 6 laser heads on the three spacecraft over a period of 5 years without any prolonged interruptions. To ensure the laser system is meeting ESA requirements, the GSFC-led LISA design team requested the NESC perform an independent assessment of the GSFC laser architecture and its technology readiness level. The NESC team assessed the design for potential weaknesses and improvements to mitigate risks, reviewed the goals and structure of the LISA Program's Reliability Plan, and assessed the current redundancy plan and components. The team concluded there were no fundamental problems or major design issues and provided feedback on areas for further consideration should the design be selected for flight by ESA. *This work was performed by LaRC, JPL, GSFC, and MSFC.* NASA/TM-20210018863

Illustration of LISA's configuration and orbit, trailing behind the Earth as it orbits the Sun

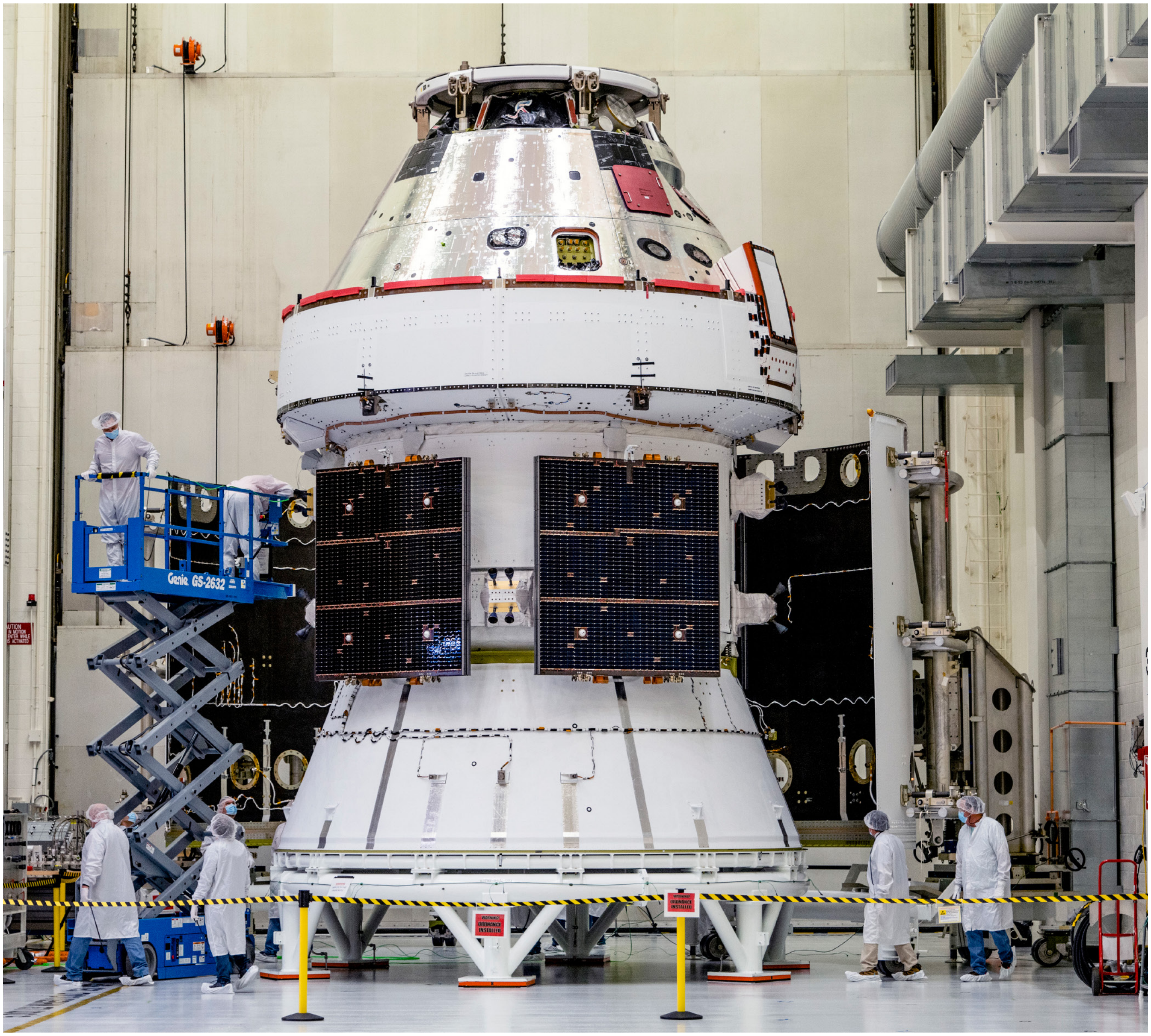
Credit: AEI/Milde Marketing

PRIORITY 2

Testing of Crewed Spacecraft Safety Equipment

NASA is often faced with challenges in the development of life support systems operating in a micro-g or zero-g environment. Issues that can arise in crewed spacecraft include leakage of ammonia used in cooling systems, toxic gasses released from onboard fires, and alternative methods for the collection, storage, and disposal of urine. The NESC recently completed an assessment of spacecraft safety equipment, specifically for projects in support of the ISS and Orion MPCV Programs, in the areas of ammonia leak clean-up systems, fire protection hardware development and verification, and contingency urine collection and disposal.

Leveraging the elements of a team already in place in 2018, the NESC team assessed a portable, rapid-response, ammonia removal technology, comparing it with state-of-the art ammonia removal equipment currently on board the ISS. Sorbents for use in the Orion MPCV Contingency Breathing Apparatus and in the Smoke Eater Filter, which could revitalize cabin air after a fire, were examined. The assessment team also matured design of a standalone waste collection device for use as a backup to the Orion crew module waste collection and disposal system. Work included full-scale testing and analytical model development, which helped strengthen the technical rigor of designs, prepared them for flight hardware development, and brought them closer to flight qualification. *This work was performed by LaRC and JSC.*



This work examined safety equipment that could fly on the Orion MPCV.

PRIORITY 2

Unique Fire Safety Systems for Orion

The Orion MPCV fire safety system is unlike the fire safety systems used on the Shuttle or the U.S. segment of the ISS. As such, unique aspects of the integrated system have driven the need for unique pieces of hardware. JSC has been designing, developing, and qualifying parts of the environmental control & life support (ECLS) equipment. The NESC conducted technical risk-reduction activities for part of that safety-critical government-furnished equipment, which included Contingency Breathing Apparatus (CBA); the Orion Portable Fire Extinguisher (OPFE); and the Orion Smoke Eater Filter (OSEF). The assessment team focused its evaluation on the hardware, organizational and process aspects of development, and the human decisions that impact overall fire safety system performance.

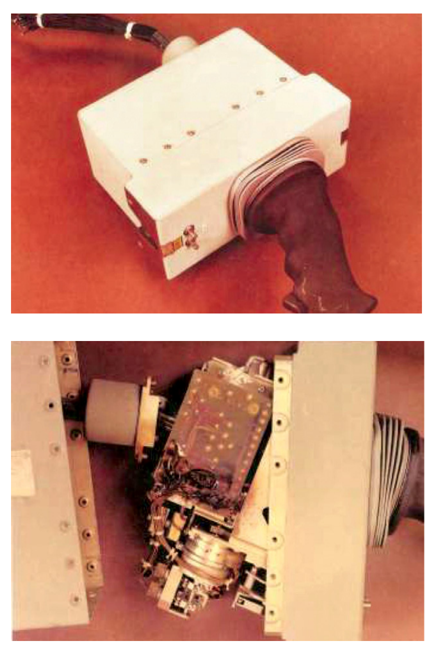
Following tests and analyses and identification of potential risks related to the development and qualification of the hardware systems, the team found that the Orion Program is using the appropriate type of fire safety equipment, and the CBA, OPFE, and OSEF designs meet the technical requirements and address the key operational risks of the program. It was found that NASA processes allow fire safety equipment to be qualified by analysis only and that no process requires fire safety equipment to be exercised regularly as part of a proficiency/proving ground-test program. NASA processes require training, but these training requirements can be met with classroom training that does not provide the trainee with the opportunity to use the equipment. The team noted the importance of human-in-the-loop evaluations in operational environments, regularly exercising hardware, and providing hands-on proficiency training. *This work was performed by LaRC, JSC, ARC, GRC, and WSTF.* NASA/TM-20210013869

Top: Prototype CBA; Bottom left: Illustration of OPFE
Bottom right: Illustration of OSEF showing prefilter removal

Evaluating Fire Suppression Systems

The NESC assisted Commercial Crew Program (CCP) engineering in determining performance requirements for a crewed spacecraft fire suppression system. As stated in JSC 29353, *Flammability Configuration Analysis for Spacecraft Applications*, “Fire is one of the many potentially catastrophic hazards associated with the operation of crewed spacecraft. A major lesson learned by NASA from the Apollo 204 [Apollo 1] fire in 1967 was that ignition sources in an electrically powered vehicle should and can be minimized but can never be eliminated completely. For this reason, spacecraft fire control is based on minimizing potential ignition sources and eliminating materials that can propagate fire. Fire extinguishers are always provided on crewed spacecraft but are not considered as part of the fire control process.” Given this guidance, the NESC undertook a detailed review of spacecraft fire suppression requirements from the CCP and ISS programs based on specific spacecraft configurations and materials. Applicable sections of CCT-REQ-1130, *ISS Crew Transportation and Services Requirements Document,* and the SSP 50808, *International Space Station (ISS) to Commercial Orbital Transportation Services (COTS) Interface Requirements Document (IRD),* were examined by the NESC team.

The team performed materials testing and analysis to evaluate extinguishment thresholds and suppressant dwell time necessary to prevent reignition of a fire after initial extinguishment and developed a computational model to generate dwell time derating factors for 1-g dwell time data for application to microgravity. *This work was performed by MSFC, KSC, GRC, WSTF, and JSC.*



Example of flammability testing from JSC 29353B performed after the Apollo 1 fire on a vented hand controller. The fire was contained by the vented controller. Similar testing has been performed on Orion crew module components.

PRIORITY 2

Independent Review of Artemis I Integrated Hazards

Artemis I will be the first integrated flight of the Orion MPCV and the Space Launch System and will bring together many complex systems across the spacecraft and launch vehicle as well as the ground systems that will support the launch, flight, and recovery. In support of upcoming milestone reviews, the Exploration Systems Development Mission Directorate requested the NESC assess that all Artemis I integrated hazards (IH) have been identified, controlled, and verified. The NESC team's assessment covered the timeframe from the Vehicle Assembly Building rollout to the spacecraft's safe-down in the recovery ship well deck. Leveraging methodology developed during previous NESC assessments, an extensive, multi-Center, multi-discipline assessment team was assembled, which developed independent fault trees, comparing them to Artemis I hazard reports. The team searched for potential gaps in IH coverage and development, evaluated the robustness/adequacy of hazard controls and verifications through selected deep dives, and looked for areas to improve cross-program interactions for future IH development and processes. *This work was performed by SSC, JSC, KSC, MSFC, LaRC, GRC, and NASA HQ.*

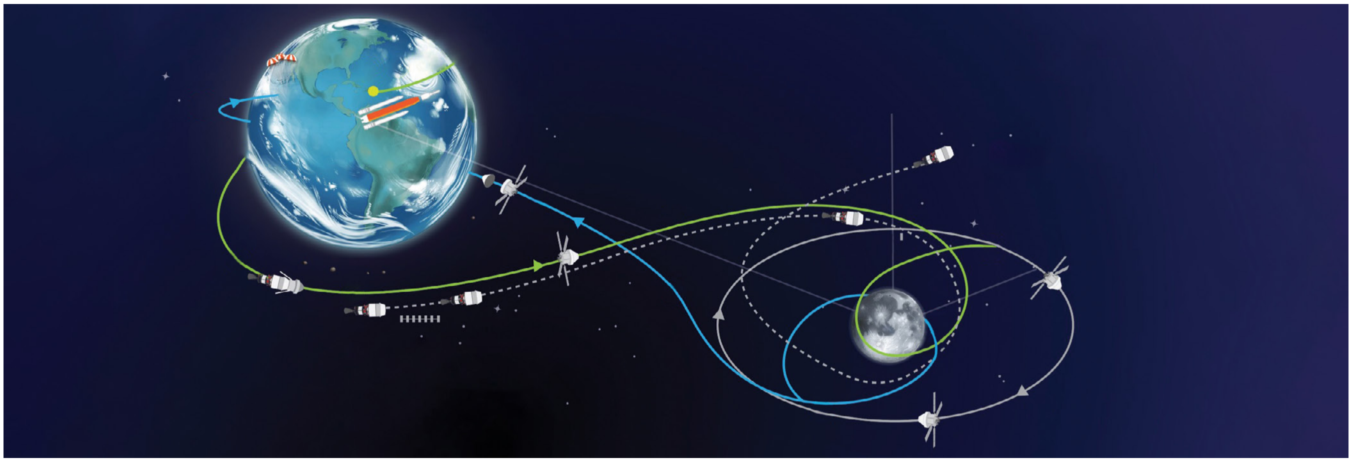
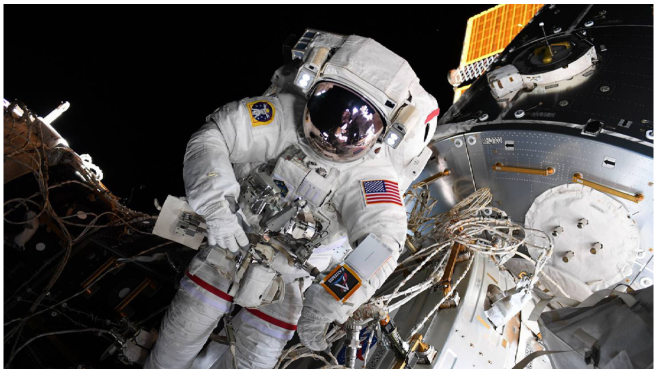
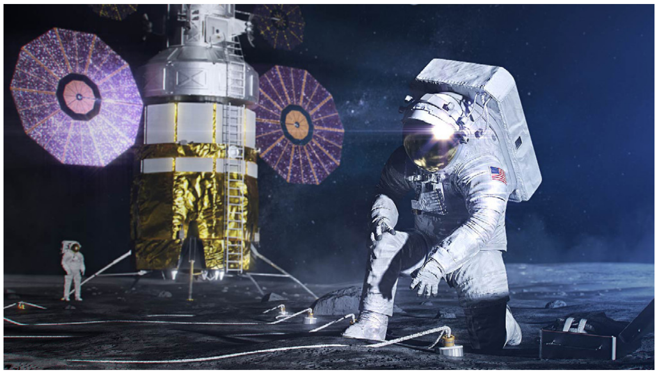


Illustration of the Artemis I mission trajectory

Reference Architecture Facilitates xEVA Trade Studies

JSC is developing two Exploration Extravehicular Activity (xEVA) power systems for future use on ISS and lunar applications. These systems are a part of the equipment used to power the extravehicular mobility unit (EMU) life support systems during pre- and post-EVA as well as EMU maintenance activities. To help guide their development and leverage those systems for future exploration use, the NESC was requested to develop a reference architecture (RA) based on the baseline ISS EVA power system design. The goal was to enable technology adoption decisions across the power supply, battery management system, and vehicle interface-to-suit-equipment projects, while mitigating the risk of unnecessary rework. Model-based systems engineering was used to develop the RA, consolidating knowledge such as requirements, use cases, activity diagrams, and operations concepts as a basis for pursuing trade studies in the thermal and power disciplines. The trades resulted in recommendations as well as the RA, which was delivered to the stakeholders for future use. *This work was performed by KSC, JSC, MSFC, LaRC, and GSFC.*





Initial xEVA power systems are scheduled for delivery to ISS in 2022 and targeted for use on Artemis lunar EVA suits.

PRIORITY 2

Test and Verification of Safety-Critical Software

Software systems have become more complex over the past several years while becoming increasingly responsible for running critical spacecraft systems. And the more complex the code, the more difficult it is to adequately test and verify. The NESC conducted a study to determine the benefits of cyclomatic complexity (CC) and basis path testing (BPT) as tools to ensure safety-critical software is not overly complicated and verification is robust. The purpose was to consider adding requirements for complexity and testing based on complexity metrics to NASA's software standards for safety-critical software with the overall objective of reducing errors. CC is a software metric used to measure code complexity. These metrics measure independent paths through source code. BPT, or structured testing, is a white-box method for designing test cases. The method analyzes the software control flow graph of a software program to find a set of linearly independent paths of execution.

An NESC team comprising NASA software engineers, industry partners, military personnel, and academia reviewed the use of CC and BPT, examined software products to evaluate complexity levels, researched previous software failures, and evaluated other data and factors including requirements development and code coverage requirements. The team determined that while BPT would be beneficial, the modified condition/decision coverage approach, a code coverage technique commonly used in software testing, was a more robust choice. The team also provided a list of factors they considered critical to a robust software system, including architectural complexity, requirements analysis, complete verification approach, and independent code reviews, and recommended additional NASA software engineering requirements. *This work was performed by GRC, NASA HQ, MSFC, JPL, GSFC, LaRC, and the U.S. Air Force.* NASA/TM-20205011566

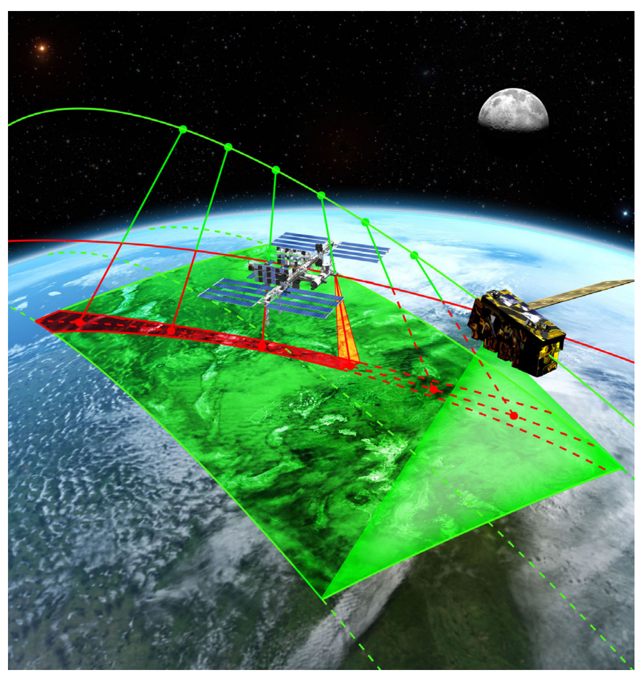
Complex software and hardware will control the Orion crew module. Shown is the Medium Fidelity Mockup at JSC.

CLARREO Pathfinder Flex Harness Cable Life Testing

Managed and under development by LaRC, the Climate Absolute Radiance and Refractivity Observatory (CLARREO) Pathfinder Mission (PFM) will demonstrate technologies to improve understanding of Earth's changing climate. This will be accomplished by taking highly accurate measurements of sunlight reflected by Earth and the Moon. These measurements, which will be anchored to international standards, will be 5 to 10 times more accurate than those from existing sensors. The PFM will also demonstrate the ability to improve measurement accuracy of other Earth-viewing instruments that overfly CLARREO PFM while in orbit. CLARREO will be hosted on the ISS.

The NESC supported a LaRC investigation team into issues associated with electrical flex harnesses during life testing. Subject matter experts evaluated the life-tested harnesses using nondestructive evaluation techniques, destructive physical analysis, and digital imaging correlation and developed parametric models to evaluate alternative designs.

The team provided a root cause analysis and recommendations to extend flex harness life and improve flex harness design, manufacturing, reliability, and quality. This led to design modifications to mitigate the identified issues and provided follow-on recommendations for designing, building, and testing the new flex harness cable. *This work was performed by LaRC, GSFC, and JPL.* NASA/TM-20210018831



The CLARREO PFM will take measurements of Earth from the ISS with on-orbit calibration using the Sun and the Moon and improve the accuracy of other Earth-sensing instruments.

PRIORITY 2

PRIORITY 2: *Projects in the Design Phase*

In-Progress Assessments

- Study of Material Sensitivities to N2O4/MON Exposure
- Materials and Processes Selection Criteria for Lunar Construction
- Oxidizer Tank Design and Qualification Assessment
- EUS COPV Helium Tank with Large Grain Aluminum Alloy
- Verification of Testing Standard for CO2 Partial Pressure in EVA Suits
- Gateway PPE COPV Damage Tolerance Life Support
- MSR EEV Dynamic Stability Assessment
- Motion Magnification for Gimbaled Bellows
- Frangible Joint Technical Support to SLS
- Parachute Dispersion Bridle Load Link Tech. Evaluation Phase-1
- MPCV Launch Abort Vehicle Powered Aero Database Development using FUN3D
- SLS Prevalve Anomaly Assessment
- Mars Sample Return MMOD Protection Review
- Reaction Wheel Bearing Contamination
- Energy Modulator Webbing Shredding Testing
- MAV Buffet / Aeroacoustics Numerical Simulations
- LC-39A Pad Modification Evaluation
- Impacts of Reduced Pressure Atmospheres on Environmental Control and Life
- MPCV COPV Damage Tolerance Life by Analysis Risk Assessment
- Independent Operational Modal Analysis of Dynamic Rollout Test Data
- RP-1 Leak Behavior Characterization
- Helium Evolution from Helium-Saturated Hypergolic Propellants
- CFD Assessment of AA-2 Axial Force Anomaly
- Lunar Meteoroid Ejecta Model Review
- Evaluation of Alternate Helium Pressure Control Component
- Trade Space Analysis: Balancing Crew and Mission Design Parameters
- Examination of Time-Triggered Ethernet in the Artemis Architecture
- EGS ICPS Umbilical Modeling Evaluation and Assessment
- Tube Test Coupon for COPV Mechanics
- Technical Support for Anaerobic Hydrogen Detection Sensor
- Orion Crew Module Side Hatch Analysis
- Hypervelocity Impact (HVI) Testing of Kevlar KM2+
- Space Launch System High Reynolds Number Testing
- CCP Ascent Stability
- Issues with Qualification of Radiographic NDE Techniques
- CCP Post-flight Reference Radiation Environments
- Review of Analysis to Support Midpoint Monitoring in Batteries
- Material Compatibility and EAC Data for Metals in Hypergolic Propellants
- Assessment of Autonomous Flight Termination System
- CCP Parachute Pack Ground Extraction Testing
- Aerodynamic Buffet Flight Test
- Thermocouple Interference During High-Speed Earth Entry
- Assessment of Lead H2 Pop During SLS RS-25 Start
- NESC Peer Review of ESD Integrated Vehicle Modal Test, Model Correlation, DFI and Flight Loads Readiness
- Titanium Hydrazine Tank Weld - Environmentally Assisted Cracking
- Infrared Laser Sensor Technology Readiness & Maturation
- Effects of Humidity on Dry Film Lubricant Storage & Performance
- CPV Working Group
- Stress Ruptures COPV
- Independent Modeling and Simulation for CCP EDL
- SLS Aerosciences Independent Consultation and Review
- Reaction Wheel Performance for NASA Missions
- Exploration Systems Independent Modeling and Simulation
- Peer Review of the MPCV Aerodynamic/Aerothermal Database Models and Methods

Completed Support Activities

- Treatment of Pressure Transients in Space Flight Pressurized Systems
- EGS Mobile Launcher Swing Arm Hydraulic Analysis Support
- Moisture in Active Thermal Coolant
- CFD/DTA Analysis for Propulsion System Cavitation Test
- Review of Solder Operations for the Mars Sample Return Mission
- Technical Support for Orion Docking Mechanism Jettison System
- Technical Support for JPSS-2 SADA Life Test
- Independent Review of Additively Manufactured Materials for xEVA
- NAFTU Software Independent Engineering Review Request
- Mars 2020 Sample Tube Anomaly
- Circuit Board Signal Integrity/Pwr Analysis and Training for CLPS Missions
- Ascent Cover Technical Support
- Support for NASA Aircraft Anomaly
- Remote Analog Interface Unit Dropout Anomaly
- Orion Spacecraft Low-g Slosh Performance and Stability Impact Investigation
- Orion Artemis II Spectrometer
- Power Electronics Technical Support for Electric Propulsion
- Super Resolution Post Processing of Air-to-Air Imagery of CCP High Altitude Parachute Test
- NOVICE Support to LSP and CCP Radiation Assessment

In-Progress Support Activities

- Support for Integrated RF and Optical Communications Project
- ESM Pressure Control Assembly Valve Model Update
- Technical Support for Ames Facility Electric Power Issues
- Support for Balloon Program Flight Safety Risk Analysis
- Review of Spacesuit Electrical Models for Lunar Operations
- Frangible Joint Technical Support to LSP
- ESD Critical Event Assessment Reviews
- Gateway Type 2 D&C Standards ESA Equivalents Adjudication Plan
- Independent SMEs for DOLILU Certification Review
- Suborbital Crew; Qualification Approach and Risk Analysis Support
- Support to Complete Artemis xEMU Visor Inspection System Hardware
- Statistical Design of Experiments Support for ICEE Formulation
- MAV Mass Properties and Mass Growth Implementation and Margin Refinement
- CCP Sensor Anomaly Investigation Support
- Rotordynamic Analysis for Europa Clipper
- Ocean Color Instrument (OCI) Engineering Test Unit Anomaly
- Space Charging of OCI Rotating Mechanism
- 1553 Databus Dropped Commands
- Support to Blue Origin, New Glenn Launch Vehicle
- Evaluating Risk of an Alternative Pyro Lot Acceptance Test Plan
- SE&I Support to CCP DCRs
- Review of SLS FTS Battery Cell Out Test Procedure
- Orion, NDSB2, and Gateway Material Electrical Properties Support
- Hydrodynamics Support for the Orion CM Uprighting System
- CCP Parachute Flight/Ground Tests & Vendor Packing/Rigging
- Support for SLS Design Certification Review
- Bond Verification Plan for Orion's Molded Avcoat Block Heatshield Design

COMPLETED ASSESSMENTS

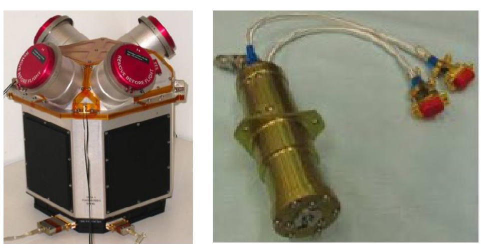
PRIORITY 3: *Known Problems not Being Addressed by any Project*

Microthrusters for Precision Attitude Control

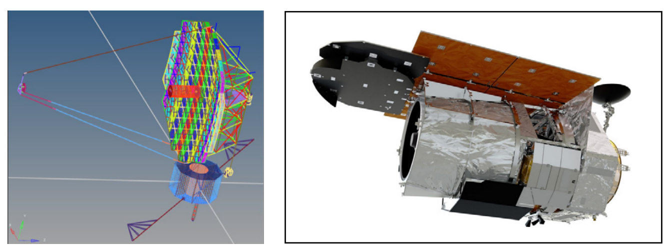
Pointing repeatability and stability (i.e., jitter) requirements are key for future space telescope missions to capture planet images on exoplanet coronagraph missions. These jitter requirements will be difficult to meet with current reaction wheel-based architectures, such as those used on the Hubble Space Telescope (HST). Disturbances from reaction wheels can be mitigated, as in HST's case, by carefully designed mechanical isolation, but this imposes system complexity and cost. A potential solution for achieving this fine pointing control are microthrusters, capable of forces in the micronewton range, which have been developed for other missions such as the Laser Interferometer Space Antenna.

An NESC assessment examined two varieties of microthrusters: cold gas, which uses a precision piezoelectric valve for fine flow-rate control; and colloid, which generates thrust by applying a high electric potential difference to accelerate a stream of charged droplets. The NESC team improved modeling fidelity and studied architectures, examined multiple mission application use cases, and addressed trade study recommendations received during a feasibility study.

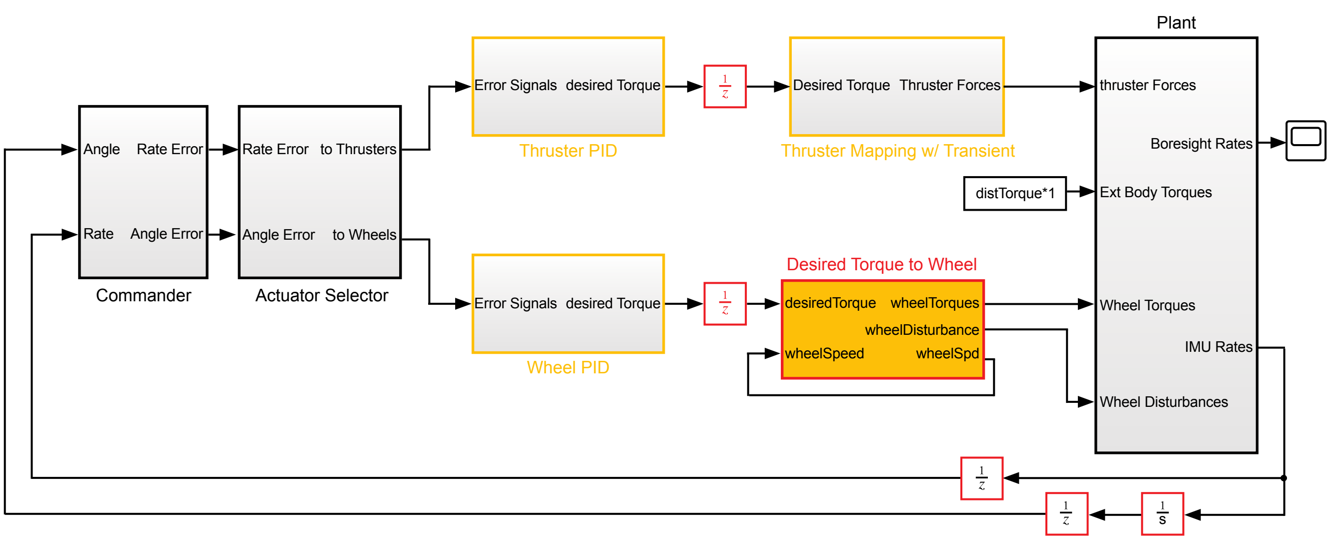
High-fidelity simulations found that microthrusters used as the sole method of control actuation improved fine pointing performance by roughly an order of magnitude compared with the HST and by roughly two orders of magnitude better than a wheels-only system without mechanical isolation. Future multi-year astronomy and astrophysics missions requiring precision pointing stability may need microthrusters with higher maximum thrust level, longer lifetime, and higher bandwidth than have been demonstrated on orbit to date. The simulation developed in this assessment is available for use NASA-wide. *This work performed by GSFC and JPL.* *NASA/TM-20205011556*



Microthrusters - Colloidal (left), Cold Gas (right)



Generic Observatories Evaluated



Overview of simulation model used to evaluate microthruster performance for two generic observatory configurations

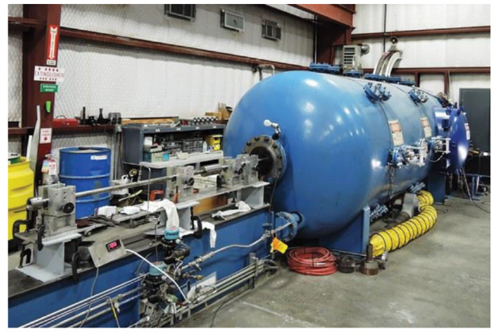
PRIORITY 3

Reducing Uncertainty in COPV MMOD Risk Assessments

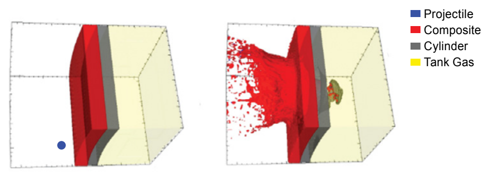
Micrometeoroid and orbital debris (MMOD) is the highest single risk in human spaceflight, and pressure vessels are a significant component in MMOD risk assessment. Because failure criteria for pressure vessels were developed in the 1960s with little refinement since, these Apollo-era MMOD criteria are being applied to modern spacecraft without tests or analyses to confirm their applicability. This is a source of uncertainty in many MMOD risk assessments, and the issue was highlighted as a finding in a previous NESC activity.

Recently, the NESC partnered with the Hypervelocity Impact Technology Group at JSC and WSTF to update failure criteria for COPV. The team performed hypervelocity impact testing on typical COPVs, instrumenting test articles to obtain and analyze impact data. The assessment results were used to update damage predictions for COPVs and will aid in understanding COPV MMOD damage tolerance. Further, the results will potentially reduce uncertainty in risk assessments of current missions and inform MMOD-related design efforts. *This work was performed by LaRC, JSC, WSTF, JSC, MSFC, and JPL.*

Typical COPV used in impact testing



Portion of hypervelocity gun at WSTF



Hydrocode simulation of hypervelocity impact

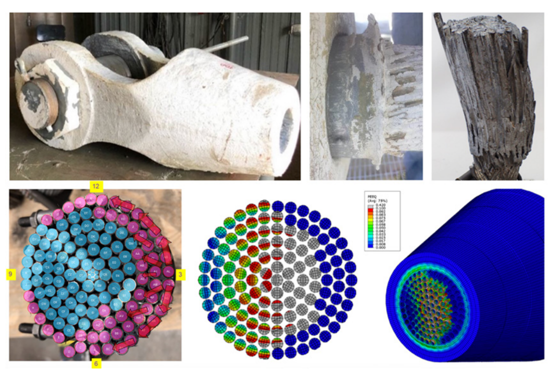
Arecibo Observatory Zinc Spelter Socket Joint Failure Investigation

NASA was asked by the University of Central Florida (UCF) to support an investigation into an auxiliary cable socket failure on the Arecibo Observatory located in Barrio Esperanza, Arecibo, Puerto Rico. Owned by the U.S. National Science Foundation (NSF) and managed by UCF, the facility was home to a radio telescope that was uniquely capable of characterization and orbital refinement of planets, comets, and asteroids; detecting optically invisible gas and revealing areas of interstellar space obscured by cosmic dust through its detection capability in the radio spectrum; and studying Earth's upper atmosphere.

The Arecibo Observatory's telescope consisted of an instrument platform suspended above the dish by stay cables connected to three towers. In August 2020, an auxiliary cable slipped from its socket joint on one of the towers, eventually leading to the total collapse of the observatory in December 2020. The NESC collaborated with KSC, MSFC, and outside organizations in support of the NSF's investigation, providing technical support, structural and failure analysis, modeling, materials testing, and fishbone analysis to determine the most probable contributors and failure scenario. NASA structural analysis and forensic investigation concluded that the M4N Arecibo socket joint failure was primarily due to cumulative damage caused by initially low structural design margins and a high percentage of sustained load, leading to zinc creep deformation, progressive internal socket wire damage, and eventual loss of joint capacity. The team's investigation results and recommendations were published to aid in the understanding of contributing factors and prevent similar occurrences. *This work was performed by GSFC, KSC, MSFC, LaRC, and JSC.* [NASA/TM-20210017934]

Refer to [NESC Technical Bulletin 21-05]:

Industry Recommendations from Arecibo Observatory Zinc Spelter Socket Joint Failure Analysis



NASA Investigation of failed Arecibo Aux M4N cable/socket.
Top: Socket (left); zinc extrusion (center); pulled out cable (right)
Bottom: Forensic and finite element model recreation of M4N failure progression

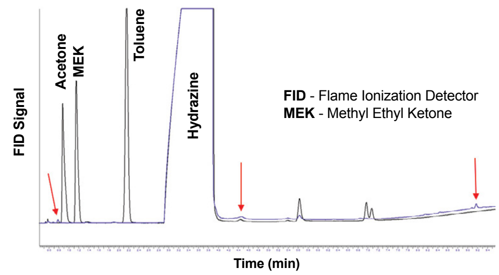
PRIORITY 3

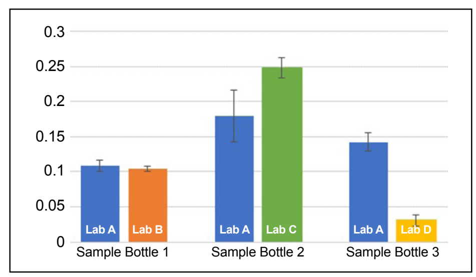
Continued Analysis of Hydrazine Hydrate

The NESC has been examining new methods in the production process for high-purity hydrazine (HPH). Hydrazine dominates the class of hypergolic liquid propellants used for rocket propulsion systems and is widely used in auxiliary power units and thrusters for satellites and spacecraft. Trace contaminants in HPH propellant impact a wide variety of commercial, Department of Defense, and NASA missions. Depending on thruster design, elemental contaminants must be kept at extremely low levels and are verified as such by routine analysis. A number of these contaminants have recently undergone an assessment to shed light on their quantities present following changes in the HPH supply chain. In 2020, the NESC provided a deep-dive analysis of ketazine-produced HPH, with a focus on identification of extraneous unknown carbonaceous materials present in the ketazine HPH and a full elemental profile of the commodity in relation to heritage Raschig-produced HPH stocks.

The NESC conducted another in-depth analysis of a lot from another hydrazine hydrate (HH) source, again focusing on the organic and elemental content and using the methodology developed from the previous assessment. Initially, there was an unexpectedly wide variation in elemental assay results from the analysis of single batch-sourced samples of HH from four laboratories. Further analysis revealed that the provided samples themselves exhibited variation, undoubtably because of pre-laboratory handling, but large discrepancies were determined to have been caused by differences in analytical procedures and methods at the laboratories themselves. The NESC produced a set of best practices for the elemental profiling of HPH. Results showed that any of the organic families detected in the HH were the same or similar to those found in the ketazine HPH. It also showed that the distillation process used in the production of ketazine HPH is removing a considerable portion of the ketazine organic side products. *This work was performed by KSC, MSFC, and WSTF.* LLIS Entry 29801

Refer to NESC Technical Bulletin 21-03:
Best Practices for the Elemental Profiling of High-Purity Hydrazine





Top: Overlay of 100-ppm acetone-MEK-toluene standard (black) and ketazine HPH sample (blue) with initially unidentified contaminants identified by red arrows.
Bottom: Lab-to-lab variation in initial analysis of elemental content across multiple sample bottles of HH.

New Standards for Additive Manufacturing

Prior to an NESC assessment that began in 2018, there were no Agency-level standards providing specific design and construction requirements for the certification of additively manufactured (AM) parts. While some organizations were developing standards, NASA mission schedules required a more timely and applicable solution as the Agency and its program partners in human spaceflight (HSF) were actively developing AM parts for flight. To bridge the gap, MSFC authored a Center-level standard for the laser powder bed fusion process, but an Agency-level standard was necessary to ensure application to multiple AM processes and adaptability to all NASA activities.

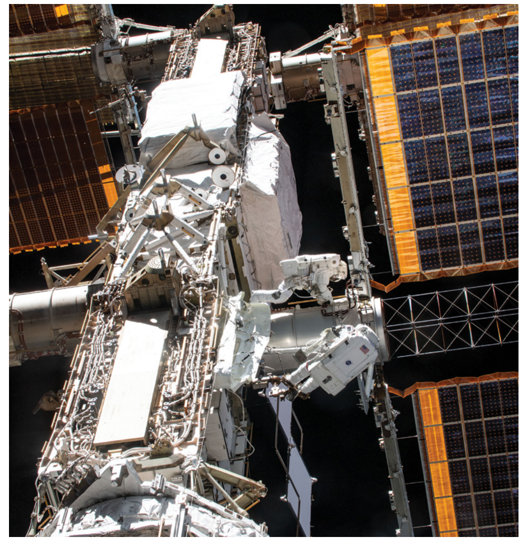
Leveraging on the principles of MSFC Standard 3716, the NESC team created and released two standards. NASA-STD-6030, *Additive Manufacturing Requirements for Spaceflight Systems*, was intended for all HSF applications. Also released was NASA-STD-6033, *Additive Manufacturing Requirements for Equipment and Facility Control*. A companion handbook for both standards is currently in work. For an in-depth discussion, see page 52. *This work was performed by KSC, JSC, GRC, GSFC, JSC, ARC, JPL, LaRC, AFRC, and MSFC.*

Liquid rocket engine turbopump housing produced using additive manufacturing

PRIORITY 3 • PRIORITY 4

High Power Li-ion Battery Module Design

A previous NESC assessment established design guidelines for high energy density Li-ion batteries using commercially mass-produced cylindrical cell designs. These guidelines were successfully used to modify battery designs on the EMU, Orion crew module, and other high-energy battery applications to achieve passive thermal runaway propagation (TR) resistance and prevent flames from exiting the battery enclosure. However, two test failures with a high-power/voltage Li-ion battery design highlighted the need to expand these existing design guidelines to address the technology's unique challenges. The new guidance encourages best prevention practices and how to avoid designs susceptible to TR propagation, while maintaining high performance. The guidance includes best practices for interstitial materials, cell connection topology, as well as passive propagation-resistant design strategies that provide NASA users a consistent, uniform, and low-risk path for achieving safe, high-power battery design solutions. *This work performed by JSC with consulting support from JPL, GRC, GSFC, DOE NREL, and NESC consultants White and Associates, SAIC, and Symmetry Resources.*



High energy density Li-ion batteries are used in EMUs, EVA hand tools, and on ISS. TR resistance is imperative.

PRIORITY 3: *Known Problems not Being Addressed by any Project*

In-Progress Assessments

- AACT Risk Reduction Project - Safe Life Category
- AACT Risk Reduction Project - inSitu Monitoring Category
- AACT Risk Reduction Project - Metallurgy Category
- Spacecraft Fire Safety Standard
- Galvanic Corrosion in Microfabricated Detectors & MEMs Devices
- NESC COG Technology Development
- Thermophysical Properties of Liquid TEA-TEB
- SpaceVPX Interoperability Study
- Test and Modeling to Predict Spacesuit Water Membrane Evaporator Failures
- New Methods for Removal of Cadmium from High Purity Hydrazine
- Safe Human Expeditions Beyond LEO
- Unconservatism of LEFM Analysis Post Autofrettage
- MIMU Operational Life Investigation
- Shock Prediction Advancement: Transient Finite Energy Predictor
- Recommendations on Use of COTS Guidance for NASA Missions
- Characterization of Internal Insulation Thermal Performance
- Soyuz Landing Reconstructions
- Occupant Protection Testing
- Solar Wind Radiation Damage of Metallic Coatings
- Capacitor Microstructure Analysis/Tools Development
- Shuttle Enterprise Main Landing Gear Fracture
- Parachute Reefing Line Cutter Modification and Qualification
- Need for Wireless EDL Instrumentation Validation
- Guidelines for Battery Thermal Runaway on Robotic Missions
- Auroral Charging Threat Assessment
- Southern Hemisphere Meteoroid Environment Measurements
- Shell Buckling Knockdown Factor Proposal

Completed Support Activities

- Mars Sample Return CCRS Mass Tiger Team Support
- ACCP SET Requests S&I TDT to Support/Perform a TRA of the Lidar Instruments
- Support for U.S. Navy Advanced Weapons Elevator (AWE)
- Support for DARPA's Experimental Space Plane (XSP)
- PAMELA Radiation Data Recovery Technical Support
- 6 Degree-of-Freedom Trajectory Simulation with Integrated CFD Aerodynamics

In-Progress Support Activities

- Low Temperature Coefficient of Thermal Expansion Measurement Capability
- Support for NDL Risk Assessment Panel
- EPIC/Athena Assessment Group Tech Support
- Support to GRC HV Fault/Transient Anomalies
- Human Factors Support for OSAM-1
- Update Human Systems Integration Practitioner's Guide
- Support for Revising NASA-HDBK-4002A
- Lunar Lander Mentor Team
- Support for Completion of NASA-HNBK-5010A

PRIORITY 4: *Work to Avoid Potential Future Problems*

In-Progress Assessments

- Filtration of Spaceflight Propulsion and Pressurant Systems
- FPMU Data Processing Algorithm Development and Analysis
- BON GCR Model Improvements
- Updating RefProp with Nitrogen Tetroxide Properties
- Wire and Wire Bundle Ampacity Testing and Analysis
- Solderless Interconnects and Interposers
- EEE Parts Copper Wire Bonds for Space Programs

Completed Support Activities

- Ethical Use of Artificial Intelligence Policy Development
- AFRL/STMD Advanced Rad-Hard Memory

In-Progress Support Activities

- Human Factors Support for the OCE Project Factors Team

COMPLETED ASSESSMENT

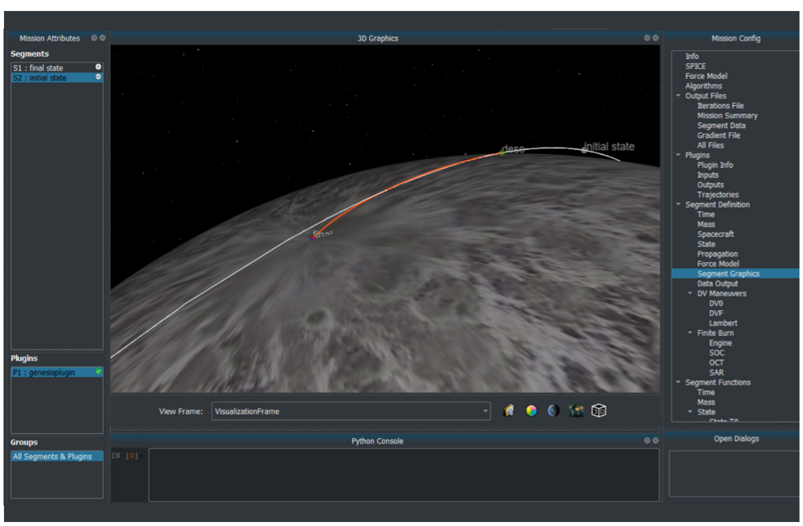
PRIORITY 5: *Work to Improve a System*

Genesis Flight Mechanics Simulation

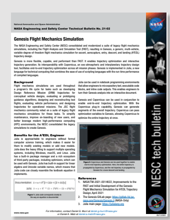
Flight mechanics simulations are used throughout a program's life cycle for tasks such as developing design reference mission trajectories for conceptual vehicle designs, evaluating or prototyping guidance algorithms, designing and reconstructing test flights, evaluating vehicle performance, and designing trajectories for operational missions. The JSC flight mechanics community relied on a suite of legacy flight mechanics simulations for these tasks.

To simplify maintenance, improve on-boarding of new users, and better leverage modern high-performance computing environments, an NESC team consolidated and modernized the legacy flight mechanics simulations, including the Flight Analysis and Simulation Tool (FAST), resulting in Genesis, a generic, multi-vehicle, variable-degree-of-freedom flight mechanics simulation for ascent, aerocapture, entry, descent, and landing trajectory design.

Genesis is more flexible, capable, and has improved performance over FAST. It enables trajectory optimization and interactive trajectory generation. Its interoperability with Copernicus, an exo-atmospheric and interplanetary trajectory design tool, facilitates end-to-end trajectory optimization across all mission phases. Genesis is implemented in Julia, a new language for technical computing that combines the ease of use of scripting languages with the run-time performance of compiled languages. Julia is approachable to engineers without formal computer science training, which makes it easier for them to modify existing models or add new models. Genesis and Copernicus can be used in conjunction to enable end-to-end trajectory optimization. With the Copernicus plug-in capability, Genesis can generate segments of the overall trajectory. Copernicus can pass optimization variables to Genesis, allowing Copernicus to optimize the entire trajectory at once. *This work was performed by LaRC, JSC, GSFC, and JPL.* *NASA/TM-202100114622*



Copernicus and Genesis can be used together to enable end-to-end trajectory optimization. Here, the white trajectory is propagated by Copernicus, and the red trajectory is propagated by Genesis for a lunar descent and landing.



Refer to NESC Technical Bulletin 21-02:
Genesis Flight Mechanics Simulation

PRIORITY 5: *Work to Improve a System*

In-Progress Assessments

- Frangible Joint Working Group
- NASA Quantum Sensing Capability
- Flight Mechanics Analysis Tools Interoperability & Component Sharing

Completed Support Activities

- Agile Software Development Methodology Use Summary
- Support for DARPA - TRADES Study

In-Progress Support Activities

- U.S. Army: Reentry Aeroballistics Trajectory and Thermal Protection

FEATURED ASSESSMENT

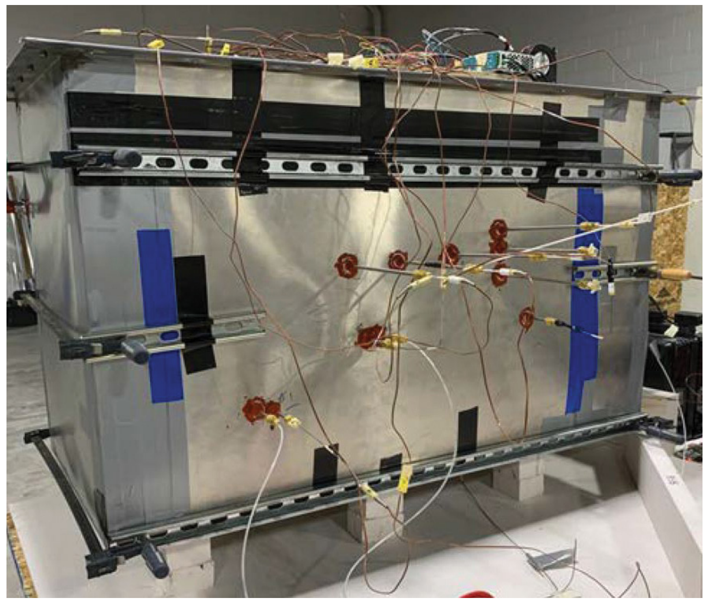
NESC Supports Development of New Medical Ceramic Oxygen Generator (M-COG)

Early in 2020, the COVID-19 epidemic quickly diminished the supply of ventilators for patients requiring oxygen in their treatment and recovery. To help provide some relief for the short supply, NASA engineers at JPL designed a new ventilator called Ventilator Intervention Technology Accessible Locally (VITAL), an easily manufactured alternative that would free up traditional ventilators to treat the most critical patients.

Because of its work to help the Navy understand physiological episodes experienced by pilots of their F/A-18 fleet, members of the NESC Pilot Breathing Assessment (PBA) Team were asked to peer review JPL's design. As questions arose about an oxygen source to drive VITAL, PBA team member, Dr. Jon Graf, a three-decade veteran of the JSC Life Support Systems Branch, suggested a ceramic oxygen generator (COG) he had been developing for use by future crews on the Moon.

Dr. Graf has been working with engineers on a new COG design that would produce more oxygen and require less power than currently existing COGs to support long-duration missions and astronauts during EVAs beyond low Earth orbit. Over the course of several years, Dr. Graf and his team developed and demonstrated the first solid-state system for a COG using solar power, then continued to refine the design to significantly decrease its power consumption.

The design was submitted as part of the NASA@work challenge for COVID-19 and drew the interest of the Department of Health and Human Services. Since then, NASA has been working with other organizations, including the U.S. Army, to develop, build, and deliver M-COG prototypes. "We are very excited about this because we think it's going to be a game changer," said Mr. Clinton Cragg, NESC Principal Engineer and lead for the PBA team. "It's going to make a big difference, especially in places of the world where they don't have enough oxygen." But bringing the M-COG design from great idea to mass production will take time, he said. "It is going to require a lot of hard work, good engineering, and the support of many people to get this accomplished." For more information, contact clinton.h.cragg@nasa.gov.



Top: Fully instrumented ceramic oxygen generator prototype; Bottom: Demonstration of a solar powered oxygen generator photographed at JSC in 2012

NASA EMPLOYEES SUPPORTING NESC WORK IN FY21

NESC AT THE CENTERS

Drawing Upon Resources from Across the Entire Agency to Ensure Engineering Excellence

- Ames Research Center 37
- Goddard Space Flight Center 90**
- Glenn Research Center 46
- NASA HQ
- Langley Research Center 214
- Armstrong Flight Research Center 10
- Jet Propulsion Laboratory 70
- Johnson Space Center 76*
- Marshall Space Flight Center 90
- Stennis Space Center 15
- Kennedy Space Center 45

* includes WSTF
** includes WFF

NESC Chief Engineer: KENNETH R. HAMM, JR.

37 Ames Research Center (ARC) Employees Supported NESC Work in FY21

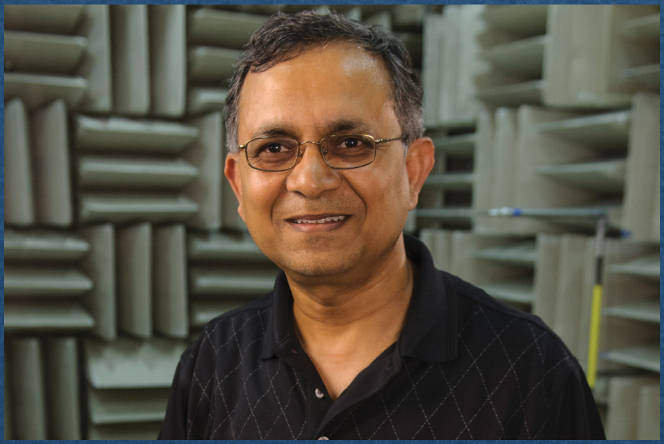
Ames Research Center

ARC supports a diverse suite of capabilities for the NESC including advanced computing, aerodynamics testing, intelligent systems, aerothermal/entry, descent, and landing modeling, thermal protection materials, and human factors research. ARC is represented on 17 NESC Technical Discipline Teams (TDT). This year's profiled individuals demonstrate the diversity of experience present at ARC. Dr. Jayanta Panda has been working in the field of aero-acoustic measurement for many years. He has brought his insight and experience to the development of a novel noise measurement system that will be used at the Artemis II launch to gain better understanding of this loading environment. Mr. Zion Young supports many development/flight programs for ARC and the Agency including thermal protection system material development efforts and small free-flyer CubeSats, serving as project chief engineer.

DR. JAYANTA PANDA: An acoustics expert involved in all aspects of noise measurement, Dr. Panda has focused his recent research efforts on continuing the development and construction of a microphone phased array. When deployed on a tower near a mobile launcher (ML), the array can identify noise sources on and around the ML during launch, and when paired with visual and infrared images, can help determine the causes of noise generation. Used as a tool for diagnostics and anomaly detection, the array will help find the root cause of damage and enable NASA to maximize the effectiveness of noise suppression systems.

From a demonstration of the array at an Antares launch, Dr. Panda learned that noise sources showed the highest thermal damage. "If we can optimize the noise suppression system, we reduce thermal damage. A reduction of just a decibel or two can mean significant savings for the vehicle and launch pad." Since 2011, the NESC has supported the build-up of this technology, from small rocket burn tests to the Antares launch and now with Artemis. "They helped bring this phased array to the Agency's attention," he said. "It's my job to provide new tools and techniques to reduce the noise environment for vehicles and introducing this new technology to the launch vehicle, it's something a researcher like myself lives for."

ZION YOUNG: Mr. Young's years of experience and expertise in mechanical design analysis have led to several leadership roles at Ames, including the lead design engineer for the Alpha Jet Atmospheric Experiment flight experiment mission, Mechanical Ground Support Equipment and Mechanical Integration & Test lead for the Lunar Atmosphere & Dust Environment Explorer Mission and the chief engineer for the Sensor Integrated Environmental Remote Research Aircraft and BioSentinel spacecraft. He is currently serving as the chief engineer for the Mars Sample Return Earth Entry Vehicle Thermal Protection System. Over the years he has brought the NESC in to help him solve technical anomalies, most recently to assist with a propulsion system material failure. "We had a series of seals and valves that were failing to actuate. The NESC did a material review and found sources of material incompatibility that caused swelling in the gaskets. They connected us to experts at White Sands Test Facility, and we were able to quickly solve the problem." He has returned the favor, serving as a technical expert on the Mechanical Systems TDT. "It is always incredible to be in TDT meetings when issues are brought forward to the team." The combined expertise within the Agency-wide TDT brings a unique approach to problem solving, he said. "That philosophy then feeds forward to smaller activities going on at Ames."



Dr. Jayanta Panda

Zion Young

NESC Chief Engineer: DR. W. LANCE RICHARDS

10 Armstrong Flight Research Center (AFRC) Employees Supported NESC Work in FY21

Armstrong Flight Research Center

The NESC concluded one of its largest AFRC-based assessments in 2021, which was focused on gathering critically important breathing data from pilots flying AFRC F/A-18 and F-15 jet aircraft. AFRC has been instrumental in the NESC's flight test campaign to gather missing information for the U.S. military regarding pilot breathing to help shed light on the human-machine interaction during high-performance flight. Over the assessment duration, AFRC flew more than 130 sorties utilizing five pilots, six fighter aircraft, and two aircrew equipment configurations for the Pilot Breathing Assessment. The team documented their seminal work in a two-volume, 750-page final report and briefed leadership from 11 different organizations within NASA and U.S. Department of Defense.

WAYNE "RINGO" RINGELBERG: An AFRC research test pilot, Mr. Ringelberg flew more than 40 sorties in an F/A-18 Hornet during the NESC's Pilot Breathing Assessment (PBA). The PBA was initiated to address an increased occurrence of physiological episodes across the fleet and understand human physiology and breathing behaviors in high-performance aircraft. "We flew scripted profiles that mimicked typical fighter maneuvers. Our equipment included special mask sensors connected to our oxygen system that collected readings on our breathing and composition of the air we were inhaling and exhaling." Another device recorded the aircraft's state while synched with the breathing sensors, and other sensors gathered environmental data in the cockpit.

Aided by a ground assistant, Mr. Ringelberg marked the time for the start and stop of each maneuver and activated the breathing data collection. Spirometry and capnography data were also collected before and after each flight. "We performed the sorties outfitted in both U.S. Navy and Air Force life support gear. The two are quite different in how they fit and are designed." He said he found himself more aware of his breathing and of cabin pressure fluctuations during flight. "Overall, this was a good program that collected a lot of reference data that will help the community as they continue to improve their understanding of the physiology of pilot breathing."

NATALIE SPIVEY: Working in the Structural Dynamics Group within the Aerostructures Branch at AFRC, Ms. Spivey brings her wide range of hands-on modal testing, airworthiness clearance, and flight-testing control room experience to the NESC Loads & Dynamics (L&D) Technical Discipline Teams (TDT). Her 20-year background at NASA has included support of numerous flight research programs, either as a structural dynamics engineer or lead for programs such as the X-53 Active Aeroelastic Wing, various F-15 and G-III flight experiments and more recently the X-57 Maxwell and X-59 Low Boom Flight Demonstrator. Representing her Center at monthly and annual TDT meetings, she shares the latest experiments and dynamic tests being conducted at AFRC. "Most L&D TDT members focus on space-related issues and enjoy seeing the aircraft-related work Armstrong is doing. The TDT brings different backgrounds and perspectives to the many L&D issues we discuss."

Conversely, Ms. Spivey enjoys when the other Centers present updates and highlights of major accomplishments. "I bring back what I learn and share it with my branch. I think that if a Center is struggling in an area or wants to build up a capability, we can feel alone in those struggles. But when I go to the annual face-to-face meetings, it's reassuring to find that other Centers have those same issues, and it's nice to get our collective thoughts and tackle things together."

Wayne "Ringo" Ringelberg

Natalie Spivey

NESC Chief Engineer: ROBERT S. JANKOVSKY

46 Glenn Research Center (GRC) Employees Supported NESC Work in FY21

Glenn Research Center

GRC provided a broad spectrum of technical expertise to 21 NESC technical assessments/activities and 19 NESC Technical Discipline Teams (TDT). These activities supported all NASA mission directorates as well as several cross-cutting discipline efforts. GRC provided significant contributions this year to the Agency's additive manufacturing efforts as well as the Loads & Dynamics TDT. The NASA Technical Fellows for Cryogenics and Loads & Dynamics, as well as deputies for the Propulsion, Electrical Power, Software, and Nuclear Power & Propulsion TDTs, are resident at GRC.

SAMANTHA BITTINGER: During college, Ms. Bittinger planned to become a roller coaster designer, but the industry wasn't looking for interns at that time. Fortunately, NASA was. Today, she specializes in vibroacoustic modeling and testing for the GRC Structural Dynamics Branch and is a member of the Loads & Dynamics TDT, which fosters discussions on analyses, tests, and new methods on the cutting edge of the discipline. "The TDT gives me an Agency-level discipline perspective and a look at the work our private-industry colleagues are doing." She's contributed directly to the development of the State of the Discipline update and was a member of the newly formed Vibroacoustic Community of Practice. "Having this wider network means I always have someone to call for help. This benefits projects and the Agency." She also serves as the Commercial Crew Program (CCP) liaison for the TDT helping to address technical areas of high risk. "CCP is a high-priority program, especially now with crewed launches. Undoubtedly there will be technical challenges, so understanding any loads and dynamics issues is valuable to the TDT."

DR. CHERYL BOWMAN: A love of cooking led Dr. Bowman to a career in metallurgy, once she discovered both pursuits allowed her to change the structural properties of materials through tweaking chemistry and processing. After 10 years as a materials coordinator for Fission Power Systems and five years as an Electric Aircraft Propulsion technical lead, she is now the Deputy Branch Chief for the High Temperature and Smart Alloys Branch. Recently she has supported the Additive Manufacturing Standards development group and has been evaluating magnetic materials used in pump motors on the ISS. "I've spent my entire career at Glenn, but it is my interactions through the NESC that have helped me broaden my knowledge and make connections throughout the Agency. We have experts in everything, and the key is being able to reach out and find that expertise quickly. The fact that the NESC helps us make those connections is invaluable."

ROBERT CARTER: As the High Temperature and Smart Alloys Branch Chief at GRC, Mr. Carter wears many hats, including the Materials and Processes Technical Authority for spaceflight hardware. His expertise in this area led to his support of several NESC activities and to the Materials TDT. As a TDT member, he has fielded questions, peer-reviewed reports, and helped develop the recently published NASA standards for additive manufacturing. "I think the strength of the TDT is in its comradery and respect. The typical Center barriers we put up in our minds fall away because it no longer matters what Center you are from. If you need technical expertise, you put out the call and someone answers." His materials expertise also brought together him and his wife, a PhD in the same discipline. The two were married in the shadow of a Saturn V at the Space and Rocket Center in Alabama.

Samantha Bittinger

Dr. Cheryl Bowman

Robert Carter

NESC Chief Engineer: FERNANDO A. PELLERANO*

90 Goddard Space Flight Center (GSFC) Employees Supported NESC Work in FY21

Goddard Space Flight Center

GSFC supported numerous NESC activities, including 40 assessments involving 70 engineers, technicians, and scientists. Key assessments included Recommendations on Use of Commerical-Off-The-Shelf (COTS) Guidance for NASA Missions, Miniature Inertial Measurement Unit Operational Life Investigation, GSFC Laser Interferometer Space Antenna Laser Study, Space Charging of the Ocean Color Instrument Rotating Mechanism, Safe Human Expeditions Beyond Low Earth Orbit, Reaction Wheel Bearing Contamination, Mars Sample Return Micrometeoroids and Orbital Debris Protection Review, and Galvanic Corrosion in Microfabricated Detectors and Microelectromechanical Systems Devices. In addition, the NASA Technical Fellows for Systems Engineering, Mechanical Systems, and GNC, and the NESC Chief Scientist, reside at GSFC.

JODY DAVIS: Working on the Roman Space Telescope for the last four years, Ms. Davis has served as both the deputy payload systems engineer and the observatory interface systems engineer. Both roles prepared her to assist the NESC in developing a reference architecture for guiding the development of two extravehicular activity (EVA) power systems for ISS and lunar systems. “I helped develop the reference architecture for our current ISS system, working with JSC to research and consolidate all of the requirements documents, some dating back to the 1990s, into a model-based system engineering (MBSE) reference architecture.” That provided the groundwork for improvements, updates, and power and thermal trade studies done during the assessment. It also provided opportunities to explore a common EVA battery charger and power supply for use on ISS, the Moon, and possibly Mars. “Ultimately, we gave a new reference architecture to JSC, an MBSE modular tool to facilitate their own complex trade studies and help them understand needs and constraints and make quick and efficient decisions in a short period of time.”

Ms. Davis enjoyed working with the NESC because it spans the Agency. “Centers can get siloed in the project world, but this assessment required collaboration between JSC, GSFC, MSFC, and LaRC to be successful. It felt badgeless. Whatever Center you come from, supporting an NESC assessment helps you develop important relationships across NASA.”

DR. JESSE LEITNER: Dr. Leitner is part of an NESC assessment team studying NASA’s use of COTS electronics parts and providing recommendations for Agency guidance on their use. “Traditional Agency and aerospace community practice has been to use parts that meet military specifications,” an approach that goes back to the 1950s when priorities focused primarily on uniformity and part survival in the space environment. Also, consumer electronics were not as readily available, making parts production for reliable applications small-batch, highly ruggedized, and expensive. “Today, many commercial manufacturers have automated manufacturing capabilities and a volume of production and usage that can drive reliability,” said Dr. Leitner, GSFC’s Chief Safety and Mission Assurance (SMA) Engineer. “But COTS parts come in all varieties, quality levels, and reliability.”

The assessment team is offering recommendations on how the Agency can ensure COTS reliability of parts produced in large quantities by numerous manufacturers and with little or no Agency control or insight into the manufacturing process. Dr. Leitner’s role is to provide the SMA perspective. “I put the parts in context and see how they might drive risk for the overall mission. I have to make sure every mission and project operates at lowest level of operational risk, so my role is to challenge every standard practice we have at Goddard and the Agency.” Dr. Leitner has supported other NESC assessments and is a member of the Avionics Technical Discipline Team.

Jody Davis

Dr. Jesse Leitner

Carmel A. Conaty

New NESC Chief Engineer at GSFC effective 9/12/2021*

Read her bio at NESC.NASA.gov.

NESC Chief Engineer: KIMBERLY A. SIMPSON

70 Jet Propulsion Laboratory (JPL) Employees Supported NESC Work in FY21

Jet Propulsion Laboratory

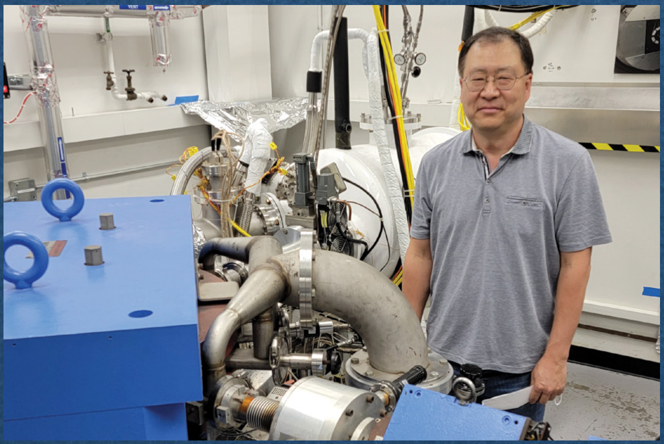
JPL supported 28 assessments spanning the Science, Human Exploration Operations, and Aeronautics Research Mission Directorates and the U.S. Department of Defense. Highlights included assessment of electrical, electronic, and electromechanical parts copper wire bonds, evaluation of high-energy/high-power commercial-off-the-shelf lithium-ion cells for space applications, troubleshooting Joint Polar Satellite System Observatory-2 Solar Array Drive life test, performing in-depth wire and wire bundle ampacity testing and analysis, updating the guideline for Mitigating In-Space Charging Effects (NASA-HDBK-4002), and planning of the Thermal and Fluids Analysis Workshop. Continual engineering expertise was also provided by the Space Environments, GNC, and Electrical Power Technical Discipline Team (TDT) deputies who reside at JPL.

DR. WOUSIK KIM: Dr. Kim is an Electrostatic Discharge lead for the Europa Clipper Project. The Europa spacecraft, which will survey Jupiter's moon of the same name, must operate in a radiation field that is orders of magnitude larger than Earth's. Dr. Kim, whose research focuses on spacecraft charging due to space radiation, is exploring ways to mitigate those risks through his testing at JPL. "Radiation and charging are major issues for Jupiter missions, and spacecraft charging is the number one cause of anomalies and failures." Radiation in the space environment can imbed electrical charge in spacecraft materials, which can result in electrostatic discharge events that can damage or even destroy spacecraft.

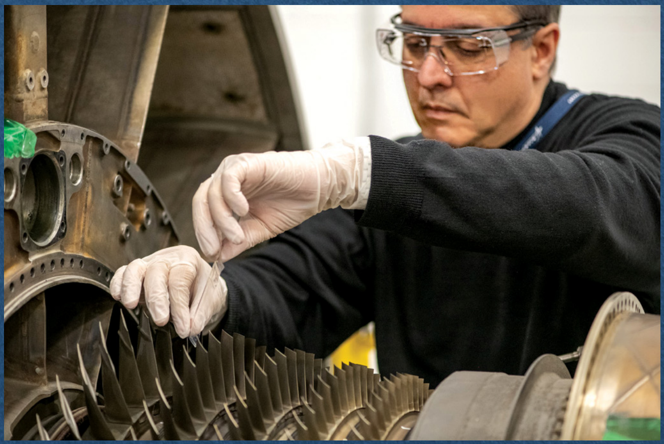
The NESC taps into Dr. Kim's expertise through the Space Environments TDT, where he and his colleagues stay up to date on the discipline, exchange ideas, and discuss current issues. Recently, he has led the revision of NASA-HDBK-4002, Mitigating In-Space Charging Effects. "Since the last revision was published in 2011, there has been a lot of research, updates, and tests conducted, and we want the handbook to reflect those changes. Revision 4002B has been in work for about two years, slowed down slightly by the COVID-19 pandemic." The original authors of the handbook are also part of his revision team, and Dr. Kim said their knowledge has been invaluable in better understanding the background and rationale used in its development.

CARLOS SOARES: When the NESC was asked to support a root cause investigation of damage on compressor blades of jet engines from a NASA Airborne Science Program aircraft, Mr. Soares led a JPL team from Contamination Control Engineering, Analytical Chemistry & Materials Development, and Spacecraft Structures & Dynamics. The NESC team, which also included multiple Centers, and U.S. military and aerospace industry partners, inspected and catalogued the damage and JPL-led modeling of particle impacts on compressor blades, chemical analysis of jet engine blade damage, as well as sampling landing/take-off sites at airports used by the aircraft. "We also leveraged computational physics modeling of impact damage to correlate with our physical observations."

Mr. Soares appreciates the opportunities NESC assessments provide. "You get access to expertise from so many NASA Centers and build lasting professional relationships. Also, every task has been technically challenging. We are looking at things not looked at before, and that makes me a better engineer. We find ways to study and analyze a problem and fold everything we learn into recommendations to make things better and safer. With this project, we leveraged analytical chemistry techniques and computational physics modeling we have developed for the space program to help determine the cause of aircraft jet engine damage. This gave us a whole new perspective on how we can apply things we develop for space to the aviation side of NASA."



Dr. Wousik Kim



Carlos Soares

NESC Chief Engineer: DR. JUSTIN H. KERR

76 Johnson Space Center (JSC) Employees Supported NESC Work in FY21

Johnson Space Center

JSC and the White Sands Test Facility (WSTF) provided engineering analysis, design, and test expertise for the continuous operation of the ISS, development of the Orion Multi-Purpose Crew Vehicle and Space Launch System for the upcoming Artemis missions, consultation for Commercial Crew Program (CCP) vehicles, and the lunar Gateway vehicle. JSC personnel provided expertise and leadership to numerous assessments within the Agency relating to ceramic oxygen generation technology development; environmental assisted cracking in titanium by hydrazine; frangible joint designs; and lunar meteoroid ejecta modelling. The NASA Technical Fellows resident at JSC joined with other Agency discipline leaders to strengthen technical community connections through joint sponsorship and participation in activities such as environmental control & life support; guidance, navigation, & control; human factors; loads & dynamics; nondestructive evaluation; propulsion; software; and the systems engineering Technical Discipline Teams.

DR. JON GRAF: A subject matter expert (SME) in environmental control systems, Dr. Graf has supported numerous life support-related NESC assessments. His most recent contribution has been to the development of a Medical-Ceramic Oxygen Generator (M-COG), a system for producing medical oxygen for hospitals and clinics in remote settings, where oxygen is not readily available. NASA collaborated with American Oxygen (with whom it has partnered on development activities to recharge space suit oxygen tanks) to develop the M-COG, which uses ceramic ion transport membrane technology to produce high purity oxygen. Since May 2020, Dr. Graf has worked with SMEs, nonprofits, and government agencies to ensure the technology can withstand challenging environments. “The NESC has supported our efforts to develop this technology in response to COVID-19. NASA has helped sharpen the technology by making it energy efficient,” he said. Previous COGs required too much power to be viable for medical applications. “This will make the Agency better, stronger, and more capable.” He added that M-COG wouldn’t have been possible without his colleagues from the M-COG Heat Exchanger Build Team photographed below: from left, Richard Hagen, Dan Rybicki, Mike Casteel, Brian Machcinski, Dr. Graf, Steve Rogers, Veronica Gonzales, Hugo Acevedo, Celina Barrera. See M-COG assessment feature on page 26.

STEVE PERALTA: As the project manager for the Oxygen Hazards Group at WSTF, Mr. Steve Peralta’s work typically involves testing and analysis of oxygen systems, looking for ignition hazards and ways to mitigate them. He recently participated in a cross-program assessment of flammability and ignition risk posed by materials that come in contact with propulsion system oxidizers. His subject matter expertise made him a good fit for the team. The assessment was the result of a previous study that found that some traditionally acceptable materials of construction (titanium and certain thicknesses of stainless steel) are flammable and ignitable in the oxidizer nitrogen tetroxide (NTO). For the cross-program assessment, Mr. Peralta performed testing with materials in the presence of NTO and/or a surrogate representing NTO. The aim was to assist the CCP and other NASA programs better understand and characterize the ignition risks associated with NTO in propulsion systems. “Ignition and fire hazards generally manifest in similar ways with all oxidizers, like oxygen, but some materials can be more sensitive than others,” said Mr. Peralta. “The assessment uncovered knowledge gaps and answered pertinent questions regarding prevalent ignition mechanisms. Our main area of focus has always been oxygen, but this assessment helped uncover some misconceptions we had regarding the physics and phenomena involved in particle impact ignition.”

Dr. Jon Graf, 5th from left, with M-COG Heat Exhanger Build Team

Steve Peralta

NESC Chief Engineer: STEPHEN A. MINUTE

45 Kennedy Space Center (KSC) Employees Supported NESC Work in FY21

Kennedy Space Center

KSC provided technical expertise to 30 NESC activities and Technical Discipline Teams (TDT) in 2021. Personnel engaged in numerous NESC assessments including: Commercial Crew Program (CCP) crew module ascent cover modeling; Exploration Systems Development hazard analysis; NASA spacesuit water membrane failure; and NASA biocide impacts on life support systems. Likewise, the NESC provided technical support for KSC programs including: CCP low flow regulator burst failure containment; CCP pressure spike effects on materials in hypergolic engines; and Exploration Ground Systems Mobile Launcher hydraulic system analysis and modeling. The NASA Technical Fellows for Electrical Power and Materials reside at KSC and rely on KSC expertise in many of their activities. The NESC also invested in KSC's laboratories to evaluate anaerobic hydrogen sensor development and hydrazine synthesis and contamination analysis for the Agency.

DR. DENTON GIBSON: As a Launch Vehicle Systems Engineer, Dr. Gibson was a valued member of an NESC activity tasked with supporting mass management efforts during the development of the Mars Ascent Vehicle (MAV), which will return samples from the Mars surface. "What makes this so complex is that the ascent vehicle is not only the launch vehicle but also part of the spacecraft. That's why the mass assessment is so important because it will drive how much you can return from the surface. We worked with the MAV team to find the best approach to tracking the vehicle's mass growth during development."

As a member of the Systems Engineering TDT, he helped develop its annual TDT workshop, creating agendas that best address Agency concerns and sharing lessons learned from his work with the Launch Services Program. The TDT has also allowed him to better promote his discipline. "We have many discipline engineers focused on their specific areas of expertise, but systems engineers take a broader look at the overall system to understand how a small change on the left side can affect the right side." Working on NESC assessments and with the TDT, Dr. Gibson said his perspective has widened. "I now recognize how much systems engineering expertise we have across the Agency and how our individual experiences have uncovered many common themes."

DR. ELSPETH PETERSEN: In the In-Situ Resource Utilization Lab at KSC, Dr. Petersen is looking for ways to extract oxygen from Moon regolith, key to making the lunar surface a habitable place for humans. But her work on an NESC assessment is putting her research and development skills to work on the new Space Suit Water Evaporator Membrane (SWME) to keep astronauts cool during extravehicular activities (EVA).

"The sublimators used since the Apollo era are not going to work on Mars because the atmospheric pressure there is too high." As the NESC technical lead, she reached out across NASA and academia to find expertise in hollow fiber membranes that offer an alternative option to the legacy cooling hardware. The resulting team is now conducting tests to predict how the SWME will perform.

"The SWME will be critical to EVA missions and must last for 15 years, so we're looking at lifetime, failure, and deterioration prediction as well as maintenance requirements." The data will then feed into a model that will show remaining life in the SWME at any time during a mission. While the work is a departure from her usual research, she has enjoyed the challenge. "I've learned so much. And the NESC is a great resource, helping projects across the Agency that need outside assistance and knowledge."

Dr. Denton Gibson

Dr. Elspeth Petersen

NESC Chief Engineer: MARY ELIZABETH WUSK

214 Langley Research Center (LaRC) Employees Supported NESC Work in FY21

Langley Research Center

LaRC provided technical and specialized facility support on over 50 NESC assessments, engaging more than 100 technical experts to resolve issues being worked across the Agency. The Langley team delivered on commitments not only to NASA but also to external partners despite the challenges faced by COVID-19. Examples include completing: an 18-month test campaign of the Space Launch System in the National Transonic Facility; a test campaign in the Unitary Wind Tunnel for external partners; remote control room operations for the shell buckling tests; parachute energy modulator (EM) tests at the Landing and Impact Research Facility; nondestructive evaluation (NDE), digital image correlation, material compatibility hardware fabrication and testing for both the Commercial Crew Program and Science Mission Directorate. These efforts allow NASA to expand human knowledge through new scientific discoveries and extend human presence deeper into space.

SANDIE GIBBS: To reduce shock loads, a parachute system can employ rip-stitch EMs to control and moderate extraction and deployment forces that occur prior to parachute inflation. Throughout 2021, the NESC tested several EMs at Langley's Landing and Impact Research Facility. A team guided by LaRC's photography lead, Ms. Sandie Gibbs, coordinated the image data capture for these tests. The team used seven meticulously positioned high-speed Phantom cameras connected to laptop computers to capture time-stamped footage of each test at 1,000 frames per second (fps). "We are the visual confirmation," Ms. Gibbs explained. "Your eye can't see what's happening, but the camera can record it frame by frame. It lets us see when and how the rip started and whether or not it went according to plan."

Working as a scientific and research photographer at LaRC since 1985, Ms. Gibbs has worked on numerous NESC assessments and enjoys the variety of work and the challenges involved in devising ways to capture the data needed. In that time, she's witnessed – and then led – the evolution of Langley's test photography capabilities from 16mm film cameras that captured 400 fps, to digital high-speed cameras capable of shooting up to a million fps. "High-speed photography can tell NASA engineers exactly where the weaknesses are and when, where, why, and how things might fail," said Ms. Gibbs.

JOHN PANDOLF: As LaRC's lead Electrical, Electronic, and Electromechanical Parts Engineer, Mr. Pandolf handles the selection, review, and approval of electronic components for the Center's flight projects. His 35 years of electronics experience also includes manufacturing and design, which has made him a valuable asset to recent assessments involving the use of commercial-off-the-shelf parts at NASA. This year, his contributions benefited the NESC's support of the Climate Absolute Radiance and Refractivity Observatory Pathfinder Project in identifying and mitigating issues with flex harnesses. "I'd learned from a previous project the types of flex cable mechanisms that need to be addressed. And the fact that the harnesses were so large made the work very challenging."

Following analysis and NDE, the assessment team would meet virtually to weigh in on results and provide technical insight to the project. "We had a great team, a real depth and breadth of NASA experience with people I would not normally get to work with, as well as members from outside NASA, which let me network with other government agencies." Mr. Pandolf has spent his career pursuing opportunities to exercise as much knowledge and experience as he can, and he has found the NESC to be another of those opportunities. "I like to capitalize on that and apply new knowledge to any project I engage in."

Sandie Gibbs

John Pandolf

NESC Chief Engineer: STEVEN J. GENTZ

90 Marshall Space Flight Center (MSFC) Employees Supported NESC Work in FY21

Marshall Space Flight Center

MSFC provided engineer, scientist, and technician subject matter expert support to over 34 NESC activities. These investigations involved exploration systems development, space operations and environmental effects, and numerous crosscutting activities. Significant development efforts included biocide, additive manufacturing, model-based systems engineering, advanced chemical propulsion, and modeling and simulation of launch vehicle/spacecraft interfaces. The NASA Technical Fellows for Propulsion; Space Environments; Environmental Control & Life Support; and the Technical Discipline Team (TDT) Deputies for Propulsion; Nuclear Power & Propulsion; Materials; Space Environments; Loads & Dynamics; Nondestructive Evaluation; Cryogenics; Flight Mechanics; and Software are resident at MSFC.

GABRIEL DEMENEGHI: Mr. Demeneghi specializes in failure analysis and materials diagnostics. The NESC has requested his expertise on several assessments and in support of the Materials TDT to find the root cause of damage to metallic materials. "I enjoy it because there is no straightforward path to an answer. Every problem requires in-depth work and research to solve." His recent contributions include determination of damage tolerance life in composite overwrapped pressure vessels through microscopy and chemical and crystallographic analysis and the characterization of metals to determine fracture and crack propagation paths. "The assessments show me what other Centers are doing and broaden my view of NASA as an Agency."

KEVIN McCARLEY: Mr. McCarley brought his systems engineering perspective to the NESC's assessment of biocide impacts on life support and extravehicular activity (EVA) architectures. By facilitating the collection and organization of data needed to develop a set of biocide requirements, the team could perform trade studies to understand the impact of various biocides on EVA mobility unit materials. "I facilitated the setting up of criteria for determining the key factors in selecting a biocide, such as cost, schedule, technical performance, and risk. The team could then use this as a scoring schema," he said. "I worked with environmental control and life support experts across five NASA Centers, and everyone's dedication to the task was educational and inspiring."

DR. ALTHEA MOORHEAD: When meteoroids strike spacecraft directly, they can puncture surfaces or cut wires; when meteoroids impact the Moon, they create debris that can threaten spacecraft and crew. Dr. Moorhead, a modeler in the Meteoroid Environment Office in the Natural Environments Branch, simulates meteoroid environments to support spacecraft risk assessments. She is also a member of the Space Environments TDT and recently served on an NESC team reviewing a new lunar meteoroid ejecta environment model. "It is always valuable to do a detailed review of someone else's work. I'd never worked with crater formation and ejecta, so I got to learn how meteor impacts relate to dust from the lunar surface."

BRIAN WEST: As a recognized Agency subject matter expert in additive manufacturing (AM), Mr. West helped develop the MSFC AM standard and specification to enable SLS to use AM parts for launch vehicle engines. With the surge of new AM materials and processes, the NESC and Materials TDT leveraged his experience and the MSFC documents as a foundation to build an Agency-wide standard, NASA-STD-6030. "It was a daunting task, but necessary to address the application of AM given the current state of the technology. Released in April 2021, it was a major accomplishment by all the Centers involved in its development. I believe, through the TDT, we can get closer to that 'One NASA' viewpoint across the materials disciplines."

Gabriel Demeneghi

Kevin McCarley

Dr. Althea Moorhead

Brian West

NESC Chief Engineer: MICHAEL D. SMILES

15 Stennis Space Center (SSC) Employees Supported NESC Work in FY21

Stennis Space Center

SSC provided expert technical support to the NESC, including hardware testing, facility capabilities, risk assessment, test operations, and modeling. SSC supplied experts and early-career engineers for numerous NESC assessments, including Zero-g Propellant Gauging Technology, Space Launch System (SLS) Core Stage Pre-Valve Failure, Artemis I Integrated Hazards, Bellows Flow-Induced Vibration, Parker O-Ring Material Obsolescence, and Filtration of Spacecraft Propulsion Pressurant Systems. Besides formal assessments, SSC additionally supplied experts for NESC position papers, the Avionics Software Tools Working Group, and the SLS wet dress rehearsal liquid oxygen temperature issue technical discussions with NESC counterparts at KSC. SSC also volunteered the A-1 Test Stand as a site for requested phased-array microphone system testing.

ROBERT SMITH: When Mr. Smith arrived at NASA in 2019, SSC was preparing for testing of the SLS Core Stage, and he was tasked with understanding the workings of the Center's High Pressure Gas Facility, which supplies commodities such as helium, hydrogen, and liquid oxygen in support of engine testing. Combined with his background in electrical power designs and lightning protection systems, the NESC felt he would be a good addition to an integrated hazards assessment team. The team was tasked with identifying potentially hazardous conditions resulting from the integration of the complex systems that make up Artemis I.

The team was divided into groups, each focused on key areas such as the Artemis SLS, ground operations, and the Orion crew module. Mr. Smith supported the SLS team and was responsible for reviewing all documentation associated with electrical hazards and identifying potential threats. "It made me appreciate the amount of time and level of detail that goes into these evaluations and how thorough they are." He also appreciated the team's Center diversity. "It opened my eyes to Kennedy's launch vehicle expertise and Langley's wind tunnel expertise, and other things I don't deal with on a regular basis. I enjoyed it, especially because I'm new to NASA and could see what all of the different Centers are doing."

JONATHAN DICKEY: Mr. Dickey's involvement with the NESC dates back more than 10 years to when he was selected for the Resident Engineer Program. As a then-junior engineer, he spent a year participating on numerous multi-Center assessment teams, gaining hands-on experience and exposure to multiple sub-disciplines and developing a broader systems engineering perspective. Today, he is the mechanical component subject matter expert at SSC and a member of the Cryogenics Technical Discipline Team (TDT). "My work involves specification and procedure writing and review as well as procurement and participation in teams and study groups looking for ways to improve capability from a mechanical component perspective."

His valve expertise is sought by many NASA Centers. "Valves are a pretty small world, and the majority of people who are valve or mechanical component experts have made very long careers out of doing it," he said. "A majority of our valve business is cryogenically-based, and testing involves cryogenic fluids," which makes him a good fit for the TDT. "In my work with the NESC, I talk with people at many different NASA Centers, some of whom I've known for more than 15 years. It's a good network of experts to call when someone in the Agency has a specific issue or a problem that needs solving."

Robert Smith

Jonathan Dickey

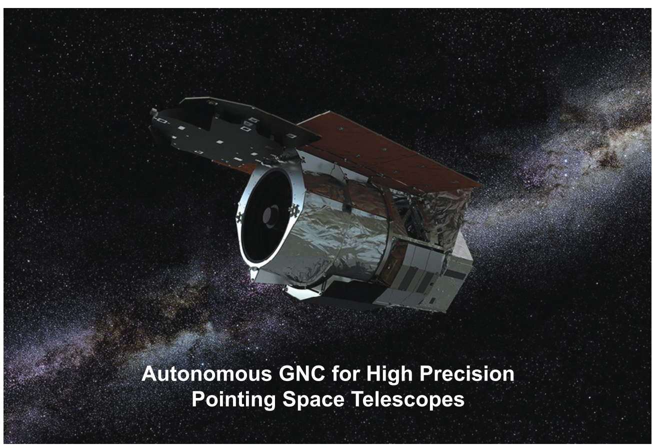
DISCIPLINE FOCUS

Discipline Perspectives Related to NESC Assessment & Support Activities

GUIDANCE, NAVIGATION, & CONTROL
NASA Technical Fellow for GNC: Cornelius J. Dennehy

Verification and Validation Challenges for Autonomous GNC Technology for NASA's Next-Generation Missions

NASA, in common with other national space agencies, has a strong interest in the Research and Development (R&D) of algorithms for autonomous Guidance, Navigation, & Control (GNC) systems. Beyond the forward-looking R&D aspects, NASA and our industry partners have the challenging responsibility of architecting, designing, developing, launching, and operating spaceflight systems for human and scientific exploration. Often, NASA serves as a bridge between the autonomous algorithm developers in the R&D community and our industry partners who subsequently infuse the advanced algorithms into their engineering practice.



Autonomous GNC for High Precision Pointing Space Telescopes

Many future NASA missions will have demanding new requirements for onboard autonomy, optimization, adaptation, and fault tolerant operations. There are many examples of future missions driving advanced non-traditional GNC system design, including a proposed Europa lander, asteroid/comet/planetary sample return missions, Phobos landers, Mars human landers, advanced launch systems, etc. These future missions may have a cadence of decision making that exceeds communication constraints (e.g., time delays, data bandwidth, and limited communication windows), and time-critical decisions for performing orbit/trajectory control maneuvers, managing GNC system health, and/or performing GNC system reconfigurations may have to be made onboard the vehicle without human intervention.

As mission goals become more ambitious, exploration vehicles will likely fly in closer proximity to unexplored bodies and operate in extreme environments with unpredictable dynamic interactions between the vehicle and the local

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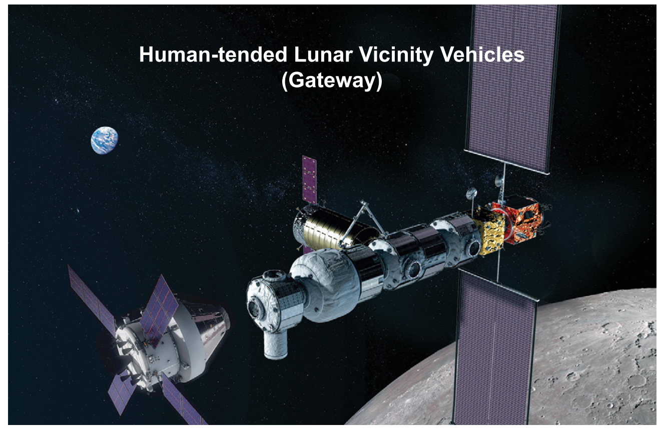


Human-tended Lunar Vicinity Vehicles (Gateway)

WHAT IS AUTONOMOUS GNC?

Autonomy is the ability of a system to achieve goals while operating independently of external control. In its most complete form, Autonomous GNC is an integrated end-to-end system of perceptive sensing hardware, processing hardware, and actuation hardware whose actions are governed by goal-driven algorithms that function and operate in a self-sufficient and self-directed manner independent of external commands.

- Autonomous GNC is not automation, but likely would be implemented in part with automatic functions. "Automation is the automatically-controlled operation of an apparatus, process, or systems by mechanical or electronic devices that take the place of human labor – Merriam-Webster." Automation is not "self-directed," but instead requires command and control (e.g., a preplanned set of instructions). A system can be automated without being autonomous.
- Autonomous GNC is not necessarily artificial intelligence (AI), but likely would employ elements of AI such as perception, machine learning, classification, etc.
- Autonomous GNC is not about making systems intelligent, advanced, smart, or uncrewed but rather is fundamentally about making them self-sufficient and self-directed.

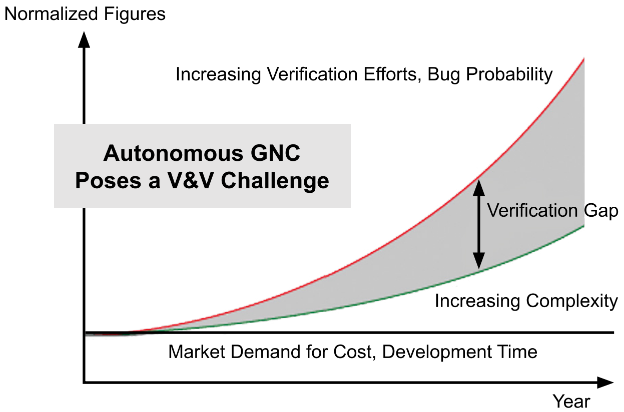
GUIDANCE, NAVIGATION, & CONTROL

NASA Technical Fellow for GNC: Cornelius J. Dennehy

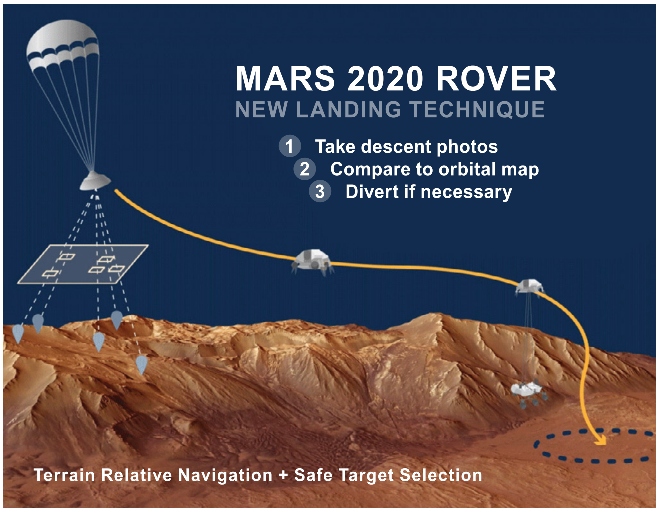
continued...

environment. Operations that extend into unknown and uncharacterized flight regimes could pose unacceptable risks without GNC technological innovations. All this drives the near-term need for Trusted Autonomous GNC. Examples are adaptive guidance for optimizing aerodynamic and/or propulsion performance during planetary entry, descent, and landing with precision, hazard-avoiding, and surface landing requirements.

As a consequence, the trend in GNC systems for NASA's aerospace platforms will be toward more complex implementations as mission requirements for higher levels of performance and for autonomous operations become more demanding as well as more prevalent. Uncertainty and nonlinear coupling add to this complexity, potentially leading to a significant gap in the capability to perform the necessary prelaunch verification and validation (V&V) work. This trend in growing GNC system complexity is one that the NESC GNC Technical Discipline Team (TDT) has observed and considered. Dealing with system complexity is a present and growing challenge for NASA and its industry partners. Verification is a very costly phase of the mission life cycle. Consider that on a typical spacecraft project, only about 20% of the total time is spent on actual design while the other 80% is used for planning and executing the V&V activities necessary to certify systems for flight readiness. There is a need for V&V tool development and education to manage the risks of flying increasingly complex GNC systems. Likewise, there is a need to narrow the gap between the new non-traditional V&V tools and those currently in use by industry. Recognizing these GNC community-of-practice needs, a subset of the NESC GNC TDT has performed significant discretionary work over the past two years to address the V&V challenges of advanced autonomous GNC systems.



To understand, quantify, and address this gap in GNC V&V capabilities for advanced applications, several space agencies including NASA and the European Space Agency



(ESA), DLR (Deutsches Zentrum für Luft und Raumfahrt, the German Aerospace Center), ONERA (Office National d'Etudes et de Recherches Aérospatiales, the French Aerospace Lab), and France's CNES (Centre National d'Etudies Spatiales) sponsored a series of seminars culminating in a GNC V&V workshop. This effort began with a series of talks by GNC subject matter experts that were presented in the autumn of 2020 and spring of 2021. Following the seminar series, a workshop was conceived to establish a common understanding of the issues between academia and industry, and between the different national space agencies.

Three major themes emerged from this first-of-a-kind inter-Agency GNC V&V workshop. The first was education of the GNC workforce about existing tools and methods that can be used for V&V of non-traditional GNC algorithms. The workshop identified several techniques including genetic programming, reachability analysis, nonlinear stability analysis, mu-analysis, and others for which applications and toolsets with a high readiness level exist, and whose use in the GNC community could be expanded with training and education.

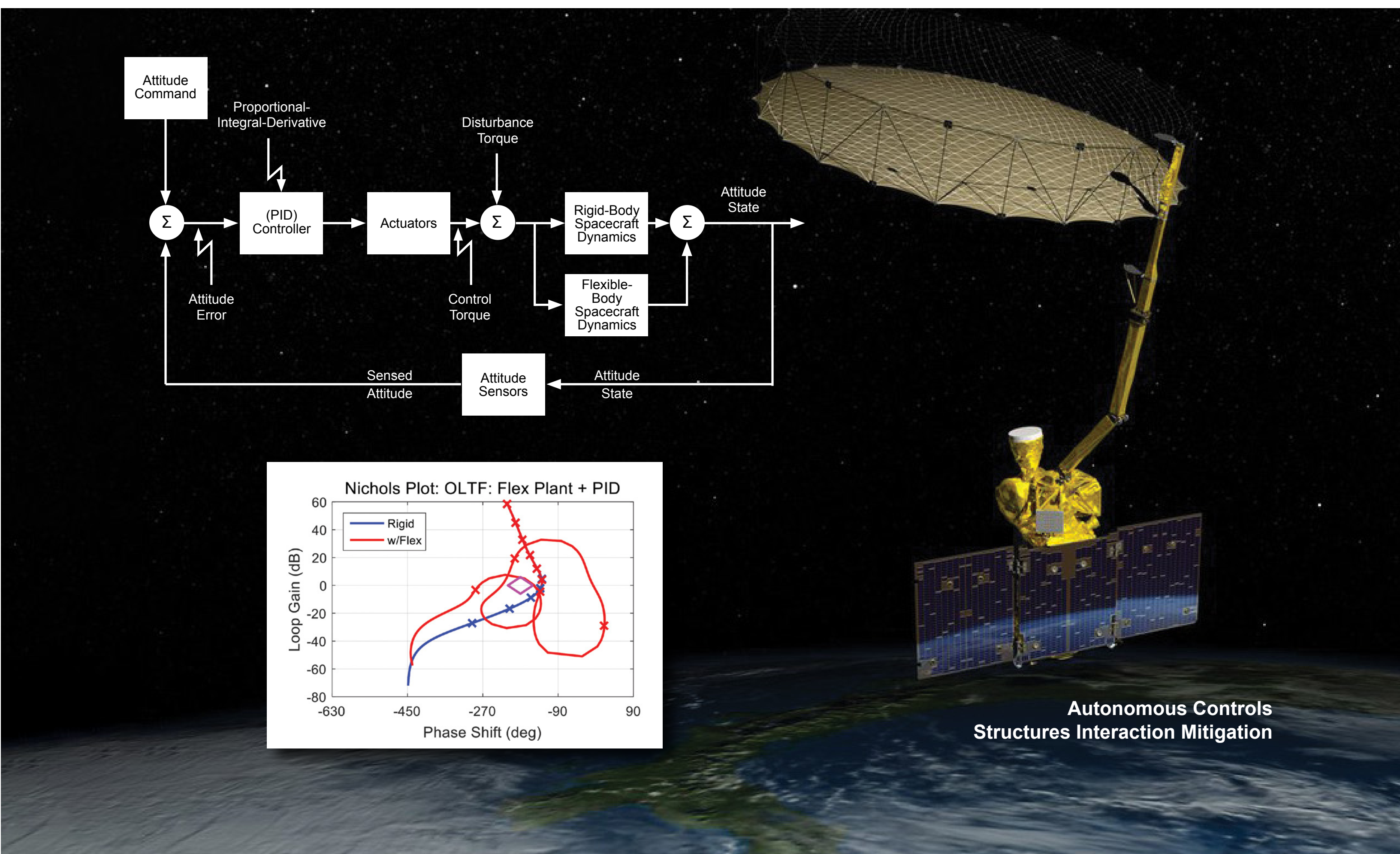
The second theme was development of new GNC V&V tools and analysis methods, targeted to meet existing needs and gaps. These include tools for nonlinear/hybrid systems with temporal specifications, tools to establish formal reasoning for hybrid (continuous and discrete) systems, increasing the efficiency of Monte Carlo simulations, and the leveraging of existing tools and techniques, such as Model Predictive Control, which are widely used in automotive and process control applications and other non-aerospace enterprises.

The third theme was creation of a set of GNC V&V benchmark problems for the GNC community of practice to solve. Example problems were discussed in presentations. Areas in which useful benchmark problems could be developed include launch vehicle flight control, high-precision space observatory pointing, reentry control, rendezvous and proximity operations, robotics servicing and assembly, active vibration control, and others.

It is clear that use of Autonomous GNC will pose a significant V&V challenge. New V&V methods, tools, and processes will be needed to build trust and accomplish pre-flight certification. The NESC GNC TDT is currently reviewing and processing the outcomes of the workshop and seminar series to formulate V&V gap-filling strategies and to prioritize V&V tool and process investments. One final observation that emerged from the workshop: NASA's Advanced Air Mobility Mission will depend on transformational tools & technologies, many from the GNC engineering discipline, to build trusted autonomy for safety-critical aeronautical flight systems. This is technology that can very likely be leveraged for space mission applications. For more information, contact cornelius.j.dennehy@nasa.gov.

SUMMARY POINTS

- NASA and ESA GNC engineers share a common technical language and, most likely, a common vision for Autonomous GNC on future missions - Why not collaborate since we should be aligned in a common purpose to build a new ecosystem?
- We have common driving interests in faster system implementation timelines and dramatically reduced mission operations support requirements. Also seeking ways to build in agility, adaptability, and on-the-fly system reconfiguration.
- Challenge will be for our GNC community of practice to learn new, non-traditional skills and techniques. Reliance on inter-disciplinary approaches and extensive system integration to effectively harness several new technologies.
- Use of Autonomous GNC will pose a significant V&V challenge. New V&V methods, tools, and processes will be needed to build trust and accomplish preflight certification.
- Transformation process we are witnessing now towards Autonomous GNC is ad hoc, which is acceptable since formality will come once the community has done some of the initial hard lifting to accomplish some early successes.



Autonomous Controls Structures Interaction Mitigation

SCIENCE

NESC Chief Scientist: Dr. Azita Valinia

Building Bridges Between Science and Engineering

Selected as the NESC's new Chief Scientist in February 2020, Dr. Azita Valinia builds bridges between the science and engineering communities at NASA.

"Scientists and engineers have different cultures, and fortunately I understand both communities well through my past experience," said Dr. Valinia, an astrophysicist and 20-year NASA veteran of Earth and space sciences research, technology development, engineering, and space science mission management. As the architect of many interdisciplinary NASA programs, such as the Science Engineering Collaboration Program and the Research Engineering Program at NASA GSFC, she plans to build on that success to foster additional collaborations, and cross-pollinate the two communities to learn from each other's best practices, and bring more awareness to the role that the NESC plays in ensuring scientific flight project success.

But in March 2020, the global pandemic hit the U.S. and building bridges and relationships became a strictly virtual endeavor. It significantly changed how she conducted business but did not change her primary objectives as NESC Chief Scientist: to become the NESC liaison to the science community and serve as an architect for interdisciplinary science-engineering collaborations.

During the first few months of her tenure, Dr. Valinia poured over NESC documents, reviewing technical discipline capabilities and NESC's support of NASA's science missions such as Hubble, JWST, Kepler, LISA, SMAP, CYGNSS, DSCOVR, ICESat-II, JPSS, and NISAR. She gave talks at science and technology conferences (virtually) and wrote technical articles on the role of the NESC in advancing NASA's scientific missions. With an ear open to the current needs and requirements coming out of the NASA science programs and projects, she found opportunities to make connections and brought NESC experts to the table to help those projects solve challenging technical issues. "Many of the best tools and innovative practices developed within the science and engineering communities stay inside the silos surrounding those communities. That's where I think I can help by breaking down the silos and have the lessons learned shared and applied to different communities," she said.

One opportunity came with the Capture, Containment, and Return System (CCRS) Project of the Mars Sample Return Program. "They had extreme back planetary protection requirements for bringing a sample with organic material back to Earth. I learned they have a significant amount of micrometeoroid and orbital debris (MMOD) risk associated with that project." Acting as a liaison, she facilitated the link up of

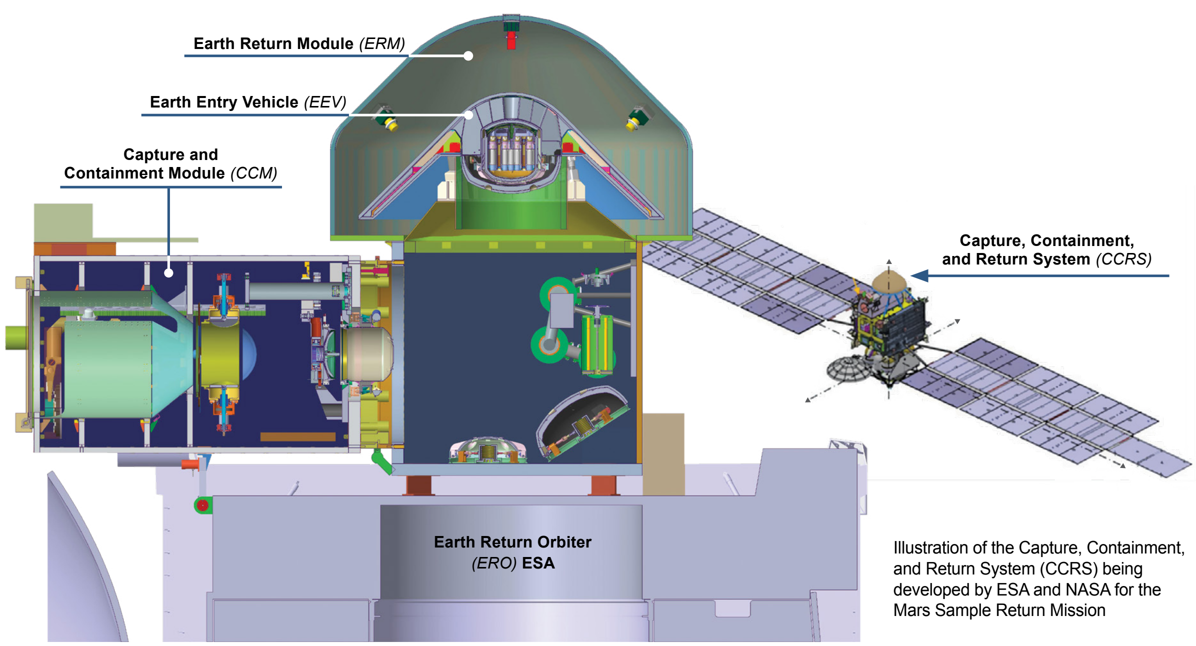


Illustration of the Capture, Containment, and Return System (CCRS) being developed by ESA and NASA for the Mars Sample Return Mission the Mars CCRS team and an NESC Principal Engineer with extensive MMOD expertise. The NESC is currently providing technical expertise to assess MMOD risk for CCRS and provide mitigation strategies.

“Those are ways to bring these two cultures together, the Human Exploration and Operations community and the Science Mission Directorate’s flight projects, to start them talking and exchanging ideas. The more I know about the NESC, the easier it will be for me to make these connections at other organizations at the Agency.”

Dr. Valinia recently coordinated the efforts of the NESC technical team that was called upon to assist with the failure investigation of the Arecibo Observatory. She also served as the liaison to the Arecibo managing organization, the University of Central Florida, and the National Science Foundation, who owns the observatory. The NESC assessment determined the most probable contributing factors to the initial auxiliary socket failure, which was followed by a number of cascading events that resulted in the eventual collapse of the observatory. Unfortunately, the observatory collapsed before recovery efforts took place. “But we all learned from it, and the NESC work has now resulted in an NESC Technical Bulletin, engineering report, and technical journal articles informing the civil engineering community of the cause of the initial socket failure. And the NESC’s work has been crucial to informing future observatory structural designs.”

“The other role I’m focusing on is to promote NASA interdisciplinary initiatives to maximize mission success and safety.” To that end, she launched the NESC study, Safe Human Expedition Beyond Low Earth Orbit (LEO). “It brings together the science, engineering, technology, and human research (medical) communities to find innovative engineering solutions that minimize risk to human health for these deep, long duration expeditions. There are three main hazards we are focusing on in this study associated with human risks: radiation exposure, microgravity exposure, and inadequate human systems integration architecture,” she said. For example, at Mars, because of communication time delay, a ground crew cannot immediately assist with resolving technical problems. “We have to replace the 100 people in mission control with a crew of 2 to 4. That explains the degree of difficulty. To do that smartly, we have to have human systems that incorporate autonomy and artificial intelligence into those architectures so that the crew can solve their problems on their own without having to wait to hear back from Earth.”

Dr. Valinia and Dr. J.D. Polk, the NASA Chief Health and Medical Officer, along with Dr. David Francisco, organized and co-chaired the “Safe Human Expeditions Beyond LEO” workshop in the Fall of 2021 to gain diverse inputs from a broad spectrum of potential stakeholders for the NESC study. Successfully building a virtual (interdisciplinary) study team of 40 members from across NASA, she is pleased with the collaboration that has resulted. “I think results will be impactful when we work together for common goals,” she said.

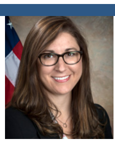
Dr. Valinia is excited to work with the NESC, pushing the frontiers of engineering toward finding solutions to challenging technical problems. For her, there is never a dull moment. “I feel privileged and honored to have the opportunity to work with some of the brightest minds and dedicated people at the NESC. It’s a thrill. I can’t wait to get back on site and meet them in person!”

“**Scientists** and **engineers** have different cultures, and fortunately I understand **both communities** well through my past experience.”

- DR. AZITA VALINIA, *NESC Chief Scientist*

Arecibo pre-collapse. NASA contributed to the Arecibo Radio Telescope failed Aux M4N cable investigation. Refer to NASA/TM−20210017934, NESC Technical Bulletin 21-05, and article on page 22.

Safe Human Expeditions Beyond LEO Workshop



ENVIRONMENTAL CONTROL & LIFE SUPPORT

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

Mentoring the Next Generation of Environmental Control & Life Support Engineers

Dr. Morgan Abney has dedicated her entire career to the Environmental Control & Life Support (ECLS) discipline, applying her chemical engineering degrees to the development of life support systems for the ISS and exploration flight projects. Her career trajectory, which brought her to her current role as NASA Technical Fellow for ECLS, was largely influenced by mentors she met along the way. It's why she readily adopted the NESC tenet of mentoring the next generation of NASA engineers, offering them opportunities to problem solve and develop the leadership skills needed to guide the Agency and the ECLS discipline into the future.

"I started mentoring in graduate school," said Dr. Abney. "My advisor encouraged us to bring in undergrads to work with us in the lab, so it was instilled in me early that it was important to do."

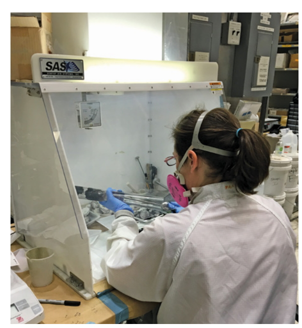
Since arriving at NASA in 2009, Dr. Abney has mentored high school and college students, and after joining the NESC in 2020, she began a six-month rotational fellowship program for early to mid-career engineers interested in the ECLS field. She selected her first two candidates through an in-depth interview process to assess their experience levels, career goals, and perspectives on the ECLS discipline. "My goal is to find someone who is motivated, interested in learning well beyond their current knowledge base, and who has a collaborative mind set. Because the ECLS discipline is located at several NASA Centers, I look for people who are interested in that cross-Agency collaboration."

Dr. Elspeth Peterson (also featured on page 34) was the first candidate selected, and Dr. Abney put her to work developing a plan to review a new SpaceSuit Water Evaporator Membrane (SWME). "I worked with Morgan to form a team of experts and develop test methods to predict how SWME would perform," said Dr. Peterson. "It was a bit intimidating at first, but everyone was happy to share their knowledge. It was a great experience. After the fellowship, Morgan made me the technical lead for the SWME assessment."

Handing over management of a project is part of Dr. Abney's mentoring process. "I start them out in a support role, getting to know people and understanding our processes. Then my target is to give them something to own and lead that

"I've had a series of incredible **mentors**, and there is no way I would be where I am without them **guiding** me, often in directions I didn't know I should be going."

- DR. MORGAN B. ABNEY, *NASA Technical Fellow for ECLS*



Left: Dr. Abney and early career employee Zach Greenwood perform a leak test on an integrated regenerative heat exchanger on a developmental life support system reactor. Middle: High school student Amber Medlen poses with her mentor, Dr. Abney, after winning first place in a poster competition in which she competed against undergraduate and graduate student interns. Right: Dr. Abney demonstrates for an intern how to remove a carbon-fouled catalyst sample from a quartz reactor tube inside a vent hood.

Chase Hopkins

Darnell Cowan

"I'm **learning** more about the ECLS side and how things work, which is what I hoped to gain from this rotation."

- DARNELL COWAN, *ISS EATCS Subsystem Manager JSC*

"This internship has completely changed my **career trajectory**. I thought there was no place for chemical engineers at NASA, and I've learned that is not the case at all."

- CHASE HOPKINS, *MSFC Intern*

puts them in front of different people in the ECLS community as well as other disciplines." It was an idea driven by her own experience.

"When I first came into NASA, my branch chief said, 'Go look into oxygen recovery and see what you can figure out,' and then left me alone. That ownership of that piece of the ECLS pie kept my interest and allowed me to make it what I wanted. The success of that project depended on me. I'm trying to give interns and associates that chance as well."

Mr. Darnell Cowan is working with Dr. Abney to identify active thermal control technology gaps in preparation for Artemis missions and is now leading an activity to formalize the process for ECLS technology down-selects and flight experiments. In these roles he has worked with thermal leads across the Centers and is designing a scoring system to better determine what technologies should be pursued.

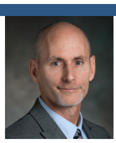
"Morgan has helped me develop presentations and articulate information to my stakeholders. She provides her assistance and guidance but lets me run the show. And she's always open to my ideas. I'm learning more about the ECLS side and how things work, which is what I hoped to gain from this rotation."

Also on Dr. Abney's mentee roster is college student Mr. Chase Hopkins, who she assigned to help evaluate the impact of reduced pressure and increased oxygen volumes on ECLS systems used in Exploration habitats. "Morgan and her team are always there to answer questions. I went from knowing nothing about ECLS to understanding all of the systems." This summer Dr. Abney asked him to take the lead on some subsystem work. "It was a lot more responsibility, but it gave me a big boost of confidence in my ability - that I could tackle something like this." He has been performing engineering analysis and bringing his ideas to the team. "I feel like I'm really contributing to a mission and the feedback has been awesome and really sustaining. This internship has completely changed my career trajectory. I thought there was no place for chemical engineers at NASA, and I've learned that is not the case at all."

Dr. Abney hopes to foster a love of the ECLS discipline in the younger generation. "That's where my heart is," she said. "I really want them to stay in the discipline if they have a knack for it and a love for it or at least remain as part of the ECLS community. They bring new ideas, new thoughts, and open-eyed curiosity to the discipline."

When the internships and rotations are over, Dr. Abney hopes her mentees walk away with three things: "One, an experience beyond what they could have received at their Center alone; two, recognition of their expertise from other Centers and in turn, their recognition that other Centers have experience they can leverage; and three, understanding the Agency is bigger than just the life support discipline at their own Centers. With that early exposure, I hope they can then take advantage of opportunities as they come along."

It is an advantage Dr. Abney has enjoyed throughout her career. "I've had a series of incredible mentors, and there is no way I would be where I am without them guiding me, often in directions I didn't know I should be going. Without that, I absolutely would not have the career I have. I recognize how important that has been, and I definitely want to do that for the next generation of engineers."



AVIONICS
NASA Technical Fellow for Avionics: Dr. Robert F. Hodson

Avionics Radiation-Hardness Assurance for Safe Exploration Beyond Low Earth Orbit

Radiation-hardness assurance (RHA) at NASA encompasses all activities undertaken to ensure that the electronics and materials in a space system perform to their design specifications after exposure to the natural space radiation environment. Avionics RHA includes environment definition; electrical, electronic, electromechanical, and electro-optical (EEEE) part selection; EEEE part testing; spacecraft layout; radiation-tolerant design; as well as development of mission, system, and subsystem requirements. It helps to group these process activities by the type or “theme” of work (e.g., modeling, analysis, or testing) or to examine the “level” or scope to which these activities can address information (e.g., mission, system, or part level). These processes, themes, and levels - as well as their linkages - are shown graphically in Figure 1. RHA must balance both design and risk trades for a given mission, environment, application, and lifetime (MEAL) [1] - all while managing programmatic and technical resource constraints of a given program or project. NASA’s current avionics RHA best practices have been captured in a new public technical memorandum [2] that was released by the NESC with support from the Office of Safety and Mission Assurance’s NASA Electronic Parts and Packaging Program.

As human exploration moves outside the protection of Earth’s magnetosphere and embraces a wider range of missions in more severe radiation environments, it is crucial to ensure that all stakeholders are cognizant of the threats presented by these evolving MEAL factors, as well as the resources required to mitigate them. In the near-term, RHA needs for exploration systems will be dominated by development efforts like the Human Landing System, shown in Figure 2, and studies for sustainable human landing systems under the Next Space Technologies for Exploration Partnerships-2 broad agency announcement. The development of RHA best practices, guidelines, handbooks, and standards for human exploration avionics systems also provide equal and significant benefits to science and space technology objectives.

For traditional approaches to RHA, there have tended to be gaps between state of the practice and state of the art based on what has been proven successful in flight and what is possible from a research and development perspective. RHA is always forced to evolve at the speed of technology development and insertion, which can strain accepted methodologies, particularly considering significant mission

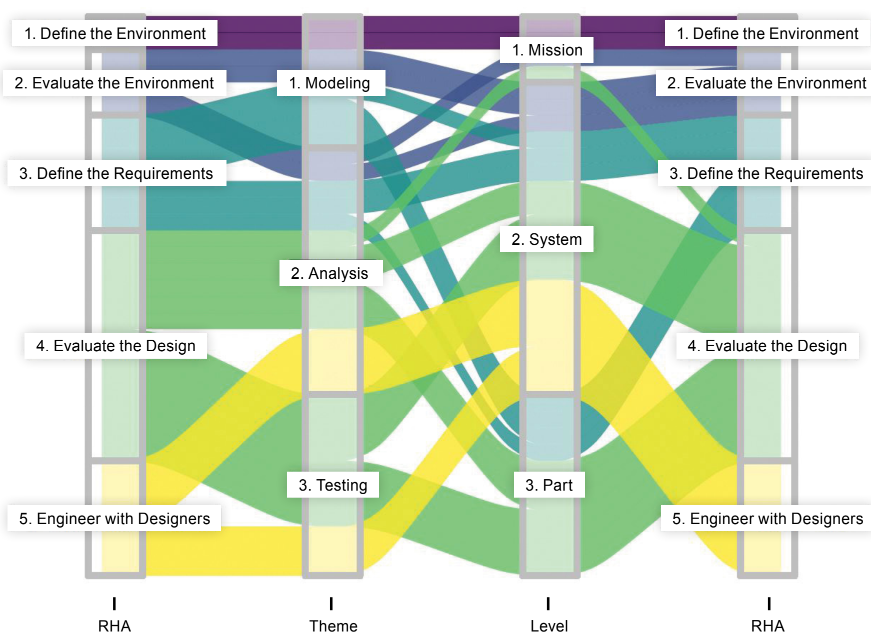


Figure 1. Sankey diagram showing a graphical mapping between RHA processes, themes, and levels

Figure 2. Concept image of an Artemis Human Landing System approaching the lunar surface

objective and acquisition strategy evolutions. Furthermore, much of the critical RHA knowledge in the spaceflight community is experiential and tied to a relatively small number of subject matter experts, placing paramount importance on continuously aggregating and documenting best practices for the wider community, which needs to leverage these discipline resources. The NESC RHA guidelines aimed to analyze and convert current best practices into a more detailed guideline resource that could serve as a crosscutting and comprehensive reference document as well as a springboard for subsequent handbooks and technical standards.

RHA is a multi-scale, interdisciplinary capability that addresses radiation-induced physical phenomena from the subatomic to system level. These skills can be used to avoid destructive radiation effects at the part level, like the Schottky diode failure shown in Figure 3, and they can also be used to support complex circuit and system design trades aimed at optimizing the balance between availability, reliability, and technological capabilities required to achieve mission objectives. A robust and thriving RHA capability helps ensure NASA's avionics capabilities are second to none and ready to tackle a wide range of exploration, science, and space technology challenges now and in the decades to come.

For more information, contact robert.f.hodson@nasa.gov and jonathan.a.pellish@nasa.gov. This article was contributed by Dr. Jonathan Pellish, Avionics TDT member, and NASA Electronics Parts Manager.

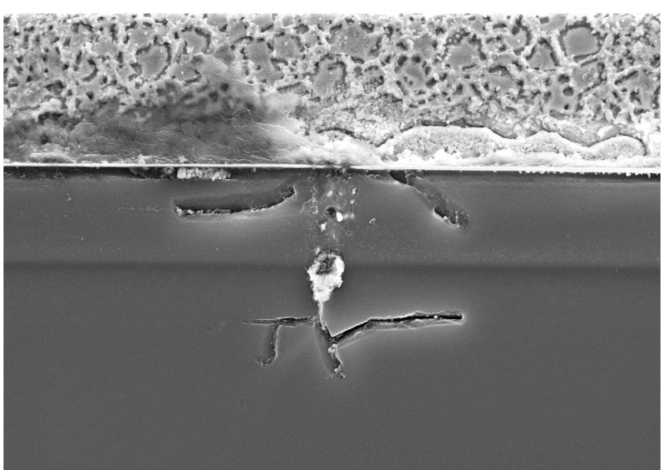


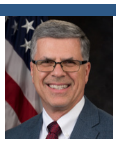
Figure 3. Scanning electron microscope image of a destructive heavy ion-induced single-event effect failure in a Schottky diode [3]

REFERENCES

1. O. Gonzalez, R. L. Ladbury, Y. Chen, D. R. Morgan, C. M. Green, and D. E. Yuchnovicz, Guidelines for Verification Strategies to Minimize RISK Based on Mission Environment, - Application and -Lifetime (MEAL), NASA Engineering and Safety Center, NASA/TM-2018220074, 2018, https://ntrs.nasa.gov/citations/20180007514.

2. R. F. Hodson, J. A. Pellish, R. A. Austin, M. J. Campola, R.L. Ladbury, K. A. LaBel, G. R. Allen, R. Gaza, and E. M. Willis, "Avionics Radiation Hardness Assurance (RHA) Guidelines," NASA Engineering and Safety Center, NASA/TM-20210018053, 2021, https://ntrs.nasa.gov/citations/20210018053.

3. M. C. Casey, J. Lauenstein, R. J. Weachock, E. P. Wilcox, L. M. Hua, M. J. Campola, A. D. Topper, R. L. Ladbury, and K. A. LaBel, "Failure Analysis of Heavy Ion-Irradiated Schottky Diodes," IEEE Trans. Nucl. Sci., vol. 65, no. 1, pp. 269-279, 2018, https://ieeexplore.ieee.org/document/8168379.



PROPULSION

NASA Technical Fellow for Propulsion: Dr. Daniel J. Dorney

NESC Leads Testing Efforts to Characterize Engine Anomalies

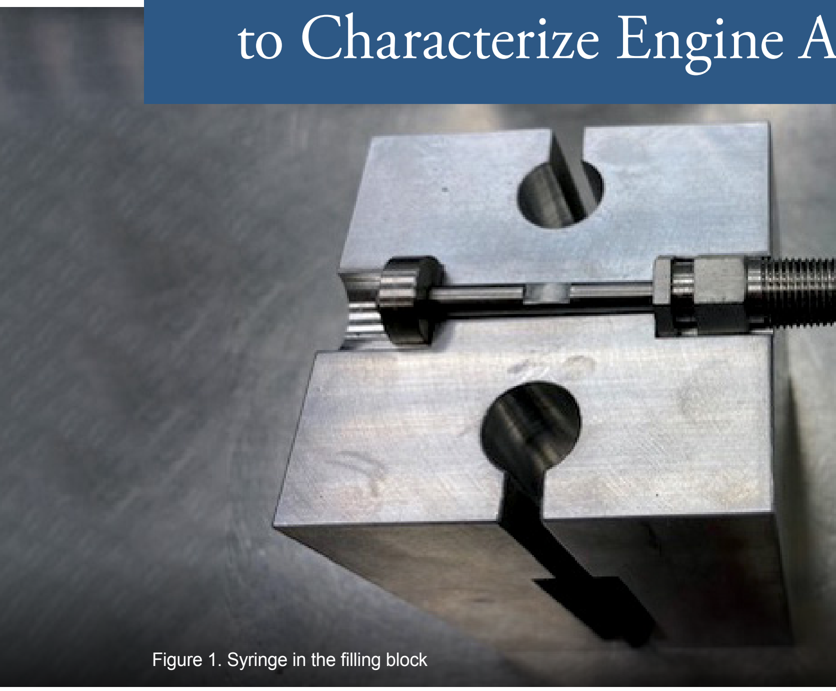


Figure 1. Syringe in the filling block

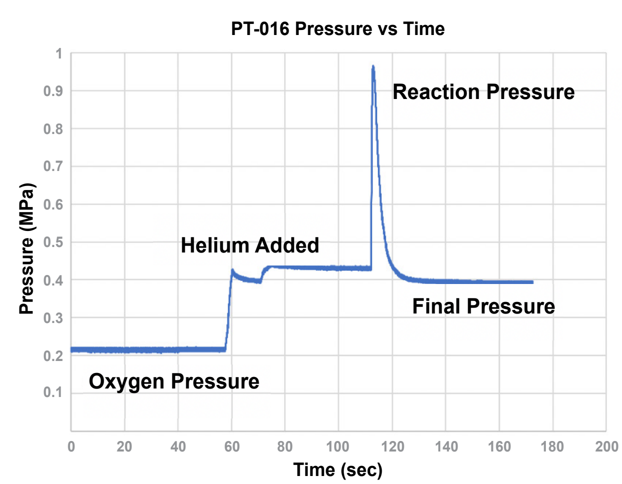


Figure 2. Sample pressure trace as a function of time

Understanding Effects of Helium Concentration on the TEA-TEB/Oxygen Ignition Process

Many gas generator (GG) cycle rocket engines (e.g., liquid oxygen/Rocket Propellant 1 (LOX/RP-1), LOX/liquid hydrogen (LH2) propellants) use a pyrophoric mixture of triethylaluminum-triethylborane (TEA-TEB) to achieve ignition. The TEA-TEB is often stored in canisters on the ground or inside the launch vehicle. The TEA-TEB is pressurized with helium (He), causing a burst disk to rupture and allow the TEA-TEB to flow into the GG. In the GG, the TEA-TEB mixture contacts the flowing LOX, combusts, and ignites the RP-1 or LH2. After the engine starts, there can be residual He in the TEA-TEB lines. When the engine is restarted, the residual He can mix with the TEA-TEB and act as a diluent as it flows into the GG chamber.

The physics of using TEA-TEB for engine ignition is understood, but the effects of He concentration on the ignition process have not been well studied. The role of GGs in several recent launch vehicle engine anomalies (e.g., hard starts, restart issues, etc.) has brought into question the dynamics of the TEA-TEB combustion process in an O_2 environment with varying concentrations of He. In addition, GG engines using TEA-TEB ignition are susceptible to pressure pops/spikes and hard starts (i.e., unwanted ignition). The NESC and White Sands Test Facility (WSTF) experimentally determined the role of He concentration in the TEA-TEB/O_2 combustion process to help in the start/restart sequences of engines and to avoid unwanted hard starts. The testing was performed at WSTF in a pressure vessel contained in a chemical fume hood. A special filling block tool was designed to load the syringe with TEA-TEB in a nitrogen (N_2)-purged dry box and move it to the pressure vessel for maximum safety (see Figure 1). The TEA-TEB was then injected into the pressure vessel using the syringe injector, and pressure was recorded as function of time (see Figure 2). The test results demonstrated that the TEA-TEB/O_2 reaction pressure increased and the combustion efficiency decreased with increasing amount of diluent (He and any excess O_2). These results can be used to help guide the formulation of start sequences in TEA-TEB ignition systems.

Transient Evolution of Helium Pressurant in MON-3 and MMH

One of the problems encountered in the development of liquid bipropellant rocket engines is the occurrence of low-frequency instabilities, some of which lead to a phenomenon commonly referred to as chugging. Chugging is caused by a vibrational coupling of the propellant feed system with the combustion dynamics in such a way as to amplify any disturbance in pressure or propellant flow. Instabilities such as chugging have been issues for 60 years and required significant effort to mitigate during the Apollo Program. Chugging mitigations are often hardware specific and include avoiding the operating regimes that generate instabilities, changing line and manifold volumes, and other design considerations. It has been demonstrated that chugging can be significantly affected by the propellant pressurant, specifically He, transitioning into and out of solution.

The NESC recently completed an assessment to characterize the transient behavior of He evolution from mixed oxides of nitrogen 3% (MON-3) and monomethyl hydrazine (MMH). The testing was performed at Purdue University (see Figure 3). The pressure range investigated envelopes most of the current and historic spacecraft, which utilize hypergolic propellants. To distinguish between He bubbles and two-phase flow bubbles, both of which can manifest due to a pressure drop, tests were first conducted with fully unsaturated propellants provided by a piston tank. The remaining tests were performed with propellants that were fully saturated with He at the given temperature and pressure for each test. The data collected included the number and average diameters of the He bubbles in the test section (via video data and a bubble counting/sizing algorithm, see Figure 4) and the speed of sound downstream of the test section.

The results indicate that when plotted versus normalized pressure drop, the measured speeds of sound for saturated MON-3 and MMH collapse into linear relationships. The volume fraction of the He bubbles is a linear function of the normalized pressure drop for MON-3 and MMH until all the He evolves from solution. The He bubbles observed immediately downstream of the test section orifice persisted in the fluid a relatively large distance in the absence of additional pressure drop. Finally, the measured speeds of sound for saturated MON-3 and MMH agree with literature values. The data generated in this assessment should help propulsion system designers avoid the He evolution conditions associated with chugging, increasing life and reliability of propulsion systems.

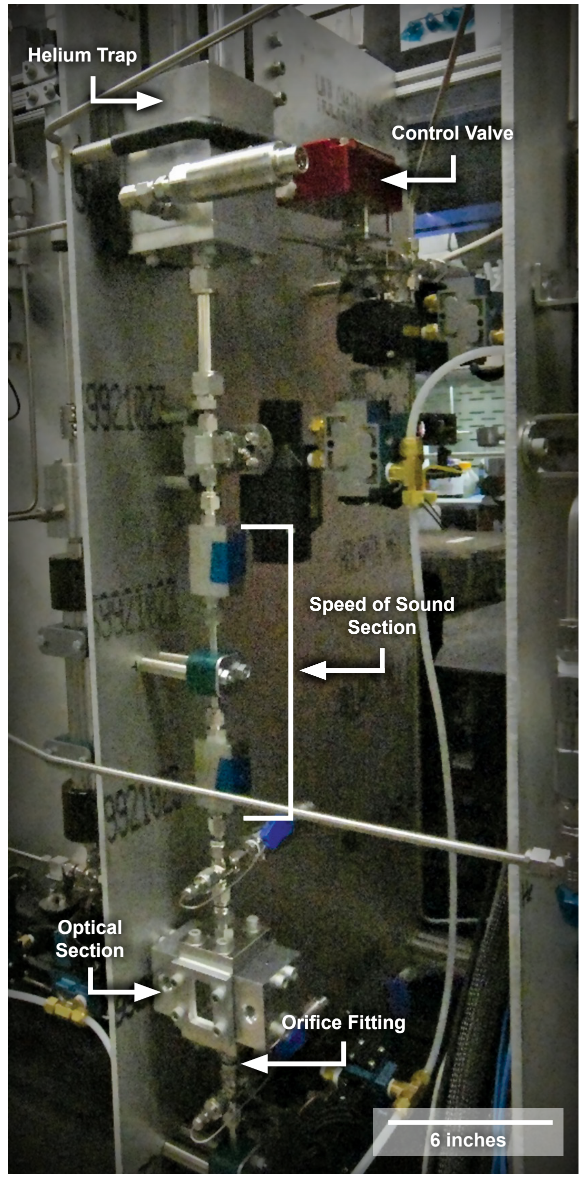


Figure 3. Test set up at Purdue University

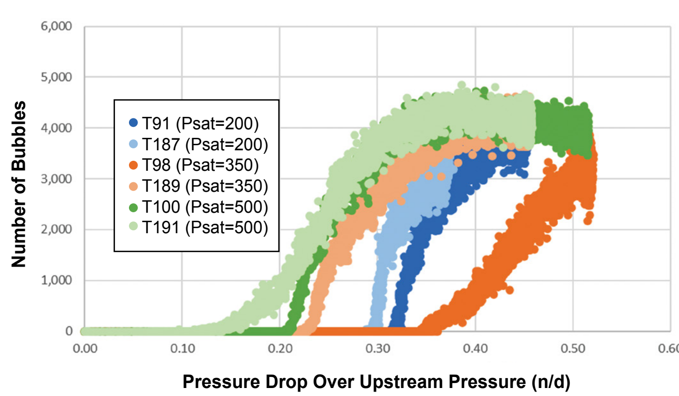
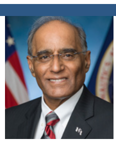


Figure 4. Total number of bubbles versus normalized pressure drop for MON-3



STRUCTURES
NASA Technical Fellow for Structures: Kauser S. Imtiaz

Treatment of Transient Pressure Events in Spaceflight Pressurized Systems

Transient pressure events are dynamic fluctuations due to disruptions within pressurized systems. Analytical and experimental evidence have shown that fast-moving pressure transients can elicit an amplified structural response above a static response. Structural failures have occurred from inadvertent overload or cyclic fatigue from pressure transients in many aerospace applications. The concept of a transient event is illustrated in Figure 1a. A pipe connecting a tank and an open valve shows steady fluid flow. As the valve is suddenly closed, a bow wave results in a dynamic pressure rise with the wave traveling back and forth between the tank and the valve. The ensuing pressure spikes, Figure 1b, can lead to pressure system component failures.

The NESC published a position paper to improve understanding of pressure transients caused by flow disturbances and document best practices with a roadmap (Figure 2), given the number of new entrants into the commercial space field where launch of crewed spacecraft is the main objective [1].

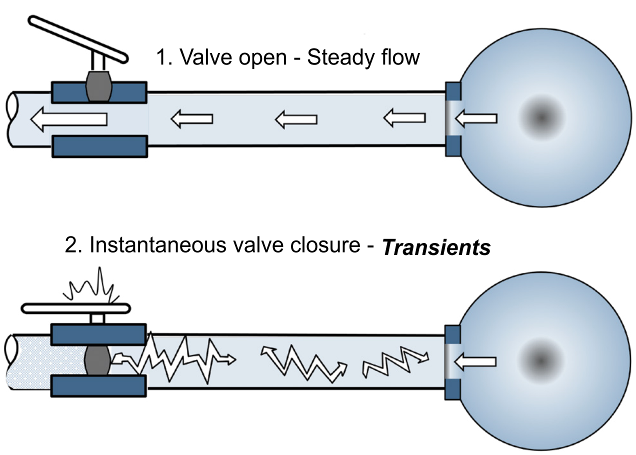


Figure 1a. Illustration of pressure transients

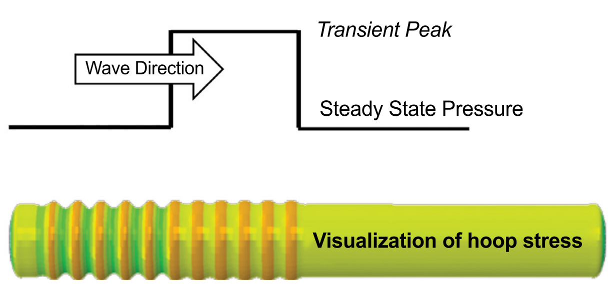


Figure 1b. A pipe's analytical structural response to a travelling pressure wave from valve closure

Five aspects of transients are presented: (1) fundamental physics of the contributing sources, and major influencing factors of transients in pressurized systems, (2) mitigation strategies to reduce the magnitude of pressure transients, (3) prediction or measurement of pressure transients with case studies illustrating their application, (4) prediction or measurement of dynamic response of the structure to transients along with case studies to illustrate methods to predict the amplified stress response, and (5) the structural verification process, which requires an understanding of the critical stress states within the pressurized hardware.

Characterizing transients in system design is performed via fluids analysis or test. The Joukowsky equation provides a simple and conservative means to predict transients for "instantaneous" valve closures. Another approach is to create one-dimensional fluid models consisting of a pair of coupled first-order partial differential equations involving continuity and momentum equations. A more detailed two-dimensional or three-dimensional model can be developed to capture losses and other geometric effects but requires additional effort to create and validate the model. Alternative to analytical models, transients can be characterized by performing instrumented (e.g., pressure transducers) subsystem tests that incorporate test-like-you-fly operational aspects (e.g., valve closure schedule).

Once the magnitude of a pressure transient is determined, it is important to assess the structure's response to these transient pressures. The structure's dynamic response is influenced by the component's geometry and material properties and the pressure wave velocity, amplitude, and shape. This dynamic response may result in amplification of stresses due to resonance or may not be affected at all depending upon the characteristics of the system. A ratio called dynamic amplification factor (DAF) provides a quantitative measure of the structure's dynamic response compared to the case where the same pressure load is applied statically. The DAF can be predicted using a structural dynamic analysis. The analysis should consider wave reflections from boundaries as it can result in higher DAF. A parametric study was performed by varying the radius (r), wall thickness (t), modulus (E), and density (ρ) of a pipe subjected to a half-sine traveling pressure wave to understand the effects on DAF. Through this study, it was found that the ratio, ω^*, of pressure wave frequency, ω, to the ring natural frequency of the pipe, ω_n, in rad/s, $\omega^* = \omega/\omega_n = r\omega/\sqrt{E/\rho}$ was a key parameter in the calculations of the DAF.

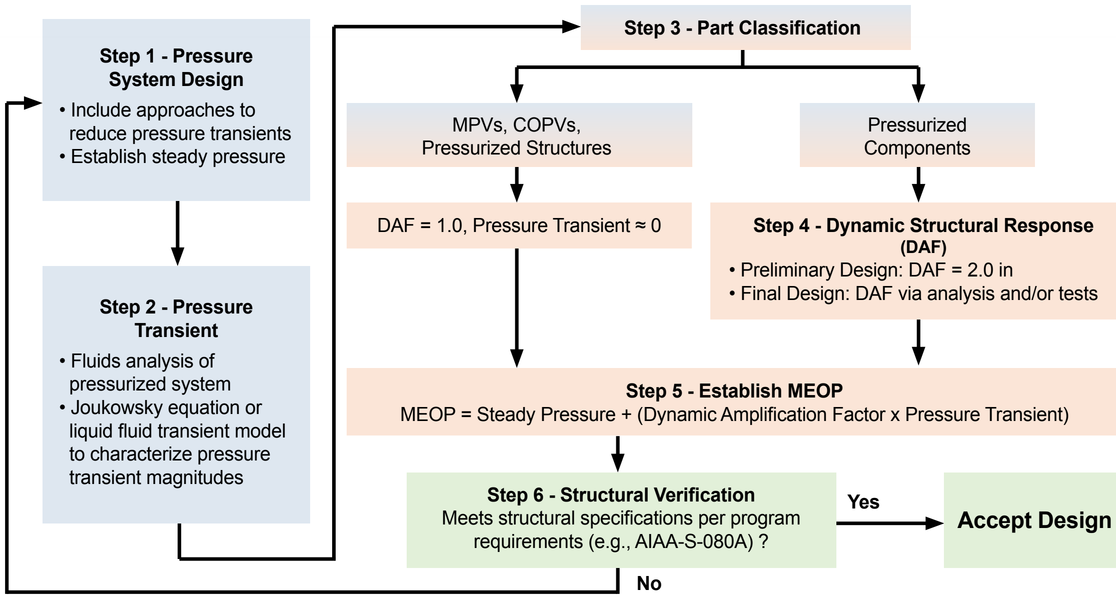


Figure 2. Workflow for Transient Pressure Evaluation

Figure 3 presents a case study that shows the DAF relationship with varying ω^*. With an assumed structural damping of 2%, three outcomes are possible:

$\omega^* << 1 \rightarrow$ similar to static pressure load, DAF = 1
$\omega^* = 1 \rightarrow$ resonance, response is amplified, DAF ~ 3
$\omega^* >> 1 \rightarrow$ structure responds slower than the load, DAF ~ 0

A graphical presentation similar to that in Figure 3 can be a useful design tool for many applications. Even a fast-moving pressure wave can cause a significant dynamic structural response, and its effects cannot always be ignored. Another approach to measuring the DAF is via subsystem tests where components can be instrumented with strain gages to directly measure the structural DAF.

The NESC paper and NASA/TM-20210022275 outline approaches to include DAF in the structural verification process. For fluid storage vessels such as tanks and pressurized structures, the pressure wave entering the vessel dissipates due to their relatively large volume compared to the connecting pipe. In these cases, the DAF is set to zero while the magnitude of the pressure transient is combined with the steady-state pressure in the vessel to determine the maximum expected operating pressure (MEOP). On the other hand, the transient pressure in pressurized components such as pipes and valves can result in either a minimal structural response (DAF~0.0), a quasi-static response (0.0 < DAF < 1.0), or an amplified response (DAF ≥ 1.0) above the static response. It is recommended to establish a MEOP such that the maximum stress produced by static pressure is equivalent to the maximum stress at the same critical location produced by the combined effect of steady state pressure and the magnitude of the pressure transient. An alternative approach is to adjust system pressure test levels to meet structural verification criteria without adjusting the MEOP definition. A damage tolerance approach with lower proof and burst factors is presented, which can result in weight savings, especially when pressure transient magnitudes are significant. For more information, contact kauser.s.imtiaz@nasa.gov or vinay.k.goyal@aero.org.

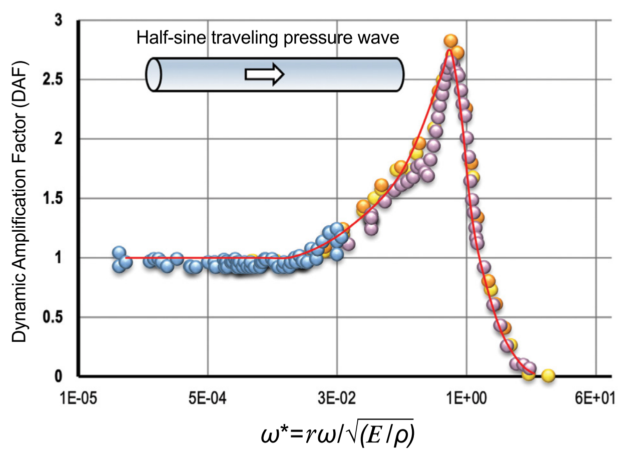
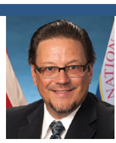


Figure 3. Design curve illustrating the effects of system characteristics on Dynamic Amplification Factor

REFERENCES

1. K. Imtiaz, V. Goyal, P. Babuska, E. Barbour, and J. Smith, "Treatment of Transient Pressure Events in Space Flight Pressurized Systems" NESC, NASA/TM-20210022275, https://ntrs.nasa.gov/citations/20210022275.



MATERIALS

NASA Technical Fellow for Materials: Richard W. Russell

NASA Additive Manufacturing Standards Support Human Spaceflight

Additive manufacturing (AM) is one of the biggest opportunities for NASA and commercial industry to reduce cost and schedule while enabling new mission capabilities for space exploration and advanced aeronautics applications. Under the leadership of the NESC Materials Technical Discipline Team, NASA has recently released two technical standards: NASA-STD-6030, *Additive Manufacturing Requirements for Crew Spacecraft Systems*, and NASA-STD-6033, *Additive Manufacturing Requirements for Equipment and Facilities Control.* These documents together provide the Agency with the framework for advanced AM programs and for the development and manufacture of hardware produced using AM technologies. Also, the implementation of these standards will have a profound and immediate impact within the additive manufacturing industry. The technical requirements will be cited in contract, program, and other Agency documents for AM processes used in the design, fabrication, and testing of all NASA space program flight hardware including crewed spaceflight hardware.

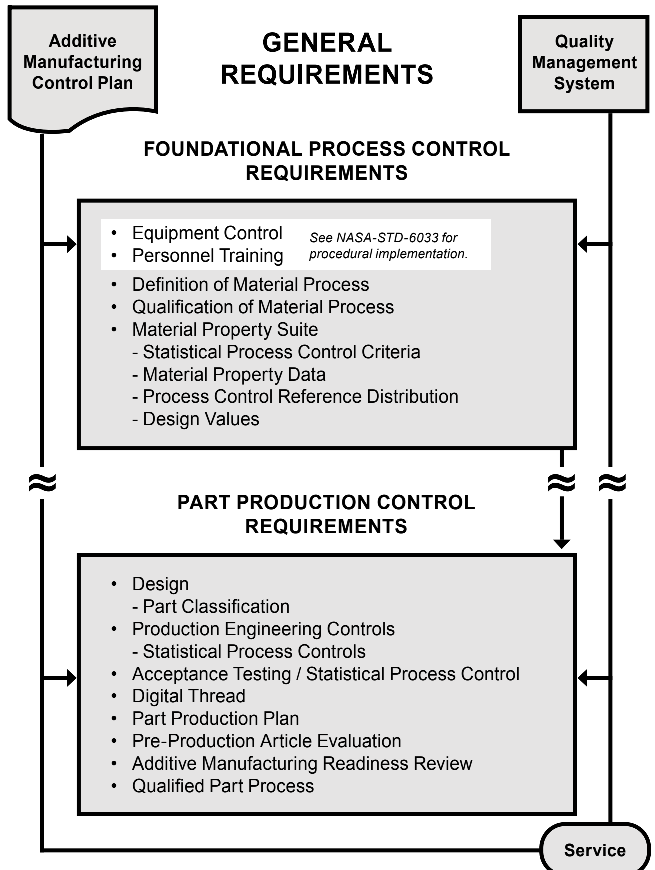


Figure 1. Topical outline for NASA-STD-6030

Building upon MSFC Center-level standards, these documents fill a void in the Agency-level standards regarding the integration of AM into spaceflight hardware. Because of the urgent need and complexity of spaceflight hardware, NASA could not wait for other national standard organizations to develop the standard. The development of these standards is a generational accomplishment and the result of more than 10 years of research and development based on integration across disciplines and foundational understanding of design, materials, processes, equipment, and part properties/performance. Producing these standards required substantial effort to address many difficult qualification challenges for fracture-critical applications in AM to produce sufficient confidence for industry-wide adoption. Hence, the core NESC-led team intentionally involved numerous government entities and experts from around the world to study the implementation and deployment strategy of AM.

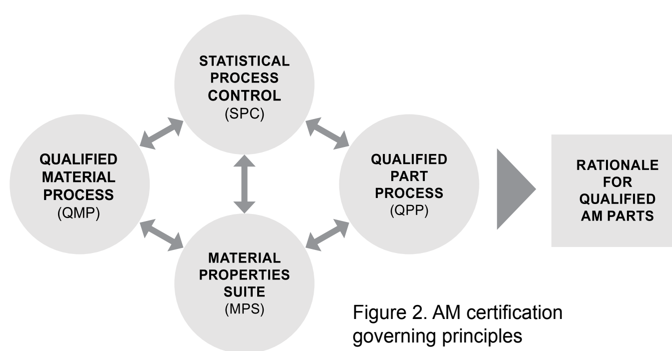


Figure 2. AM certification governing principles

NASA-STD-6030 begins with the general requirements for an AM Control Plan (AMCP), which along with a Quality Management System (QMS), forms the backbone that defines and guides the engineering and production practices. As shown in Figure 1, the requirements of NASA-STD-6030 fall into two categories. The first, foundational process control, includes the requirements for AM processes that provide the basis for reliable part design and production. These include qualification of material processes, equipment controls, personnel

AM assembly of an engine injector

training, and material property development. The second category, part production control, consists of requirements typical of many aerospace operations and includes design and assessment controls, part production plans (PPP), pre-production article processes, and AM production controls.

Equipment control and trained operators are key foundational controls required by these NASA Technical Standards and are implemented through NASA-STD-6033. Being essential aspects of any successful AM operation, plans are required to define how controls are implemented. An Equipment and Facility Control Plan (EFCP), the basic contents of which are covered in NASA-STD-6033, is developed and maintained by any facility producing AM parts. The EFCP sets and enforces the requirements for qualification, maintenance, and calibration activities on AM machines and associated equipment. NASA-STD-6033 also defines acceptable personnel training protocols to be implemented and tracked through QMS records.

The interaction of the key aspects of an AM plan are shown in Figure 2. The left-most circle illustrates the fundamental importance of always beginning with a qualified material process (QMP). The QMP will ensure a consistent process using specified controls of the raw material feedstock and an evaluation of the process capability for each AM machine, all which are documented in a configuration controlled QMP record. The QMP uses data from machine qualification, monitored by process control metrics and SPC, which all feed into the material properties suite (MPS) and documentation of material properties.

continued...

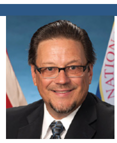
ADDITIVE MANUFACTURING OVERVIEW

Additive Manufacturing has begun to revolutionize much of the aerospace design and manufacturing paradigm.

The process of building parts incrementally, layer by layer, reduces costs, enables new designs, and challenges the order of the traditional aerospace hardware development cycle. For existing designs, AM offers a unique ability to substantially reduce the cost of manufacturing complex hardware, particularly in the limited quantities common to spaceflight applications. For new designs, the high cost and lead time associated with production of complex development hardware by conventional processing have moved the industry to near-complete reliance on meticulous analysis to mitigate the programmatic impact of test failures. With the advent of AM processing, prototype hardware designs will be iterated with minimal cost and impact to schedule, restoring the role of systematic, incremental development testing for aerospace systems.

The unique strengths of the AM process have motivated the spaceflight industry to lead in the application of AM technology. The greatest challenge associated with the implementation of AM in aerospace systems lies not in changing paradigms, but in the safe implementation of a new and rapidly changing technology. Compared to most structural material processes, the brevity in the timeline for AM implementation, from invention to commercialization to critical application, is unprecedented.

Source: Douglas N. Wells, MSFC



MATERIALS

NASA Technical Fellow for Materials: Richard W. Russell

continued...

The MPS concept includes three entities: a material property database; a subset of that database used to derive and implement a Process Control Reference Distribution (PCRD), which provides SPC criteria for witness test evaluation; and a maintained set of material allowables and design values for part design. Integrating simple SPC concepts to monitor the process and substantiate the integrity of material allowables is a unique aspect of NASA-STD-6030 and is necessary given the process-sensitive nature of AM. Figure 3 outlines how the QMP becomes the foundation for the establishment of the MPS, which along with SPC leads to part qualification.

The PPP documents the rationale for, and the implementation of, the production methodology, including such items as the part build orientation, associated QMP, witness test requirements, inspection methods and limitations, and proof-testing methodology. The PPP is a deliverable product requiring NASA approval prior to proceeding into production; the PPP needs to convey succinctly the full design and production intent of the part. Once approved, the combination of drawing and PPP serve as the basis for establishing the complete engineering production controls. Once a pre-production article is manufactured and found to meet requirements, the Qualified Part Process is established, and production of flight parts can begin.

This accomplishment will have a direct and significant impact within the aerospace AM community and an even wider impact to worldwide standardization, qualification, and certification in other commercial/industrial sectors. For more information, contact richard.w.russell@nasa.gov, alison.m.park@nasa.gov, douglas.n.wells@nasa.gov, and brian.m.west@nasa.gov.

AM parts that make up the rotating assembly of the AM demonstrator engine produced by MSFC

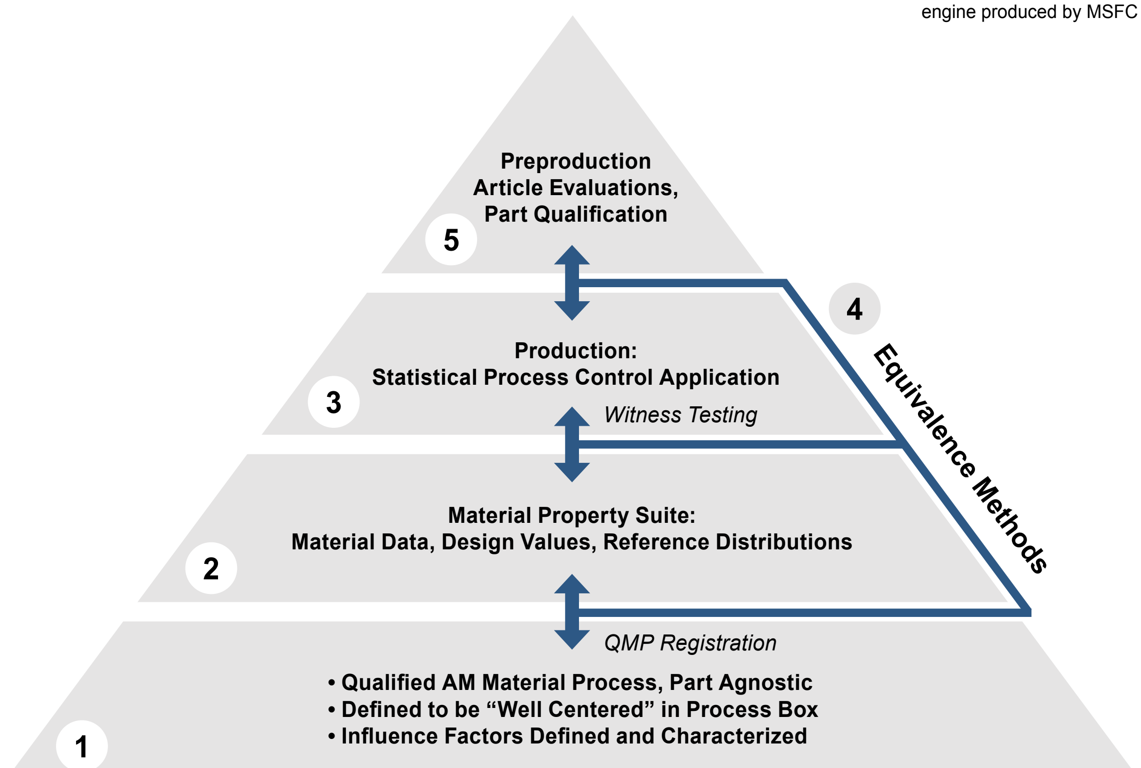
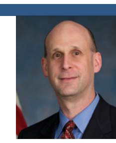


Figure 3. Material properties building block

PASSIVE THERMAL

NASA Technical Fellow for Passive Thermal: Steven L. Rickman



Fractional Thermal Runaway Calorimeter Provides Key Insights into Lithium-Ion Battery Safety

Lithium-ion (Li-ion) cells are widely used in aerospace and terrestrial applications due to their energy storage capability. However, these cells can experience thermal runaway (TR), a failure phenomenon resulting from mechanical, thermal, or electrochemical abuse whereby stored energy is rapidly released at a rate greater than the cell can dissipate the heat. If a battery assembly is not properly designed, TR can propagate to adjacent cells with potentially catastrophic results.

In 2016, the NESC pursued the development of the Small Format Fractional Thermal Runaway Calorimeter (S-FTRC) to measure TR energy yield for the widely used 18650 format Li-ion cell. The S-FTRC was designed to provide unique insight into TR by allowing a tally of the total thermal energy release plus the fractions liberated as vented energy and energy that conducts through the cell casing. These data are important in understanding Li-ion battery thermal design and analysis.

After NESC involvement ended, engineers at the Johnson Space Center continued to use the calorimeter to support NASA's missions while improving the calorimeter design to further increase both rapid turnaround testing and durability. Experiments can now be conducted with a 25-minute turnaround when working with a team of 3 to 4 people, allowing many experiments to be conducted during a single test campaign. Given that no two TR events are the same, a statistically significant set of tests is required to characterize the range of potential TR behaviors.

The most recent version of the S-FTRC is depicted in Figure 1. Additionally, the FTRC architecture has been expanded to support pouch format cells and large format prismatic cells with capacities greater than 100 A-h. NASA has pursued a patent on the S-FTRC and has advertised the calorimeter as a licensable technology through NASA's Technology Transfer (T2) Office, which has already sparked interest by private sector entities. The T2 Office actively works today to license the technology to interested parties.

NASA engineers and collaborators at the National Renewable Energy Laboratory (NREL) and the University College London have executed hundreds of calorimeter runs to date. The majority of the experiments have been conducted at synchrotron facilities in the United Kingdom (Diamond Light Source) and in France (European Synchrotron Radiation Facility). These special experiments allow the internal failure mechanisms of the cell to be studied with high-speed X-ray videography capturing recordings in excess of 1700 frames-per-second; a still image captured from one of these experiments is shown with Figure 2. These combination synchrotron/S-FTRC experiments provide researchers and engineers with data that helps to link internal failure mechanisms to the external thermal characteristics of a cell undergoing TR.

The bulk of the data gathered by these experiments has been compiled into a publicly accessible resource known as the Battery Failure Databank. The databank can be downloaded from NASA.gov/ftrc and is also available via NREL web channels. The databank consists of a spreadsheet containing the tabular S-FTRC results with hyperlinks to the X-ray videos hosted on the NREL YouTube channel when applicable. The structure of the spreadsheet is designed to be compatible with modern visual analytics techniques.

In the years to come, NASA engineers aim to use the FTRC data to inform the design of battery assemblies created for NASA programs and also hope to see the S-FTRC hardware and data contained in the Battery Failure Databank leveraged by private industry to help make batteries safer here on Earth.

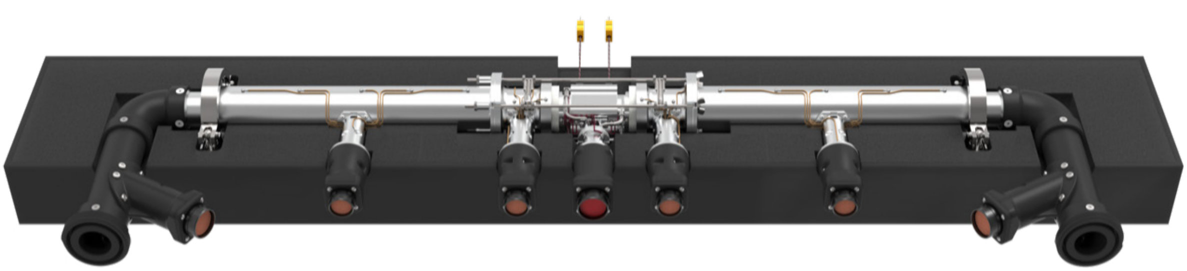


Figure 1. Rendered image of the Generation 11 S-FTRC

Top insulation removed to show internal components

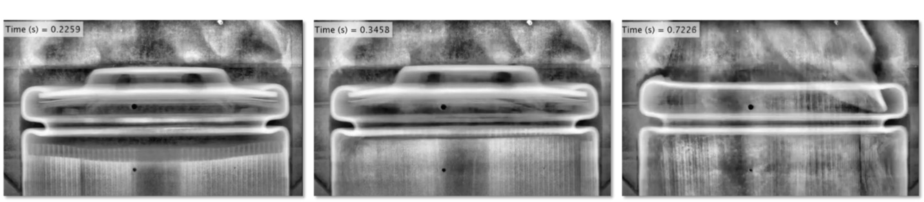


Figure 2. Stills from high-speed X-ray video of a Li-ion cell at the moment it is triggered into TR while installed inside fractional calorimeter

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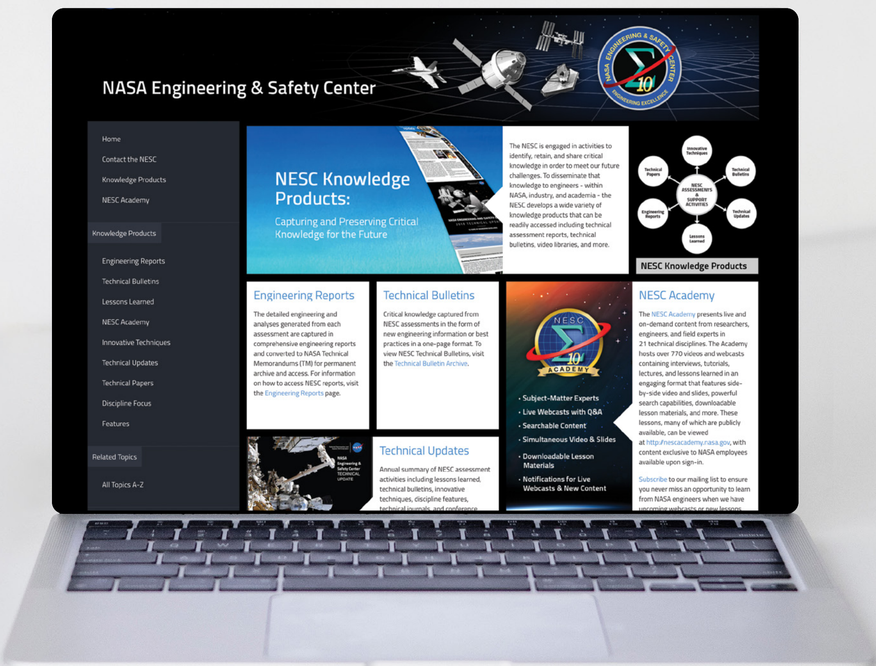

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Written by members of the NESC and NESC Technical Discipline Teams to convey new knowledge learned on NESC assessments.

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Highlight information, gleaned from NESC assessments, which may benefit a wider audience.

NESC Academy

NASA Engineering & Safety Center

Beginning in 2007, the NESC Academy was formed to capture and disseminate knowledge from NASA discipline experts to the engineering community. The NESC Academy enables effective knowledge capture and transfer, ensuring technical information remains viable and accessible. The Academy hosts more than 830+ videos and webcasts containing interviews, tutorials, lectures, and lessons learned.

It provides a forum for the NASA community to gain critical knowledge to aid professional development and support the NASA mission. Researchers and engineers in 20 technical disciplines present live and on-demand content relevant to the design, development, test, and operation of NASA programs and projects.

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- **39,870 Views**
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2. Lithium-ion Batteries: Fundamental Concepts, Heating Mechanisms and Simulation Techniques
3. Creating a World Class Safety Culture, Part I: Lessons Learned from Launch Vehicle Failures
4. 7 Habits of Highly Effective (NASA) Systems Engineers
5. Systems Engineering & Model Based Systems Engineering Stakeholder State of the Discipline
6. Shock & Vibration: 01. Natural Frequencies, Part 1
7. Spacecraft Design for Manual Control
8. Getting Stuff Done
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ENVIRONMENTAL CONTROL & LIFE SUPPORT
Space Radiation Environments

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

GUIDANCE, NAVIGATION, & CONTROL
Fundamentals of Kalman Filtering and Estimation

HUMAN FACTORS
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MATERIALS
Selected Apollo & Shuttle Lessons Learned, Part 1

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Overview of Fastener Requirements in the New NASA-STD-5020

NONDESTRUCTIVE EVALUATION
Introduction to Probability of Detection (POD) for Nondestructive Evaluation (NDE)

PASSIVE THERMAL
Short Course on Li-Ion Batteries

PROPULSION
Generalized Fluid System Simulation Program Training Course 01: Course Intro

SENSORS & INSTRUMENTATION
ARCSTONE: Calibration of Lunar Spectral Reflectance from Space

SOFTWARE
Introduction to Software Engineering 05: Peer Reviews and Inspections

SPACE ENVIRONMENTS
(MOWG) NASA Robotic CARA Probability of Collision

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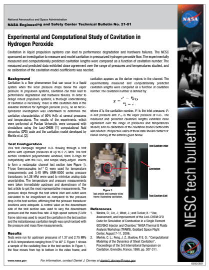
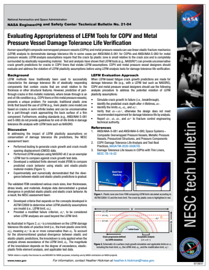
NESC TECHNICAL BULLETINS: *Released in 2021*



[NESC Technical Bulletin 21-01](#)

Experimental and Computational Study of Cavitation in Hydrogen Peroxide



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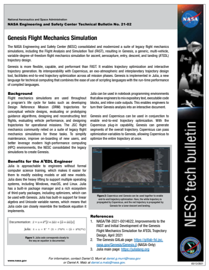
Evaluating Appropriateness of LEFM Tools for COPV and Metal Pressure Vessel Damage Tolerance Life Verification



[NESC Technical Bulletin 21-02](#)

Genesis Flight Mechanics Simulation

[NESC Technical Bulletin 21-05](#)

Industry Recommendations from Arecibo Observatory Zinc Spelter Socket Joint Failure Analysis

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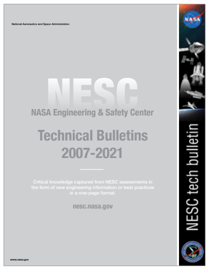
Best Practices for the Elemental Profiling of High-Purity Hydrazine



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LLIS Entry 29801

Best Practices for the Elemental Profiling of High-Purity Hydrazine

Trace contaminants in high-purity hydrazine (HPH) propellant impact a wide variety of commercial, Department of Defense, and NASA missions. Depending on thruster design, contaminants must be kept at extremely low levels and are verified as such by routine analysis. Several impactful contaminants are not currently controlled in the current MIL-PRF-26356 specification that governs procurement. A number of these elemental contaminants have recently undergone an assessment to shed light on potential contaminants present following changes in the HPH supply chain. A round-robin analysis utilizing four separate laboratories resulted in unacceptably high variability in the quantification of these contaminants.

Efforts were made to ascertain the causes of this lab-to-lab variability. These efforts highlighted several sample preparation and analytical method considerations that can impact laboratory results. The principal objective of this lesson learned, and these recommendations, is to establish an analysis methodology that yields accurate and repeatable quantification by providing best practices for both quantitation methodology and strategies for avoiding sample contamination during analysis.

LLIS Entry 30101

Cable Harness Wiring and Connector Anomalies Caused by Induced Damage in Human Spaceflight Vehicles

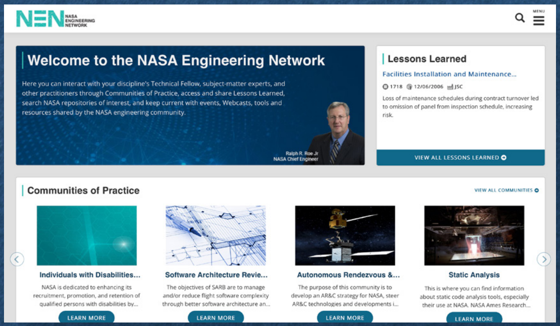
Early indications show that the commercial spacecraft developers and operators are experiencing a reduced incidence of wiring anomalies compared to the Space Shuttle Program (SSP). There are differences in implementation of wiring designs between the new vehicles and the Space Shuttle. Recognition of these differences and an appreciation of where SSP failure mechanisms can pose a risk to new crewed launch vehicles and spacecraft can help to manage the incidence of wiring anomalies. Decisions that reduce wire inspection and testing post installation may need to be revisited if the factors resulting in reduced wire incidents change.

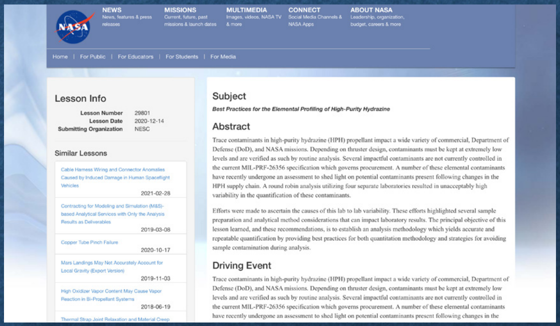
— LESSONS LEARNED —

Learning from the Past to Safeguard Spaceflight's Future

Important and broadly applicable lessons learned are captured from NASA work and available in an Agency-wide database called the Lessons Learned Information System (LLIS).

https://nen.nasa.gov and https://llis.nasa.gov





HONORING THOSE WHO MADE OUTSTANDING CONTRIBUTIONS IN 2021

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 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.

Andrew L. Glendening - In recognition of outstanding technical leadership in the development of NASA's Additive Manufacturing Standards

Erin L. Lanigan - In recognition of outstanding leadership in addressing radiographic nondestructive evaluation techniques for fracture critical flight hardware inspections

Matthew A. Reed
In recognition of outstanding technical leadership in support of the NASA Langley Unitary Plan Wind Tunnel testing for the United States Army Futures Command

John H. Wall - In recognition of exceptional leadership, perseverance, and technical rigor in establishing expectations for human space flight and justifying deviations from Commercial Crew Program stability margin expectations

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.

Brian A. Davis - In recognition of exceptional engineering achievement leading to the successful flight of the Aerodynamic Buffet Flight Test vehicle

Mitchell L. Davis - In recognition of engineering excellence through analysis, simulation, and identifying engineering solutions for the Commercial Crew Program Remote Analog Interface Unit Reset Anomaly

Lucas J. Day - In recognition of engineering excellence in support of the NASA Engineering & Safety Center's Shell Buckling Knockdown Factor Project testing activities

Dustin E. Dyer - In recognition of the rigorous comprehensive flight control analyses and engineering excellence in support of the NASA Engineering & Safety Center's Commercial Crew Program Ascent Stability Assessment

Nathaniel W. Gardner - In recognition of engineering excellence in support of the NASA Engineering & Safety Center's Shell Buckling Knockdown Factor Project large-scale composite testing

Ajay M. Koshti - In recognition of engineering excellence in identifying deficiencies and potential solutions in flaw detectability for nondestructive evaluation of fracture critical flight hardware

Danny J. Lovaglio - In recognition of exceptional engineering achievement in understanding pressure instrumentation systems and aerodynamic modeling leading to the successful flight of the Aerodynamic Buffet Flight Test vehicle

Carl S. Mills - In recognition of exceptional engineering achievement in developing the data acquisition system leading to the successful flight of the Aerodynamic Buffet Flight Test vehicle

Peter A. Parker - In recognition of engineering excellence in the development and validation of new statistical methodologies to demonstrate flaw detectability for non-destructive evaluation of fracture critical flight hardware

David J. Petrick - In recognition of engineering excellence through analysis, simulation, and identifying engineering solutions for the Commercial Crew Program Remote Analog Interface Unit Reset Anomaly

Brett R. Starr - In recognition of exceptional engineering achievement in flight mechanics leading to the successful flight of the Aerodynamic Buffet Flight Test vehicle

Loc D. Tran - In recognition of exceptional engineering achievement in flight software leading to the successful flight of the Aerodynamic Buffet Flight Test vehicle

NESC ADMINISTRATIVE EXCELLENCE AWARD

Honors individual accomplishments that contributed substantially to support the NESC mission.

Amanda S. Drake - In recognition of exemplary and innovative program analyst support in executing fiscal processing of multi-year NASA Engineering & Safety Center resource data and trends

Elizabeth M. Hartman - In recognition for exceptional support in administering and allocating NASA advanced supercomputing resources for NASA Engineering & Safety Center assessments

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.

Aerodynamic Buffet Flight Test Assessment Team - In recognition of technical excellence and exceptional perseverance in accomplishing the Aerodynamic Buffet Flight Test

Additive Manufacturing Standards Development Team - In recognition of outstanding dedication and support in the development of NASA's Additive Manufacturing Standards

Arecibo Failure Investigation Technical Assessment Team - In recognition of outstanding technical achievement in determining the most probable cause of the Arecibo Observatory socket failure and providing industry recommendations to mitigate future failures

Avionics Radiation Hardness Assurance Assessment Team - In recognition of outstanding engineering excellence in the development of avionics radiation hardness assurance guidance for NASA and the emerging commercial space sector

Exploration Systems Development Integrated Hazard Analyses Assessment Team - In recognition of outstanding dedication and innovative analytical technique development to assess the completeness and adequacy of the exploration systems development integrated hazard analyses

Flex Harness Cable Assessment Team - In recognition of outstanding performance diagnosing the Climate Absolute Radiance and Refractivity Observatory Pathfinder flex harness cable failure and developing a new design to address vulnerabilities and improve performance

Mass Gauging Technology Assessment Team - In recognition of exemplary contribution and thorough evaluation of mass gauging technologies for microgravity operations

NASA Special Publication 8007 Update Team - In recognition of outstanding dedication, engineering excellence, and technical knowledge in completing major modernization and revision to NASA Special Publication 8007

Triethylaluminum-Triethylborane (TEA-TEB) Combustion in Oxygen Assessment Team - In recognition of exemplary contributions to the development of a novel method of testing pyrophorics and generating a unique TEA-TEB data set

TECHNICAL PAPERS, CONFERENCE PROCEEDINGS, AND TECHNICAL PRESENTATIONS

AEROSCIENCES

1. Ivanco, T.; Keller, D.; and Pinkerton, J.: Wind-Tunnel to Full-Scale Mapping of Winds and Loads for Launch-Vehicle Ground Wind Loads. 10.2514/6.2021-1072, AIAA SciTech 2021 Forum, January 11-15 and 19-21, 2021, virtual.
2. Schuster, D.: CFD 2030 Grand Challenge: CFD-in-the-Loop Monte Carlo Simulation for Space Vehicle Design.10.2514/6.2021-0957, AIAA SciTech 2021 Forum, January 11-15 and 19-21, 2021, virtual.

ENVIRONMENTAL CONTROL & LIFE SUPPORT

1. Abney, M.; McCarley, K.; Feather, M.; Campbell, C.; Williams, E.; Gazda, D.; Callahan, M.; Montgomery, E.; Delzeit, L.: Assessment of Biocide Impacts on Life Support and Extravehicular Activity Architectures. ICES-2021-47, 50th International Conference on Environmental Systems, July 12-15, 2021.
2. Abdou, J.; Lu, A.; Abney, M.; Delzeit, L.: Identification of the Chlorine- and Bromine-Based Biocides – Task 1 of the NESC Assessment of Biocide Impacts on Life Support and Extravehicular Activity Architectures. ICES-2021-29, 50th International Conference on Environmental Systems, July 12-15, 2021.
3. Broyan, J.; Shaw, L.; McKinley, M.; Meyer, C.; Ewert, M.; Schneider, W.; Meyer, M.; Ruff, G.; Owens, A.; Gatens, R.: NASA Environmental Control and Life Support Technology Development for Exploration: 2020 to 2021 Overview. ICES-2021-384, 50th International Conference on Environmental Systems, July 12-15, 2021.

GUIDANCE, NAVIGATION, & CONTROL

1. Bennani, S. and Dennehy, C.: Verification and Validation Challenges for Future Space Guidance, Navigation, & Control (GN&C) Systems. A Multi-Agency Workshop and Seminar Series – ESA and NASA Perspectives, September 15, 2020.
2. Dennehy, C.; Wolf, A.; Wu, A.; Chiang, R.; Stoneking, E,; and Ziemer, J.: Application of Micro-Thruster Technology for Space Observatory Pointing Stability. NASA/TM-20205011556/NESC-RP-18-01375, December 2020.
3. Dennehy, C.: Autonomous GN&C Technology for NASA's Next-Generation Missions: Drivers, Benefits, and Challenges. LSI Launch Event Presentation, March 3, 2021.
4. Dennehy, C.; Wolf, A.; and Swanson, D.: Spacecraft Line-of-Sight Jitter Mitigation and Management Lessons Learned and Engineering Best Practices. 11th International ESA Virtual Conference on Guidance, Navigation & Control Systems, June 24, 2021.
5. Wolf, A.; Dennehy, C.; Wu, A.; and Chiang, R.: Application of Micro-Thrusters for Space Observatory Precision Attitude Control. 11th International ESA Virtual Conference on Guidance, Navigation & Control Systems, June 20-25, 2021.
6. Lockard, A.; VanZwieten, T.; Mann, J.; Keenan, M.; Behrend, C.; and Connell, B.: NASA's Orion Crew Module Seakeeping Simulation and Test Comparisons in Ocean Wave Environments. OCEANS 2021, San Diego, CA.

LOADS & DYNAMICS

1. Johnson, A.; Doan, A.; Bremner, P.; Sills, J.; and Bruno. E.: Assessment of Artemis-1 Pogo Flight Instrumentation System. AIAA SciTech Forum, January 2021, virtual.
2. Kammer, D.; Blelloch, P.; and Sills, J.: SLS Integrated Modal Test Uncertainty Quantification using the Hybrid Parametric Variation Method. IMAC XXXIX, February 2021, virtual.
3. Kammer, D.; Blelloch, P.; and Sills, J.: Probability Bounds Analysis Applied to Multi-Purpose Crew Vehicle Nonlinearity. NASA/TM−20210013948, NESC-NPP-16-01110.
4. Sills, J.; Majed, A.; and Henkel, E.: A Flexible Multibody Approach to Space Launch System Liftoff Pad Separation with Umbilical Disconnect. AIAA SciTech Forum, January 2021, virtual.
5. Sills, J.; Majed, A.; and Henkel, E.: Fusion of Test and Analysis: Artemis I Booster to Mobile Launcher Interface Validation. IMAC XXXIX, February 2021, virtual.

MATERIALS

1. Glendening, A.; Russell, R.: NASA's Standards and Qualification for Additive Manufacturing. TRISMAC2021, 6th Trilateral Safety and Mission Assurance Conference, May 20, 2021.
2. Wells, D.; Glendening, A.; Cordner, S.; and Russell R.: Additive Manufacturing Design, Process and Quality Controls. Quality Leadership Forum, May 27, 2021.
3. Frazier, W., et. al.: Unleashing the Potential of Additive Manufacturing: FAIR AM Data Management Principles. AM&P, July/August 2021.
4. Hochhalter, J. and Paez, R.: Designing Validation Experiments: Combining Modeler and Experimentalist Perspectives. TMS VV&UQ Short Course, August 2021
5. Glass, D.: NASA Hypersonics Technology Project Research and Development on Advanced Carbon/Carbon-6. JANNAF Conference, December 2020.
6. Russell, R.: A Summary of NASA's Efforts for the Development and Certification and Qualification of Additively Manufactured Hardware. 16th European Conference on Spacecraft Structures, Materials and Environmental Testing, March 2021, virtual.
7. Russell, R.: Qualification and Certification Strategies for Additive Manufactured Parts for Manned Spaceflight. TMS EPD/MPMD Awards Ceremony, March 16, 2021.
8. Gumpinger, J.; Seifi, M.; Shamsaei, N.; Seidel, C.; Russell, R.: Recent Progress on Global Standardization. Book chapter.
9. Wells, D.: NASA's Implementation of Additive Manufacturing in Space Systems. U.S. Army AM Summit, June 2021, Auburn University.

MECHANICAL SYSTEMS

1. Miller, C.; DellaCorte, C.; and Zou, M.: Nanomechanical Properties of Hardened 60NiTi. Materials Science and Engineering, A, Volume 800, 2021, 140284.
2. Sean H. Mills, Christopher DellaCorte, Ronald D. Noebe, Behnam Amin-Ahmadi, Aaron P. Stebner, Rolling contact fatigue deformation mechanisms of nickel-rich nickel-titanium-hafnium alloys, Acta Materialia, Volume 209, 2021, 116784.
3. Mills, S.; DellaCorte, C.; Noebe, R.; Mills, M.; Stebner, A.; and Amin-Ahmadi, B.: Heat Treatment – Microstructure – Hardness Relationships of New Nickel-Rich Nickel-Titanium-Hafnium Alloys Developed for Tribological Applications. Materialia, Volume 16, 2021, 101064.
4. Hawkins, L.; Filatov, A.; Khatri, R.; DellaCorte, C.; and Howard, S.: Design of a Compact Magnetically Levitated Blower for Space Applications. Journal of Engineering for Gas Turbines and Power, Volume 143/09101-2.

NONDESTRUCTIVE EVALUATION

1. Koshti, A.; Parker, P.; Forsyth, D.; Suits, M.; Walker, J.; and Prosser, W.: Guidebook for Limited Sample Probability of Detection Demonstration for Single-Hit Nondestructive Evaluation Methods. NASA/TM-20210018515, July 2021.

PASSIVE THERMAL

1. Rickman, S. L.: Introduction to Orbits. Aerospace and Aviation Academy, June 27, 2021. Houston, TX.
2. Rickman, S.; Furst, B.; and Johnson, K.: Thermal Testing and Analysis Techniques for Wires and Wire Bundles. 8th European Thermal Sciences Conference, September 2021, virtual.

PROPULSION

1. Coutts, J.; Parker, D.; Dorney, D.; and McClure, M.: NASA State of Evaluation of High Purity Hydrazine and Monomethylhydrazine. JANNAF Paper, 68th JPM/PIB/15th MSS/12th LPS/11th SPS Joint Subcommittee Meeting, June 7, 2021.
2. Dorney, D.; McClure, M.; Ward, J.; Hamilton, S.; Wentzel, D.; and Dickens, K.: Effects of Helium Concentration on TEA-TEB Combustion in Oxygen, JANNAF Paper, 68th JPM/PIB /15th MSS/12th LPS/11th SPS Joint Subcommittee Meeting, June 8, 2021. NASA/TM-20210018852.
3. Hickman, H.; VanZwieten, T.; Youngquist, R.; Biagi, C.; Dorney, D.; Brown, A.; Wray, T.; Williams, R.; Guzik, M.; Nguyen, T.; Leidecker, H.; and Huang, Z.: Independent Assessment of Three Mass Gauging Technologies for Cryogenic Propellants in Microgravity. NASA/TM-20210018846.
4. DeSain, J. Brian, B. B., and Mueller, M. J.: Literature Review of Helium Solubility in Nitrogen Tetroxide and Monomethylhydrazine. Aerospace Corporation Report No. ATR-2021-01550, June 1, 2021.

SCIENCE

1. Valinia, A.; Dennehy, C.; Dube, M.; Gentz, S.; Kirsch, M.; Minow, J.; Pellicciotti, J.; Singh, U.; Wilson, T.: The Role of NASA Engineering and Safety Center (NESC) in Advancing NASA's Astrophysics Missions (Past, Present, and Future). Proc. SPIE 11443. Space Telescopes and Instrumentation 2020: Optical, Infrared, and Millimeter Wave. 1144308;

https://doi.org/10.1117/12.2575657, December 13, 2020.
2. Valinia, A.; Minow, J.; Pellish, J.; Allen, J.; Vera, A.; White, N.: Safe Human Expeditions Beyond Low Earth Orbit. NOAA Space Weather Workshop, April 20-22, 2021, virtual.
3. Valinia, A.: NESC Update, Lunar Surface Science Workshop: Progress and Challenges (Updates from NASA HQ and Artemis). April 29, 2021, virtual.
4. Valinia, A.: Preserving the Space Domain (Keynote Speech). MITRE Grand Challenges Power Hour, September 23, 2021, virtual.
5. Pham, T.; Ganel, O.; Valinia, A.; Siegler, N.; Crill, B.; and Perez, M.: Advances in Optical and Mechanical Technologies for Telescopes and Instrumentation IV. Volume: 11451, Pages: 1145107. Dec 13, 2020.

SOFTWARE

1. Prokop, L.; Dorney, D.; Feather, M.; and Johnson, S.: Case Studies in Verifying Spacecraft Autonomy. 2021 IEEE Aerospace Conference, March 6-13, 2021. Also accepted as a book chapter by Springer.

SPACE ENVIRONMENTS

1. Debchoudhury, S.; Barjatya, A.; Minow, J.; Coffey, V.; Chandler, M.: Comparison of Plasma Parameters at Solar Minima between Langmuir Probe Observations onboard International Space Station and IRI Empirical Model, Abstract SA010-000. 2020 Fall Meeting, American Geophysical Union, December 1 – 17, 2020, virtual.
2. Minow, J.: Solar Wind as a Space Radiation Environment. 43rd COSPAR Scientific Assembly, January 28 – February 4, 2021, Sydney, Australia (and virtual).
3. Zheng, Y.; Ganushkina, N.; Jiggens, P.; Jordanova, V.; Jun, I.; Meier, M.M.; Mann, I.; Minow, J.; O'Brien, P.; Pitchford, D.; Shprits, Y.; Tobiska, W.; Xapsos, M.; Rastaetter, L.; Kuznetsova, M.: Near-Earth Radiation and Plasma Environment Community Approach to Model Validation Regarding Impacts on (Aero)space Assets. 43rd COSPAR Scientific Assembly, January 28 – February 4, 2021, Sydney, Australia (and virtual).
4. Jun, I.; Guo, J.; Yao, Z.; Plainaki, C.: COSPAR ISWAT-H4: Space weather at planetary bodies in the Solar System, 43rd COSPAR Scientific Assembly, January 28 – February 4, 2021, Sydney, Australia (and virtual).
5. Bruzzone, J.; Weryk, R.; Janches, D.; Baumann, C.; Stober, G.; Hormaechea, J.: Observation of the A Carinid Meteor Shower Unexpected Outburst. The Planetary Science Journal, 2, 56, 2021; https://doi.org/10.3847/PSJ/abe9af.
6. Martinez-Sierra, L.; Jun, I.; Ehresmann, B.; Hassler, D.; Litvak, M.; Mitrofanov, I.; Zeitlin, C.: Mars Neutron Radiation Environment from HEND/Odyssey and DAN/MSL Observations. 2021 Lunar and Planetary Science Conference, March 2021, Woodlands, TX.
7. Parker, L.; Minow, J.; Pulkkinen, A.; St. Cyr, O.; Jun, I.; Semones, E.; Onsager, T.; Hock, R.; Mertens, C.; Allen, J.; Fry, D.: Space Weather Architectures for NASA Missions. Heliophysics 2050, May 2021, virtual.
8. Minow, J.; Janches, D.; Jun, I.; Matney, M.; Parker, L.: NESC Space Environment Activities. SCAF 2021 Virtual Workshop, May 11-12, 2021, virtual.
9. Mertens, C.; Gronoff, G.; Zheng, Y.; Buhler, J.; Willis, E.; Jun, I.; Minow, J.: NAIRAS Model Characterization of the LEO Environment for the Assessment of SEE Radiation Risks. SEE Symposium and MAPLD Workshop, August 31-September 2, 2021, virtual.
10. Minow, J.; Parker, L.; Mertens, C.; Allen, J.; Fry, D.; Semones, E.; Hock, R.; Jun, I.; Onsager, T.; Pulkkinen, A.; St. Cyr, C.: An Assessment of Space Weather Architectures to Support Deep Space Exploration. SEE Symposium and MAPLD Workshop, August 31-September 2, 2021, virtual.
11. Debchoudhury, S.; Barjatya, A.; Minow, J.; Coffey, V.; Chandler, M.: Observations and Validation of Plasma Density, Temperature, and O+ Abundance from a Langmuir Probe Onboard the International Space Station. Journal of Geophysical Research, https://doi.org/10.1029/2021JA029393, 2021.
12. Panka, P.; Weryk, R.; Bruzzone, J.; Janches, D.; Schult, C.; Stober, G.; Hormaechea, J.: An Improved Method to Measure Head Echoes Using a Meteor Radar. The Planetary Science Journal, 2, 197, https://iopscience.iop.org/article/10.3847/PSJ/ac22b2, 2021.

STRUCTURES

1. Kenneth R. Hamm, K.; Imtiaz, K.; Raju, I.: Some Remaining Challenges in Aerospace Structures. AIAA SciTech 2021,10.2514/6.2021-0574, January 2021.

SYSTEMS ENGINEERING

1. Palma, G.; Mesmer, B.; Guerin, A.; Weger, K.: Identifying Multidisciplinary Metrics to Analyze NASA Case Studies. IEEE Transactions on Professional Communication, June 2021, Volume 64, Issue 2, p. 170-184.
2. Lambe, L.; Watson, M.; Camberos, J.; Mesmer, B.; Johnson, S.: Category Theory for Engineers and Scientists. Submitted to IEEE Journal of Systems Engineering in September 2020.
3. Eaton, C.; White, C.; Mesmer, B.: Comparing Formation Methods for Value Models for the NASA Artemis Human Landing System. AIAA SciTech 2021, January 2021, virtual.
4. Banks, A.; Matsuyama, L.; Eaton, C.; Palma, G.; Guerin, A.; Mesmer, B.; Weger, K.; Friedrich, D.: The Truth is Out There: Insights from Improv with NASA. AIAA SciTech 2021, January 2021, virtual.
5. Eaton, C.; McGukin, R.; Gearhardt, L.; Mesmer, B.; Weger, K.: Using a Failure Classification Scheme to Better Understand NASA Case Studies. UAH Research Horizons, March 2021, virtual.
6. Driscoll, A.: Debunking Stress Rupture Theories Using Weibull Regression Plots. DATAWorks, April 12-14, 2021.
7. Womack, J.: Computing Risk of Pyrotechnic Devices Using Lot Acceptance Testing. Military Operations Research, Vol 26, No. 1, pp. 1-20.

NASA TECHNICAL MEMORANDUMS

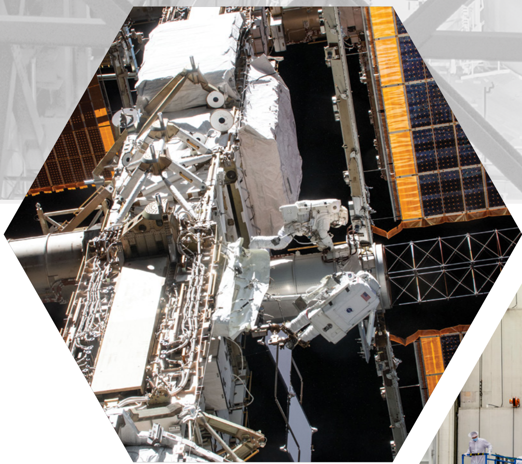
1. NASA/TM-20205008777 Cryogenic Technologies for the Stratospheric Observatory for Infrared Astronomy Science Instruments
2. NASA/TM-20205011556 Application of Micro-Thruster Technology for Space Observatory Pointing Stability
3. NASA/TM-20205011566 Cyclomatic Complexity & Basis Path Testing Study
4. NASA/TM-20205011579 Recommendations on Use of Commercial-Off-The-Shelf Electrical, Electronic, and Electromechanical Parts for NASA Missions
5. NASA/TM-20210009638 NASA Engineering and Safety Center Technical Bulletins 2007-2020
6. NASA/TM-20210009713 Space Launch System Core Stage Debris Footprint Analysis: Artemis I Flight Readiness Analysis Cycle 1
7. NASA/TM-20210009733 NESC Peer Review of Exploration Systems Development Integrated Vehicle Modal Test, Model Correlation, Development Flight Instrumentation and Flight Loads Readiness; Uncertainty Propagation for Model Validation Sub-task
8. NASA/TM-20210013644 Assessment of Biocide Impacts on Life Support and Extravehicular Activity Architectures
9. NASA/TM-20210013653 Reference Architecture for the International Space Station and Exploration Extravehicular Activity Power System
10. NASA/TM-20210013869 Risk Reduction of Orion Multi-Purpose Crew Vehicle Program Government-Furnished Equipment for Environmental Control and Life Support
11. NASA/TM-20210013948 Probability Bounds Analysis Applied to Multi-Purpose Crew Vehicle Nonlinearity
12. NASA/TM-20210014622 Improvements to the Flight Analysis and Simulation Tool and Initial Development of the Genesis Flight Mechanics Simulation for Ascent, Aerocapture, Entry, Descent, and Landing Trajectory Design
13. NASA/TM-20210015074 Space Launch System Liftoff Clearance: Artemis I Flight Readiness Analysis Cycle 0
14. NASA/TM-20210017871 Spacecraft Line-of-Sight Jitter Management and Mitigation Lessons Learned and Engineering Best Practices
15. NASA/TM-20210017934 Arecibo Observatory Auxiliary M4N Socket Termination Failure Investigation
16. NASA/TM-20210018053 Avionics Radiation Hardness Assurance Guidelines
17. NASA/TM-20210018458 Guidance and Lessons Learned from COVID-19 for Human-Subjects Research
18. NASA/TM-20210018515 Guidebook for Limited Sample Probability of Detection Demonstration for Single-Hit Nondestructive Evaluation Methods
19. NASA/TM-20210018831 Climate Absolute Radiance and Refractivity Observatory Pathfinder Flex Harness Cable Technical Assessment
20. NASA/TM-20210018846 Independent Assessment of Three Mass Gauging Technologies for Cryogenic Propellants in Microgravity
21. NASA/TM-20210018852 Effects of Helium Concentration on Triethylaluminum-Triethylborane Combustion in Oxygen
22. NASA/TM-20210018863 Independent Reliability Assessment of the NASA GSFC Laser Transmitter for the LISA Program
23. NASA/TM-20210018900 Understanding Pilot Breathing - A Case Study in Systems Engineering
24. NASA/TM-20210021650 Probability Bounds Analysis Applied to Multi-Purpose Crew Vehicle (MPCV) Nonlinearity

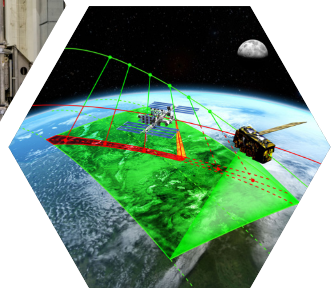
3-D	Three Dimensional
AA	Ascent Abort
AACT	Agency Additive Manufacturing (AM) Certification Support Team
ACCP	Aerosols and Cloud-Convection Precipitation
AFRC	Armstrong Flight Research Center
AFRL	Air Force Research Laboratory
Ah	Amp Hour
AI	Artificial Intelligence
AIAA	American Institute of Aeronautics and Astronautics.
AM	Additive Manufacturing
AMCP	Additive Manufacturing Control Plan
ARC	Ames Research Center
ARMD	Aeronautics Research Mission Directorate
ATCS	Active Thermal Control System
ATD	Anthropomorphic Test Device
AWE	Advanced Weapons Elevator
BON	Badhwar-O'Neill
BPT	Basis Path Testing
BSD	Breathing Sequence Disruptions
CBA	Contingency Breathing Apparatus
CC	Cyclomatic Complexity
CCP	Commercial Crew Program
CCRS	Capture, Containment, and Return System
CFD	Computational Fluid Dynamics
CLARREO	Climate Absolute Radiance and Refractivity Observatory
CLPS	Commercial Lunar Payload Services
CM	Crew Module
CNES	Centre National d'Etudies Spatiales
CO_2	Carbon Dioxide
COG	Ceramic Oxygen Generator
COPV	Composite Overwrapped Pressure Vessel
COTS	Commerical off the Shelf
COTS	Commercial Orbital Transportation Services
CPV	Composite Pressure Vessel
CT	Computed Tomagraphy
CYGNSS	Cyclone Global Navigation Satellite System
D&C	Design and Construction
DAF	Design Amplification Factor
DARPA	Defense Advanced Research Projects Agency
DCR	Design Certification Review
DFI	Development Flight Instrumentation
DLR	Deutsches Zentrum für Luft und Raumfahrt
DoD	Department of Defense
DOLILU	Day-of-Launch Initialization Load Update
DSCOVR	Deep Space Climate Observatory
DTA	Debris Transport Analysis
EAC	Environmentally Assisted Cracking
EATCS	External Active Thermal Control System
ECLS	Environmental Control & Life Support
ECLSS	Environmental Control & Life Support System
EDL	Entry, Descent, and Landing
EEE	Electrical, Electronic, and Electromechanical
EEEE	Electrical, Electronic, Electromechanical, and Electro-Optical
EEV	Earth Entry Vehicle
EFCP	Equipment and Facility Control Plan
EGS	Exploration Ground Systems
EM	Energy Modulators
EMU	Extravehicular Mobility Unit
EPA	Environmental Protection Agency
EPIC	European Photon Imaging Camera
ESA	European Space Agency
ESD	Exploration Systems Development
ESDMD	Exploration Systems Development Mission Directorate
ESM	European Service Module
EUS	Exploration Upper Stage
EVA	Extravehicular Activity
FAST	Flight Analysis and Simulation Tool
FGB	Functional Cargo Block
FEM	Finite Element Model
FPMU	Floating Potential Measurement Unit
FPS	Frames Per Second
FTS	Flight Termination System
FUN3D	Fully Unstructured Navier-Stokes Three-dimensional [CFD code]
g	Gravity
GCR	Galactic Cosmic Rays
GG	Gas Generator
GNC	Guidance, Navigation, & Control
GRC	Glenn Research Center
GSFC	Goddard Space Flight Center
H2	Hydrogen
HH	Hydrazine Hydrate
HDBK	Handbook
HLS	Human Landing Systems
HPH	High-Purity Hydrazine
HQ	Headquarters
HSF	Human Space Flight
HST	Hubble Space Telescope
HV	High Voltage
HVI	Hypervelocity Impact
ICEE	ISS Cryogenic External Experiment
ICESat-II	Ice, Cloud, and Land Elevation Satellite
ICPS	Interim Cryogenic Propulsion Stage
IEEE	Institute of Electrical and Electronics Engineers
IH	Integrated Hazards
IMU	Inertial Measurement Unit
IRD	Interface Requirements Document
ISS	International Space Station
JPL	Jet Propulsion Laboratory
JPSS	Joint Polar Satellite System
JSC	Johnson Space Center
JWST	James Webb Space Telescope
KSC	Kennedy Space Center
L&D	Loads and Dynamics
LaRC	Langley Research Center
LEFM	Linear Elastic Fracture Mechanics
LEO	Low Earth Orbit
LF	Low Flow
LH2	Liquid Hydrogen
Li-ion	Lithium-Ion
LISA	Laser Interferometer Space Antenna
LLIS	Lessons Learned Information System
LOX	Liquid Oxygen
LSP	Launch Services Program
LSTC	Livermore Software Technology Company
MAV	Mars Ascent Vehicle
MBSE	Model-Based Systems Engineering
MCOG	Medical Ceramic Oxygen Generator
MD	Mission Directorate
MEAL	Mission, Environment, Application, and Lifetime
MEK	Methyl Ethyl Ketone
MEMS	Microelectromechanical Systems
MEOP	Maximum Expected Operating Pressure
MIL-PRF	Military Performance Specification
MIMU	Miniature Inertial Measurement Unit
ML	Mobile Launcher
MMH	Monomethyl Hydrazine
MMOD	Micrometeoroid and Orbital Debris
MON	Mixed Oxides of Nitrogen
MOWG	Mission Operations Working Group
MPCV	Multi-Purpose Crew Vehicle
MPS	Material Properties Suite
MPV	Metallic Pressure Vessel
MSFC	Marshall Space Flight Center
MSR	Mars Sample Return
MTSO	Management and Technical Support Office
N2	Nitrogen
N2O4	Nitrogen Tetroxide
NAFTU	NASA Automated Flight Termination Unit
NASA	National Aeronautics and Space Administration
NCE	NESC Chief Engineer
NDE	Nondestructive Evaluation
NDL	Navigational Doppler Lidar
NDSB2	NASA Docking System Block 2
NESC	NASA Engineering and Safety Center
NIO	NESC Integration Office
NISAR	NASA-Indian Space Research Organisation Synthetic Aperture Radar
NREL	National Renewable Energy Laboratory
NRB	NESC Review Board
NSF	National Science Foundation
NTO	Nitrogen Tetroxide
O_2	Oxygen
OCE	Office of the Chief Engineer
OCI	Ocean Color Instrument
OLTF	Open Loop Transfer Function
ONERA	Office National d'Etudes et de Recherches Aerospatiales
OP	Occupant Protection
OPFE	Orion Portable Fire Extinguisher
OSAM	On-Orbit Servicing, Assembly, and Manufacturing
OSEF	Orion Smoke Eater Filter
PAMELA	Payload for Antimatter Matter Exploration and Light-Nuclei Astrophysics
PBA	Pilot Breathing Assessment
PCRD	Process Control Reference Distribution
PE	Principal Engineer
PFM	Pathfinder Mission
PID	Proportional Integral-Derivative
POD	Probability of Detection
PPE	Power and Propulsion Element
PPP	Part Production Plans
QMP	Qualified Metallurgical Process
QMS	Quality Management System
QPP	Qualified Part Process
R&D	Research and Development
RA	Reference Architecture
RF	Radio Frequency
RHA	Radiation Hardness Assurance
RP	Rocket Propellant
S&I	Sensors and Instrumentation
SADA	Solar Array Drive Assembly
SEE	Single-Event Effects
SE&I	Systems Engineering and Integration
SET	Systems Engineering Team
S-FTRC	Small Cell Fractional Thermal Runaway Calorimeter
SLS	Space Launch System
SMA	Safety and Mission Assurance
SMAP	Soil Moisture Active and Passive
SMD	Science Mission Directorate
SME	Subject Matter Expert
SOMD	Space Operations Mission Directorate
SPC	Statistical Process Control
SSC	Stennis Space Center
SSP	Space Shuttle Program
STD	Standard
STMD	Space Technology Mission Directorate
SWME	Space Suit Water Evaporator Membrane
TB	Technical Bulletin
TDT	Technical Discipline Team
TEA-TEB	Triethylaluminum-Triethylborane
TFAWS	Thermal and Fluids Analysis Workshop
Ti-NTO	Titanium/Nitrogen Tetroxide
TLYF	Test Like You Fly
TM	Technical Memorandum
TR	Thermal Runaway
TRA	Technical Readiness Assessment
TRADES	TRAnsformative DESsign
UCF	University of Central Florida
UF	University of Florida
US	United States
USAF	United States Air Force
USN	United States Navy
V&V	Verification and Validation
VITAL	Ventilator Intervention Technology Accessible Locally
WFF	Wallops Flight Facility
WSTF	White Sands Test Facility
xEMU	Exploration Extravehicular Mobility Unit
xEVA	Exploration Extravehicular Activity
XSP	Experimental Space Plane

NASA ENGINEERING & SAFETY CENTER

10

ENGINEERING EXCELLENCE





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