National Aeronautics and Space Administration

NESC TECHNICAL UPDATE

Annual Summary of 2022 Technical Activities

NASA ENGINEERING & SAFETY CENTER

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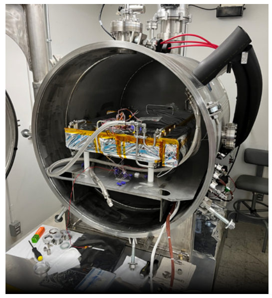


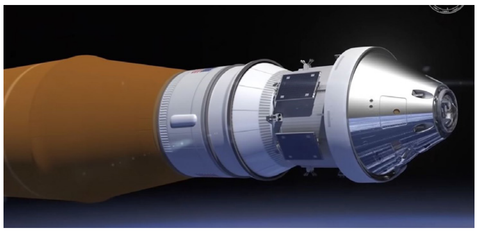
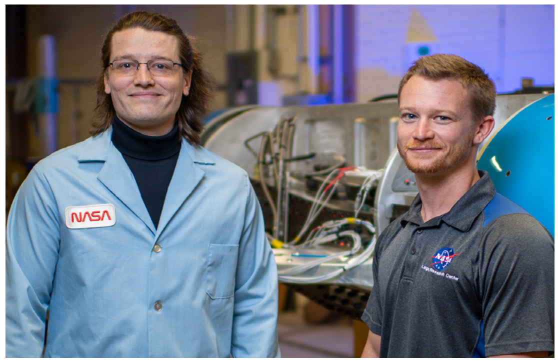






Except where noted, all photographs and illustrations are NASA images.

ON THE COVER

Front: Launch of Artemis I, November 16, 2022
Back: Orion approaches the Moon for outbound powered flyby during the Artemis I mission, November 21, 2022

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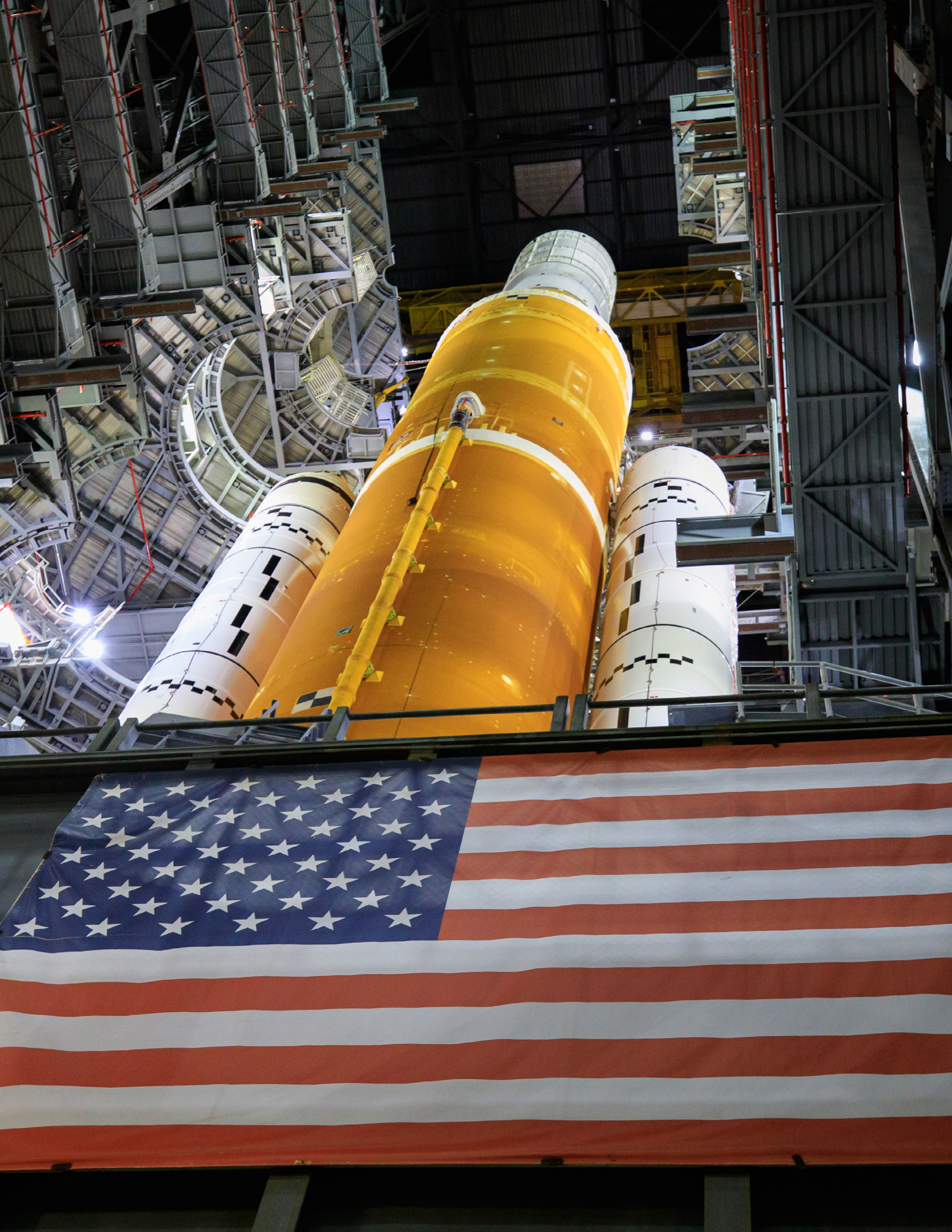
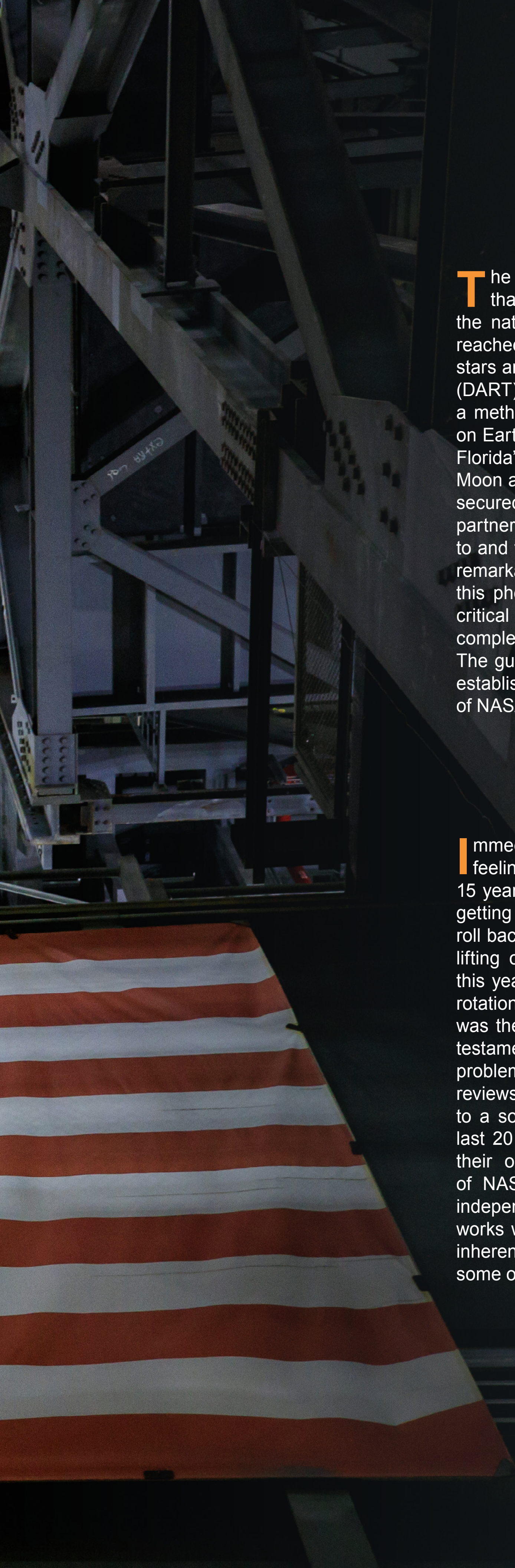




The NASA team has many reasons to celebrate this year, reaching milestones that were years and even decades in the making – achievements that captivated the nation, as well as the world. The James Webb Space Telescope (JWST) reached deep into the history of the universe, sending back images filled with stars and galaxies never before visible. And the Double Asteroid Redirection Test (DART) demonstrated that we could redirect an asteroid into a new orbit, offering a method of planetary defense against objects that could threaten our life here on Earth. The successful launch of Artemis I, which set alight the night sky along Florida's east coast, marked NASA's monumental first step in returning us to the Moon and forward to Mars. While our Perseverance Rover secured samples of the red planet for return, our commercial partners continued to successfully transport our astronauts to and from the International Space Station (ISS). It was a remarkable year for science and space travel. Throughout this phenomenal year, the NESC provided expertise and critical support to these programs and projects whenever complex, technical questions needed quick resolutions. The guidance and engineering rigor provided by this well-established Agency resource were essential to the success of NASA's accomplishments in 2022.

ROBERT D. CABANA

NASA ASSOCIATE ADMINISTRATOR

Immediately following the Artemis launch in November, I was left with a spectacular feeling of pride thinking about the countless numbers of people who worked for 15 years to design, build and test this rocket and spacecraft. Their dedication in getting us back to the Moon never wavered even after multiple launch attempts, a roll back due to a hurricane, and enduring another storm at the pad before finally lifting off to the moon. And Artemis was not NASA's only successful mission this year—JWST, DART, collecting samples from Mars, multiple crew and cargo rotations to the ISS—the list is astounding. Contributing to each of those missions was the NESC. The organization completed its 1,000th assessment this year, a testament to the value they bring to solving NASA's most challenging technical problems. All of the Agency's programs have benefited from NESC independent reviews, tests, and analyses that have either reinforced a program's approach to a solution or helped them find a better one. Over the last 20 years, the NESC has proven time and again that their operational model—assembling specialized teams of NASA, industry, and academia expertise to provide independent, unbiased perspectives—is an approach that works well and has helped NASA mitigate the many risks inherent to spaceflight. This Technical Update highlights some of the NESC's contributions to the Agency in 2022.

RALPH R. ROE, JR.

NASA CHIEF ENGINEER

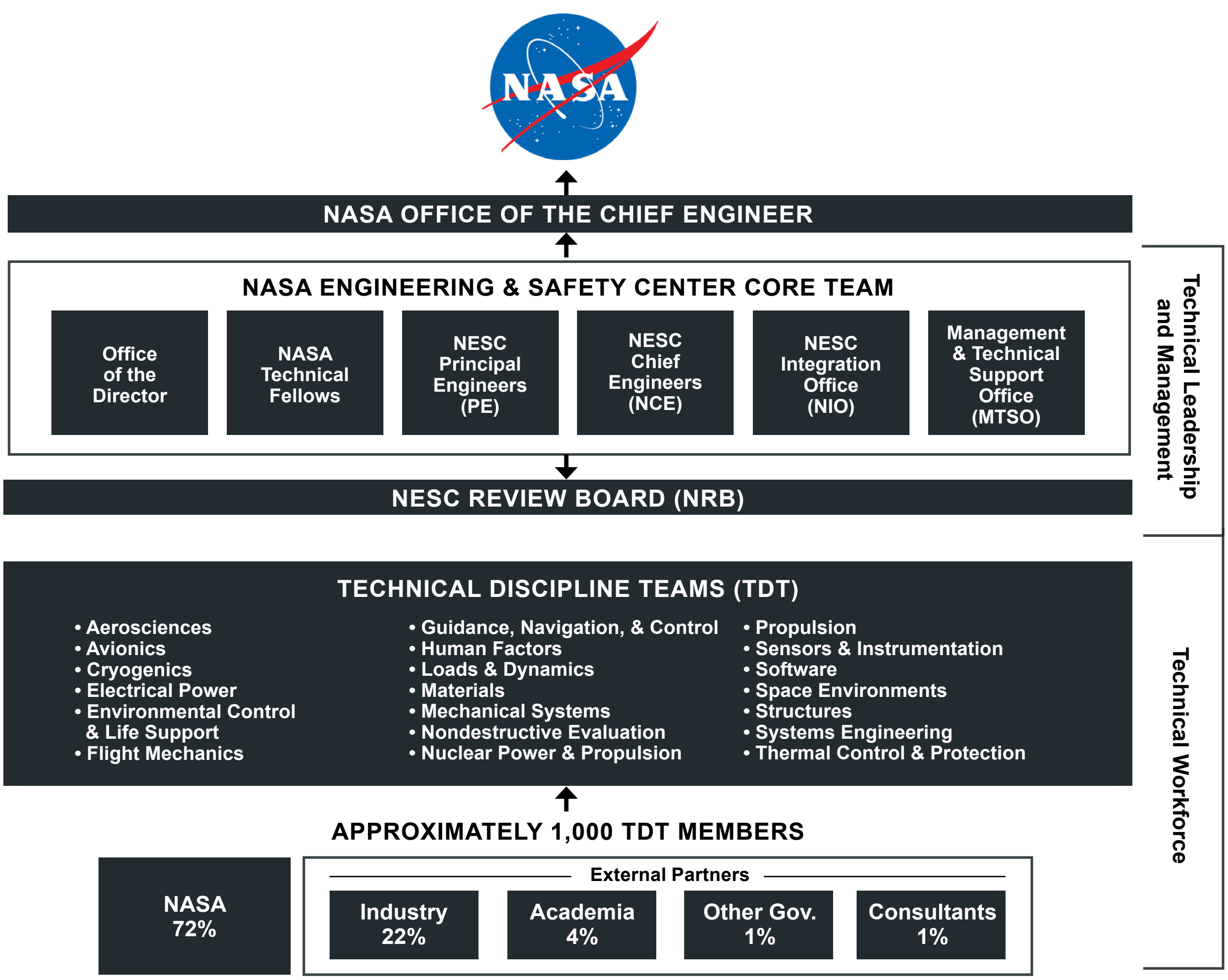
NASA ENGINEERING & SAFETY CENTER

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 also 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 within NASA, industry, academia, and other government agencies. Collaborating with leading engineers allows the NESC to consistently optimize processes, strengthen technical capabilities, and broaden perspectives. This practice further reinforces the NESC's commitment to engineering excellence.

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



NESC Members
May 2022

1,000TH ASSESSMENT COMPLETED
September 2022

This marks 1,000 times that Agency-wide teams have pooled their expertise to address NASA's most challenging technical problems—across all NASA mission directorates—to help ensure safety and mission success.

MESSAGE FROM NESC DIRECTOR

The year 2022 was a busy and rewarding one for NASA. The most powerful space telescope ever constructed began capturing new views of the universe. A Mars rover collected soil samples and is keeping them safe for a future delivery back to Earth. Commercial spacecraft continued to safely fly astronauts to the ISS and back. A controlled impact into an asteroid demonstrated techniques that may one day be used to protect the Earth. And NASA's Artemis Program took one giant step toward returning humanity to the Moon—and on to Mars.

This NESC Technical Update shines a light on a few of the people who have contributed to these and the other successes of the past year.

These people are members of the NESC's extended team of experts that support assessment teams addressing NASA's most difficult problems. They represent a broad range of knowledge and experience—from a 40-year veteran using decades of charting the meteoroid environment to an early-career engineer installing strain sensors on the heat shield of a commercial partner's spacecraft. They also come from industry, academia, and other government agencies. Together, they fulfill the NESC mission to ensure safety by bringing those who have a technical problem in contact with those who can help find a solution.

This year's Technical Update provides a glimpse into some of the 162 open technical assessments and support activities underway and the 65 that have been completed this year. The activities span all of NASA's mission directorates and touch every Center. The unique nature of the NESC and its reporting hierarchy allows the work performed by the NESC to remain independent of other engineering and programmatic organizations.

The NESC has established a successful framework and fostered the reputation for engineering excellence that will allow it to continue to play an important role in NASA accomplishments yet to be achieved or even imagined.

OFFICE OF THE DIRECTOR


Timmy R. Wilson
NESC Director


Michael T. Kirsch
NESC Deputy Director


Mary Elizabeth Wusk
NIO Manager


Lisa McAlhaney
MTSO Manager

Vacant
NESC Deputy Director for Safety


Dr. Azita Valinia
NESC Chief Scientist

NESC PRINCIPAL ENGINEERS


Clinton H. Cragg
LaRC


Jon P. Haas
JSC/WSTF


Donald S. Parker
KSC


Michael D. Squire
LaRC

NESC CHIEF ENGINEERS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ARC


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AFRC


Robert S. Jankovsky
GRC

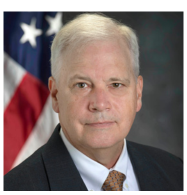

Carmel A. Conaty
GSFC

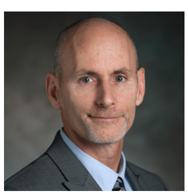

Kimberly A. Simpson
JPL


Joel W. Sills
JSC


Stephen A. Minute
KSC

NASA TECHNICAL FELLOWS


Dr. David M. Schuster
Aerosciences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Avionics


Michael L. Meyer
Cryogenics


Dr. Christopher J. Iannello
Electrical Power


Dr. Morgan B. Abney
Environmental Control & Life Support


Heather M. Koehler
Flight Mechanics


Cornelius J. Dennehy
Guidance, Navigation, & Control


D


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Nondestructive Evaluation


Dr. Jonathan E. Jones
Propulsion


Dr. Upendra N. Singh
Sensors & Instrumentation


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Software


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Space Environments


Kauser S. Imtiaz
Structures

NESC LEADERSHIP

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NESC Chief Astronaut

LIASONS

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Office of the Chief Health and Medical Officer (OCHMO)

Glen W. Lockwood
Office of Safety and Mission Assurance (OSMA)

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LaRC

Steven J. Gentz
MSFC

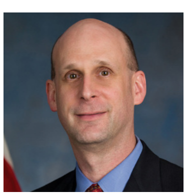
Michael D. Smiles
SSC

Dr. Cynthia H. Null
Human Factors

Dr. Dexter Johnson
Loads & Dynamics

Richard W. Russell
Materials

Jon B. Holladay
Systems Engineering



Steven L. Rickman
Thermal Control & Protection

Scan for
NESC LEADERSHIP BIOS

ALUMNI

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

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

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

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

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

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

Steven F. Cash
MSFC NCE (2005)

Derrick J. Cheston
GRC NCE (2003-07)

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

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

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

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

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

Freddie Douglas, III
SSC NCE (2007-08)

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

Dawn C. Emerson
GRC NCE (2011-14)

Walter C. Engelund
LaRC NCE (2009-13)

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

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

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

T. Randy Galloway
SSC NCE (2003-04)

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

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

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

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

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

Michael Hagopian
GSFC NCE (2003-07)

David A. Hamilton
JSC NCE (2003-07)

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

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

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

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

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

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

George L. Jackson
GSFC NCE (2015-18)

Danny D. Johnston
MSFC NCE (2003-04)

Michael W. Kehoe
DFRC NCE (2003-05)

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

R. Lloyd Keith
JPL NCE (2007-16)

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

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

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

Nans Kunz
ARC NCE (2009-15)

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

Matthew R. Landano
JPL NCE (2003-04)

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

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

Richard T. Manella
GRC NCE (2009-10)

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

Brian K. Muirhead
JPL NCE (2005-07)

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

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

Stan C. Newberry
MTSO Manager (2003-04)

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

Fernando A. Pellerano
GSFC NCE (2018-21)

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

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

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

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

Paul W. Roberts
LaRC NCE (2016-19)

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

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

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

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)

T. Scott West
JSC NCE (2012-20)

Barry E. Wilmore
NESC Chief Astronaut (2017-20)

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

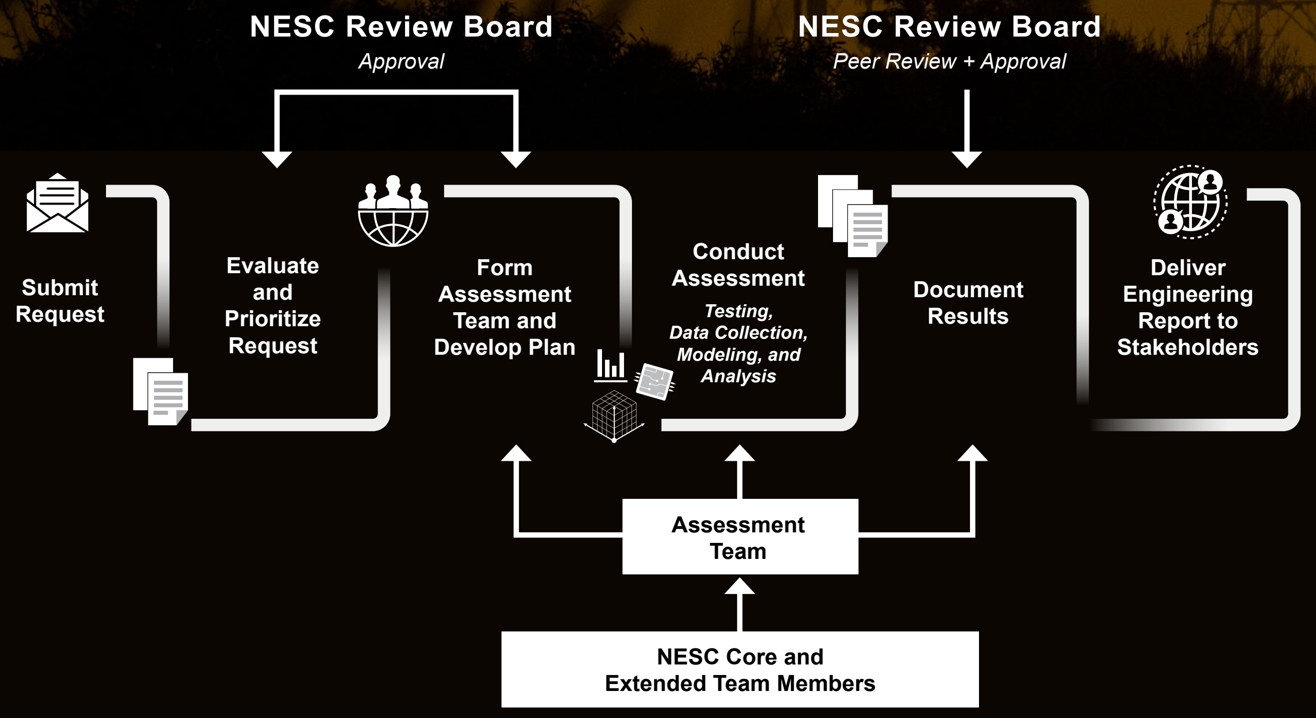
ASSESSMENTS & SUPPORT ACTIVITIES

1,162 ACCEPTED REQUESTS SINCE 2003 • 74 IN FY22

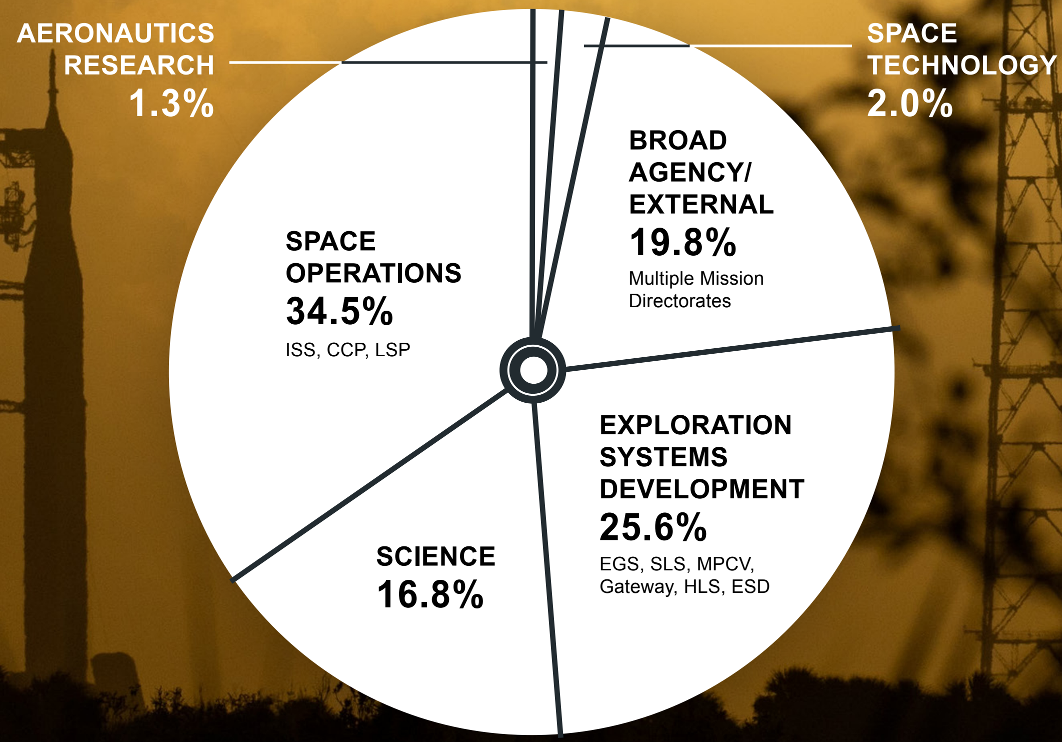
ASSESSMENTS *typically include independent testing and/or analyses, the results of which are peer reviewed by the NESC Review Board and documented in engineering reports.*

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

NESC ASSESSMENT PROCESS



The NESC assessment process is key to developing peer-reviewed engineering reports for stakeholders. Requests for technical assistance are evaluated by the 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.

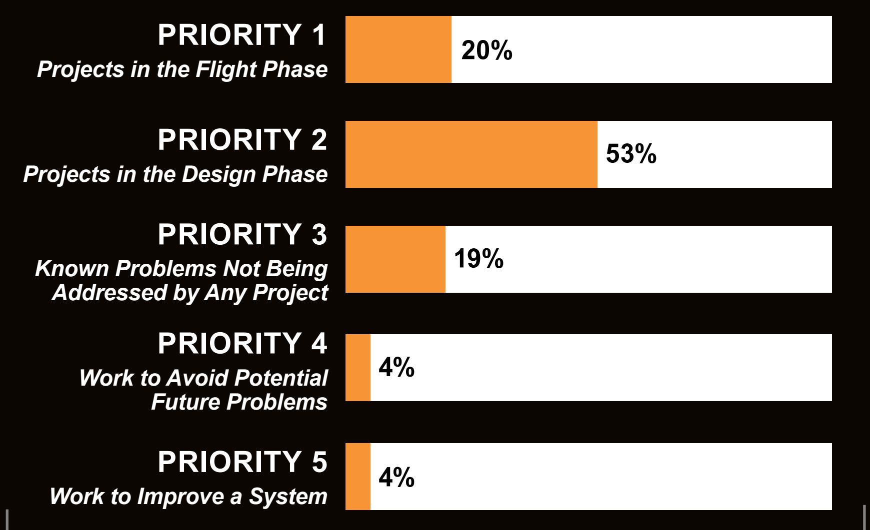


NESC ACTIVITIES SUPPORT ALL MISSION DIRECTORATES

ACCEPTED REQUESTS BY MISSION DIRECTORATE

FY18 - FY22

NESC ACTIVITIES ARE PRIORITIZED FROM 1 TO 5



162 IN-PROGRESS REQUESTS

REQUEST SUMMARY:

- 74 Accepted Requests in FY22
- 65 Completed Requests in FY22
- 1,162 Accepted Requests since 2003
- 1,000 Completed Requests since 2003

Data as of September 30, 2022

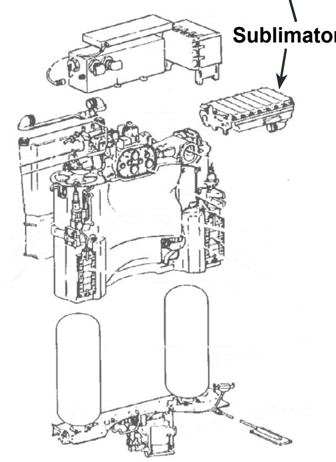
COMPLETED ASSESSMENTS IN FY22

PRIORITY 1: Projects in the Flight Phase

Inspecting EMUs for Sublimator Corrosion

Astronauts rely on extravehicular mobility units (EMU) for life support during extravehicular activities. In addition to key necessities like oxygen, water, and communications, EMUs also provide astronaut cooling using heat exchangers, also known as sublimators. Because the EMU sublimators at the ISS have been in use for decades, they can potentially be subject to corrosion. To determine a reliable inspection technique to locate areas of corrosion and help determine pass/fail criteria for flight, an NESC team reviewed sublimator data collected by JSC using digital radiography (DR) and computed tomography (CT), then selected a sublimator with known corrosion issues for inspection and destructive physical analysis (DPA).

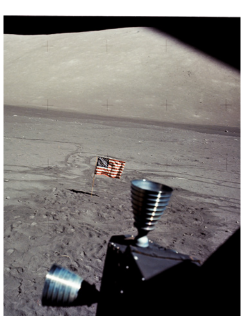
The team aimed to validate the DR/CT images with the DPA results, determine the internal conditions, and understand the types of potential corrosion mechanisms. The team also evaluated whether statistical correlations about life-of-use could be made from the original JSC DR/CT data. The team concluded that DR/CT was a reliable inspection technique and identified the need for enhanced inspections in specific areas. To determine pass/fail criteria, the team recommended collecting data during future inspections that could be used to identify any corrosion issues with on-orbit EMUs or determine when they should be retired from service. This work was performed by KSC, LaRC, JSC, and GSFC. NASA/TM-20220000586



The EMU sublimator removes heat from the water circulating through the astronaut's liquid cooling garment.

Effects of Pressure Spikes in Hypergolic Engines

Since the days of the Apollo Program, pressure spikes and transients have been an issue in propulsion systems using hypergolic propellants. The pressure spikes can occur in several areas of the engine, including fuel or oxidizer manifolds, combustion chambers, and instrumentation tubes, and have the potential to cause damage. During engine operation, spikes appear to be affected by operational and environmental variables. While many studies have been performed to determine their origin, historically, pressure spikes have been alleviated through operating modifications. Recently, the NESC conducted simulations and experiments to help isolate the origins of these spikes by performing detonation tube testing and Kolsky bar testing at Purdue University along with computational fluid dynamics and finite element modeling to determine their effects on hypergolic propellant thruster materials. The testing results provided data describing material capability to withstand a representative distribution of pressure spikes. This work was performed by MSFC, JSC, KSC, LaRC, GRC, ARC, WSTF, and Purdue University.

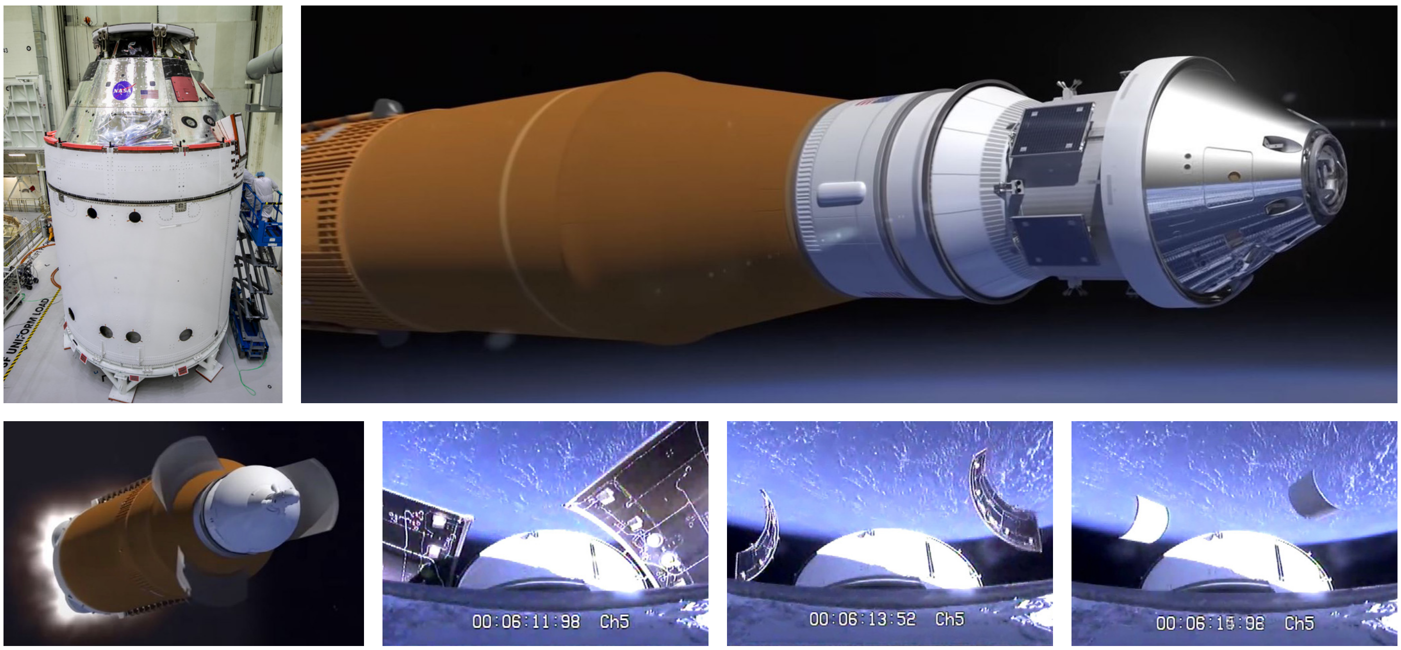


Examples of hypergolic engines used in reaction control systems (RCS).

From left: R-4D engines on an Apollo service module and lunar module, R-4D-11 engines on Orion's Artemis I service module, and Space Shuttle orbiter RCS engine.

Orion Frangible Joint Analysis

Leveraging the NESC's extensive study of frangible joints (FJ), an assessment team was able to provide the Artemis Program with a reliability analysis of the FJs used on the Orion spacecraft's service module (SM). The Orion SM is covered by three fairing panels that protect it during ascent, which are held in place with FJs. The FJs are pyrotechnically activated to jettison the panels when the spacecraft is out of the atmosphere to lighten the load. To understand the reliability of the SM panel FJs, the assessment team first developed a validated Orion FJ finite element model based on cases from the NESC's previous FJ empirical testing. Then Orion FJ data were gathered to construct statistical distributions of performance-affecting factors and related panel FJ sensitivities. The team then performed Monte Carlo analyses to understand reliability as well as the FJ hardware's ability to successfully separate in flight when commanded. This work was performed by JSC, WSTF, LaRC, and The Aerospace Corporation.



Top left: Panels integrated to Orion's service module for Artemis I. Top: Illustration of Artemis after panel jettison.
Bottom: Panel jettison concept (left) and jettison during Exploration Flight Test -1.

PRIORITY 1

IN-PROGRESS ASSESSMENTS

- Energy Modulator Extension Testing
- Peer Review of NTO-HFE Compatibility
- TPS Reuseability
- LOX-Methane QD and Safety
- Hardline O2 and Fire Response
- Cracked Samples for NDE Standards
- Capsule Dynamic Pitch Testing at Transonic Speeds
- ISS Universal Waste Management System Optical Sensor
- Examination of Space Vehicle Ethernet Interconnects
- ECLSS-ATCS Review
- Cross-Program Exposure Testing Review
- CCP Fracture Control Risk Reduction
- Hot Gas Intrusion in Engine Bays
- Fire Cartridge Investigation, Manufacturing, and Hardware Verification
- Ti-NTO Compatibility Cross-Program Impact and Lessons Learned
- Validation of ISS Lithium-Ion Main Battery's Thermal Runaway Mitigation Analysis and Design Features

COMPLETED SUPPORT ACTIVITIES

- CCP Engine Reuse Support
- Artemis I Wet Dress Rehearsals
- Support for Waste Management System Anomaly
- LF Regulator Debris Catcher Development
- Parachute Impact Damage Tolerance Evaluation - Phase 3
- CCP Launch Vehicle Orbital Tube Welding POD Study Samples
- ISS Battery Charge Discharge Unit Support
- Rapid Slews for Lunar Reconnaissance Orbiter

IN-PROGRESS SUPPORT ACTIVITIES

- Artemis I SCIFLI Imaging Support
- Artemis I SLS FTS Battery Waiver Rationale Development
- Artemis I SLS Cryo Servicing Team
- ISS Supplemental Heat Rejection Evaporative Cooler
- Parachute Impact Damage Tolerance Evaluation - Phase 4
- EVA Fan/Pump/Separator Mitigation
- Heatshield ATP
- CCP Engineering and Safety Review Efforts
- EMU Water Management
- U.S. EVA 80 Water in Helmet Investigation
- Support of LNG Detank Anomaly Investigation Team
- Materials Expertise for Lucy Project ART Kevlar Lanyard
- ISS FGB Air Leak

COMPLETED ASSESSMENTS IN FY22

PRIORITY 2: Projects in the Design Phase

Space Launch System Engine Launch Environments

Building on previous Space Launch System (SLS) launch environment assessments and in partnership with the SLS Program, the NESC evaluated the acoustic loads on the booster nozzle throat plug that could occur during an H2 pop event at core stage RS-25 engine start. An H2 overpressure “pop,” resulting from hydrogen combustion and expansion, can occur if the engines start in a fuel-rich state with a significant amount of hydrogen present in the engine nozzle. That pop could then produce substantial loads on the RS-25 engine, booster nozzle, booster plug, and nearby ground system components. Nozzle plugs in the solid rocket booster act as an environmental barrier, keeping heat, moisture, and dust from entering prior to ignition.

The evaluation’s objective was to refine the design load specification to reduce the booster-plug mass, thereby reducing the likelihood of booster-plug debris damage to the RS-25 and other SLS components. The refined launch environment was delivered to the SLS stakeholder and was included in the Launch Acoustics Environments Databook. In addition, a combined series of computational fluid dynamics and computational aeroacoustics simulations was used to develop the booster nozzle volume’s Acoustic Transfer Function (ATF), and subscale tests then validated the ATF prediction approach. This work was performed by LaRC, MSFC, and The University of Texas at Austin. NASA/TM-20220012197.

Top left: Booster throat plug visible prior to mating of aft skirt. Bottom and right: The solid rocket boosters and RS-25 engines operate in close proximity, creating a complex acoustic and debris environment.

Scale model of SLS Block 1 cargo configuration in the NTF test section at LaRC

Reynolds Number Effects on the SLS

During launch, the SLS will see rapidly changing flow physics as it accelerates from subsonic to supersonic speeds, called the transonic flight regime (near Mach 1.0). This is when the vehicle will experience maximum dynamic pressure and aerodynamic loads. Understanding the transonic flow physics is critical for ensuring successful launches, and the effect of Reynolds number on ascent aerodynamics has been an open question for the complex, multibody SLS launch vehicle.

The NESC led wind tunnel tests at the National Transonic Facility (NTF) at LaRC to investigate the SLS in the transonic regime. The NTF allowed the SLS model to experience higher Reynolds numbers than in other NASA wind tunnels, providing more flight-like results. The tests involved an internal six-component sting-mounted balance to measure aerodynamic forces and moments on the model as well as numerous pressure taps distributed across the surface. The results showed where the SLS solid rocket boosters were most sensitive to Reynolds number effects. These data would help verify and validate the computational fluid dynamics simulations. This work was performed by LaRC. NASA/TM-20220002215.

Modeling of ICPS Umbilical Lift-off Clearances

During lift-off, the clearance between the SLS vehicle and the mobile launcher (ML) tower is highly dynamic, in particular the clearance between the SLS and the interim cryogenic propulsion stage (ICPS) umbilical, which is located about 240 feet up on the ML tower. Positioned between the core stage and Orion, the ICPS provides propulsion for the translunar injection burn. The ICPS umbilical is one of a series of umbilical lines from the ML to the SLS that provide power, fuel, and communications until they are released at lift-off. The ICPS umbilical release, however, has complex kinematics that can result in a minimum clearance between the umbilical and SLS.

Using an NESC-developed flexible multibody framework for nonlinear liftoff simulations and leveraging knowledge gained during previous umbilical-related activities, an assessment team evaluated the Exploration Ground System (EGS) ICPS umbilical clearance models. By performing independent systems analysis and modeling of the ICPS umbilical-to-SLS interface, the team assisted EGS in the understanding of worst-case lift-off clearances. This work was performed by JSC, LaRC, KSC, GRC, and The Boeing Company. NASA/TM-20210022984.

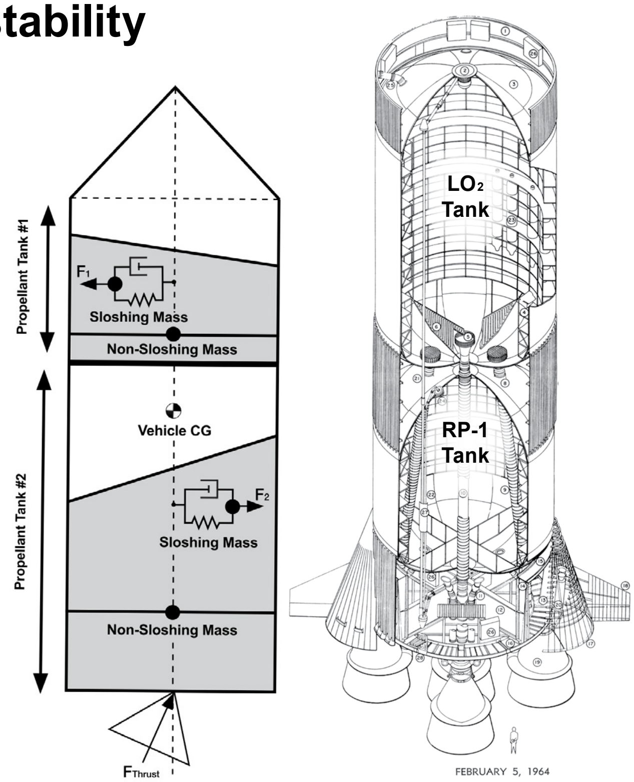
Above: ICPS mating with SLS core stage. Right: Multiple interfaces exist between the ML and the Artemis I vehicle. The crew access arm and Orion service module umbilical are located at 280 feet, the ICPS umbilical complex is next at 240 feet, followed by the vehicle stabilizer system and the core stage forward skirt umbilical at 200 and 180 feet, respectively.

Reducing Risk of Propellant Slosh Instability

The NESC began investigating proposed reductions in vehicle flight control system (FCS) stability margins and factors that can complicate stability margins—especially if reductions are proposed for crewed missions. During ascent, the FCS must handle anticipated disturbances while maintaining industry-accepted gain and phase margins. Liquid-fueled launch vehicles (LV) have the potential for slosh-induced instability if the propellant tanks are unbaffled.

The NESC team reviewed historical slosh margins for LV used for crewed spaceflight and compared post-flight data with pre-flight predictions to look for any indications of slosh instability during ascent. The team's perspective for crewed-flight FCS is that acceptance of flight control gain/phase stability margin reductions from industry standards should be accompanied by analyzing the fundamental physics involved using linear and nonlinear simulation tools; conducting sensitivity studies in both time and frequency domains to analyze effects of possible parameter and system variations; and studying the effects of instability associated with offending modes by running stressing cases in the time domain. Also, alternative FCS designs must be assessed to demonstrate that the design appropriately balances overall vehicle risk (i.e., quantitatively delineate chosen tradeoffs between various stability margins and LV performance in the context of risk/consequence).

This approach represents an example summary of expected engineering work to flight-certify crewed missions with unstable slosh modes and reduced stability margins. This work was performed by GSFC, KSC, MSFC, JPL, LaRC, Dynamic Concepts LLC, and Mclaurin Aerospace. NESC/TB-22-05, NESC/TB-22-06, NASA/TM-20220009857.



Slosh modeling is critical to determine FCS stability margins. The Saturn V first stage contained two liquid propellant tanks. A basic model to analyze the slosh dynamics is shown at left.

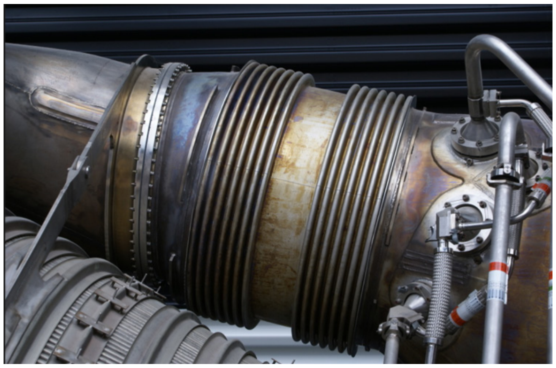
Flight Test to Improve Transonic Buffet Load Predictions

As an LV reaches the speed of sound during its ascent through the atmosphere, it experiences transonic aerodynamic buffet loads, often the largest contributor to the vehicle's structural loads. Overpredicting these loads can lead to a heavier-than-necessary structural design, while underpredicting them can lead to structural failure. The approach to buffet prediction has been limited to acquiring unsteady pressure data with a rigid model in a wind tunnel at steady Mach numbers, then assuming the loads will translate to a rapidly accelerating, flexible LV.

The NESC and NASA Sounding Rocket Program designed, built, and launched a unique sounding rocket payload to investigate this buffet phenomenon often encountered by LVs in a hammerhead configuration. The vehicle's Coe & Nute Model 11 hammerhead shape was derived from a previously tested and documented wind-tunnel model that included science instrumentation and data acquisition components, with multiple aerodynamic surface pressure measurements and other installed sensors throughout. The goal was to characterize its transonic environment at both accelerating and quasi-steady velocity conditions in flight. The data generated were compared to wind tunnel data at corresponding flight conditions, the results of which should help address the validity of historical assumptions LV designers used for predicting buffet loads. This work was performed by LaRC, WSTF, WFF, and ARC.

Top: Hammerhead shape test flight test article (from Coe & Nute Model 11, 1962). Bottom: Assembly, integration, and testing at the Wallops Flight Facility.

Detecting Flow-Induced Vibration in Bellows

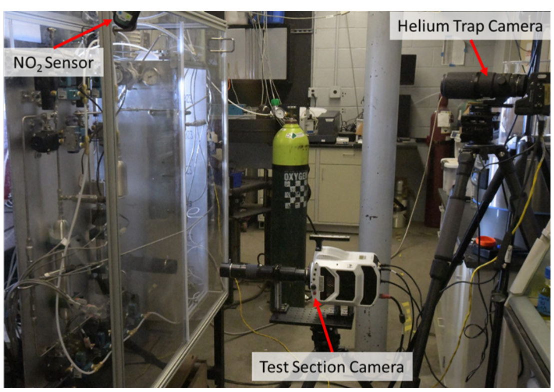


Example of rocket engine bellows

Extensive testing has provided proof-of-concept that motion magnification (MM) and digital image correlation (DIC) techniques can predict the onset of flow-induced vibration (FIV) in gimballed bellows. Bellows are used to connect systems/components in rocket engines while allowing for expansion or contraction associated with temperature variations and articulation due to engine gimbaling. FIV is caused by resonance generated through the coupling of vortex shedding from bellows convolutions with the flexible line natural structural frequencies. It has been implicated in in-flight engine shutdowns and ground-support equipment anomalies dating back to the Apollo Program. Existing methods used to predict FIV in bellows have not accounted for bends in bellows and flex lines from engine gimbaling, and complex hardware shapes reduce the reliability of strain gage measurements, particularly for gimbaled bellows.

The non-contact MM technique, which amplifies minute motions in a video sequence, can capture deformations that would otherwise be invisible. The method decomposes frames of high-speed digital video into local spatial amplitude and phase, assessing the spatial phase changes between images to detect small system motions to enhance motion visibility. DIC uses non-contact stereo imaging to extract displacements, strains, velocities, and accelerations. An NESC team instrumented a representative angulated bellows with strain gauges, microphones, and MM/DIC high-speed video cameras to detect the onset of FIV. The three measurement techniques showed the same dominant frequency for the onset of FIV. Although testing was limited to one single-ply unshielded bellows test sample, the effort provided proof-of-concept that MM and DIC are feasible methods for determining FIV onset. This work was performed by MSFC, SSC, and LaRC. NASA/TM-20220002233, NESC/TB-22-01.

Improved Characterization of Helium Evolution in Propellants



Helium solubility testing setup at Purdue University

One of the problems encountered in the development of liquid bipropellant rocket engines is the occurrence of low-frequency instabilities, some of which can lead to a an off-nominal, potentially damaging phenomenon referred to as chugging. Chugging is caused by a dynamic coupling of the propellant feed system with the combustion dynamics in such a way that it amplifies any disturbance in pressure or propellant flow. It has been demonstrated that chugging can be significantly affected by the propellant pressurant, specifically helium, transitioning into and out of solution. As pressure drop occurs through the feed system, helium will evolve back out of solution in bubble form, which can cause chugging.

An NESC-led team of NASA, university, and industry experts performed fundamental transient tests of helium evolution from mixed oxides of nitrogen (MON-3) and monomethylhydrazine (MMH) to develop a data set that can be used to anchor analytical modeling capabilities of the transitional phenomena. They first performed a literature search followed by a test program. The focus of the literature search was to find laboratory data where controlled experiments were performed for the purpose of quantifying helium going into solution of both MON-3 and MMH. Results of the literature search found that many of the documents containing data on helium evolution of both MON-3 and MMH were reprinted data that was obtained from other sources. Sorting through the reports allowed the original source data to be identified. The NESC test program, performed at Purdue University, determined the fundamental characteristics of the transient behavior of helium evolution from MON-3 and MMH. Testing focused on identifying when helium evolves out of solution and quantifying the amount that comes out of solution. The investigated pressure ranges enveloped most of the current and historic spacecraft that use hypergolic propellants.

The team provided the data describing the characteristics of helium evolution to programs using bi-propellant hypergolic engines. The information was also added to NASA Materials and Processes Technical Information System (MAPTIS) and provided to appropriate reference organizations. This work was performed by MSFC, GRC, JSC/WSTF, Purdue University, and The Aerospace Corporation. NASA/TM-20210023030, NESC/TB-22-07.

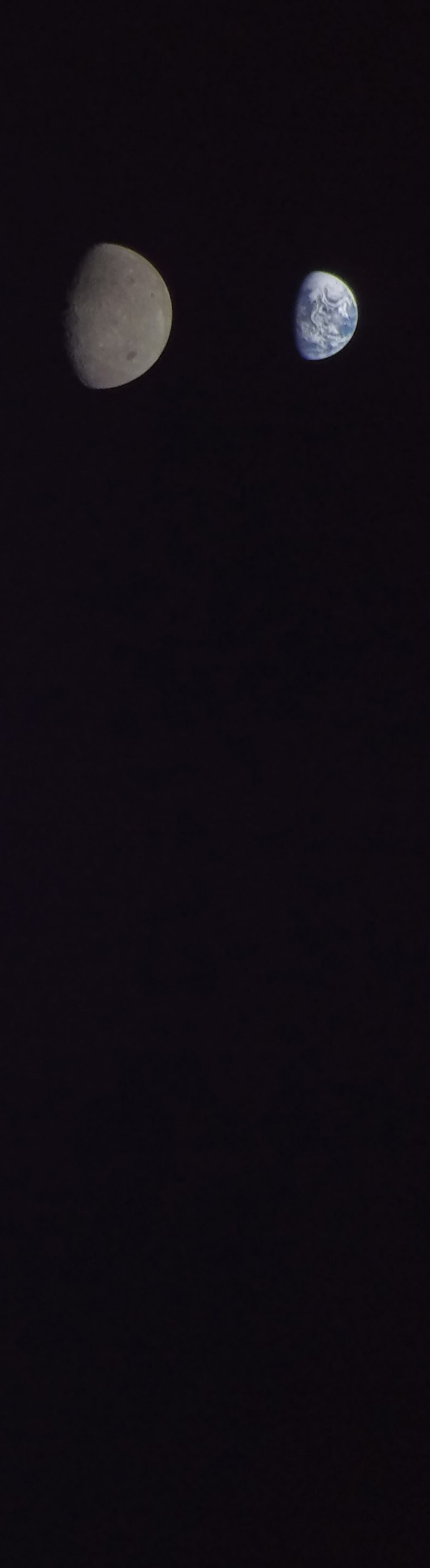
Propellant Performance in ISS Thermal Environments

The thermal environments experienced by LV engines tend to be relatively benign and short duration as most missions range from several minutes to several hours. Spacecraft, however, can be exposed to thermal extremes for weeks, months, and even years. When docked to the ISS, for example, a spacecraft can experience temperatures from 121°C for sun-exposed surfaces to −157°C for shaded surfaces. This could cause some classes of propellants to chill and thicken, potentially clogging engine injectors and causing operational issues.

In 2020, an NESC team began an assessment to better understand the thermal and phase behavior of rocket propellants in a low-pressure, low-temperature environment (i.e., space), including the characterization and detection of propellant leakage. The team performed propellant modeling in the environments using analytical equations and computational fluid dynamics. Tests were performed at WSTF and included representative flight hardware at low-pressure conditions to replicate the flight environment. These tests included characterization of propellant leaks to aid in generating flight rules for on-orbit operation. This work was performed by MSFC, JSC, WSTF, GSFC, and GRC.

ISS photographed by Expedition 56 crew members from a Soyuz spacecraft after undocking. Spacecraft propulsion systems must be designed to operate in the temperature extremes found when docked to the ISS for long periods.


NASA

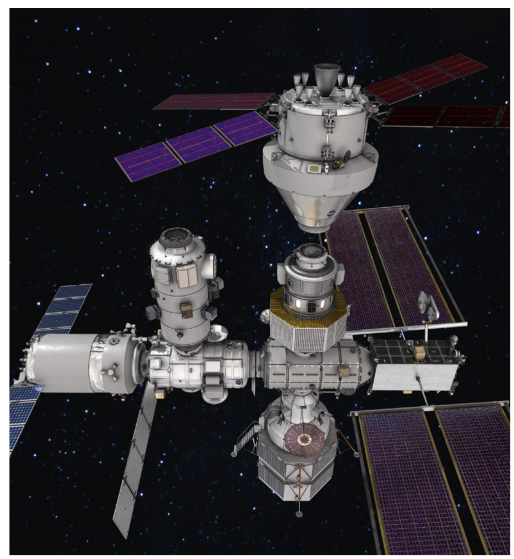


On flight day 13, Orion reached its maximum distance from Earth during the Artemis I mission when it was 268,563 miles away. ECLS and spacecraft network interoperability will be critical to deep-space exploration.

Operating ECLS Systems at Reduced Cabin Pressures

NASA's state-of-the-art environmental control and life support (ECLS) systems are well designed for the cabin atmospheres found onboard the ISS, which range from 14.2-14.7 psia and 19-24% oxygen. To reduce structural loads, there is a desire to reduce the atmospheric pressure on future Exploration Mission vehicles like Gateway, Human Lander Systems, and lunar habitats, but oxygen concentrations must be increased to sustain the crew. Whether or not current ECLS systems will continue to operate nominally in the new operational environments was the subject of an NESC assessment.

The team of ECLS experts looked at the potential impacts to performance, thermal control, and material selection for ISS ECLS hardware used in cabin atmospheres with lower pressure and higher O_2 concentration, conditions for which the hardware was not originally designed and certified. Exploration atmospheres might include either 10.2 psia with 26.5% O_2 or 8.2 psia with 34% O_2. A total of 33 subsystems and/or ECLS components were evaluated using available design data and historical literature. Several common factors were identified across multiple subsystems such as the reduced performance of fans, blowers, and air movers due to decreased air density; performance changes in valves, regulators, sensors, and bellows; reduced heat rejection capability of electronic systems; and increased flammability of materials. The assessment identified the impacts to critical components and subsystems and recommended analysis and testing to quantify those impacts and inform any necessary design modifications.



Conceptual illustration of Gateway

Examination of the Artemis Network Architecture

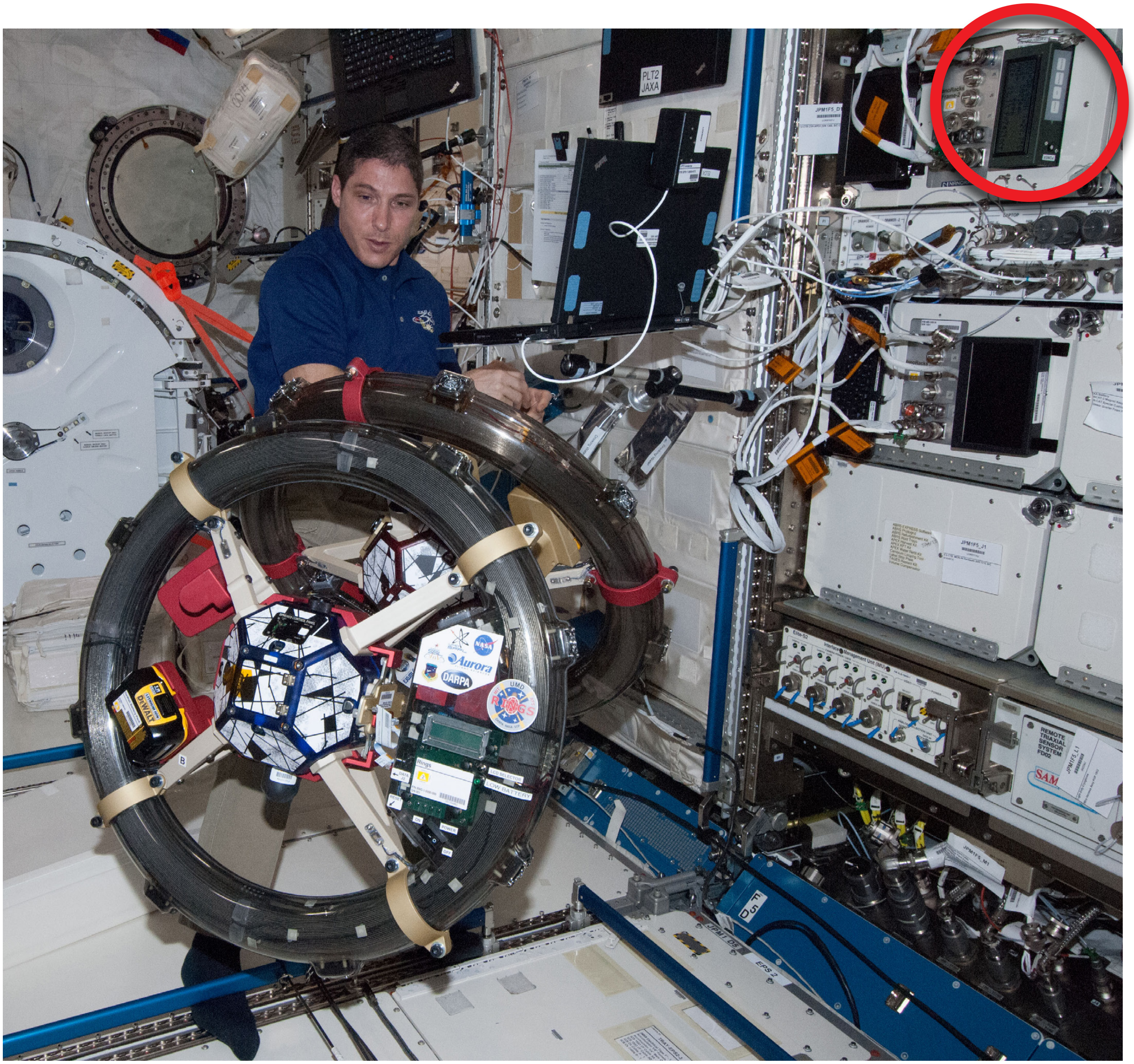
Time-Triggered Ethernet (TTE) is a networking technology that extends the capabilities of traditional Ethernet to enable deterministic, time-critical, and reliable applications. TTE provides three distinct and standardized traffic classes and data from each can operate on the same physical wires, supporting both critical and non-critical applications simultaneously. A TTE network includes end-systems and switches, all of which are synchronized by a network schedule. A variant of TTE is used on the Orion spacecraft and the Gateway vehicle to create a multi-domain distributed network across vehicles (e.g., Orion, Gateway, and Human Lander System).

An NESC assessment team analyzed the integrated Artemis TTE network architecture requirements, network implementation, and associated development tools for potential vulnerabilities, degree of fault tolerance, and integrated system fault containment. The team also examined network determinism, network reconfiguration approaches, technical performance measures, and network development tools for developing and verifying network schedules. This work was performed by LaRC, ARC, GSFC, and WFF.

Sensors for Measuring Gas Constituents in Spacecraft

Future NASA exploration missions will require continuous monitoring of various gases to enable life support and ensure a safe breathing environment for the crew. However, commercial-off-the-shelf gas sensing devices are not typically qualified to measure multiple gas constituents in spacecraft. An NESC assessment helped address the technology gaps present in sensor development and the associated safety impacts.

Several tasks completed during the assessment helped mitigate possible risks to the implementation of laser-based sensor technology, such as enabling long-term calibration stability over the span of years (e.g., long duration ISS and lunar missions); developing reduced-volume sample cells to minimize mass and volume risks; and identifying and testing radiation hardened electronics for robust flight hardware. The result was a substantial increase in the technical readiness level of laser sensor technology. This work was performed by LaRC and JSC.



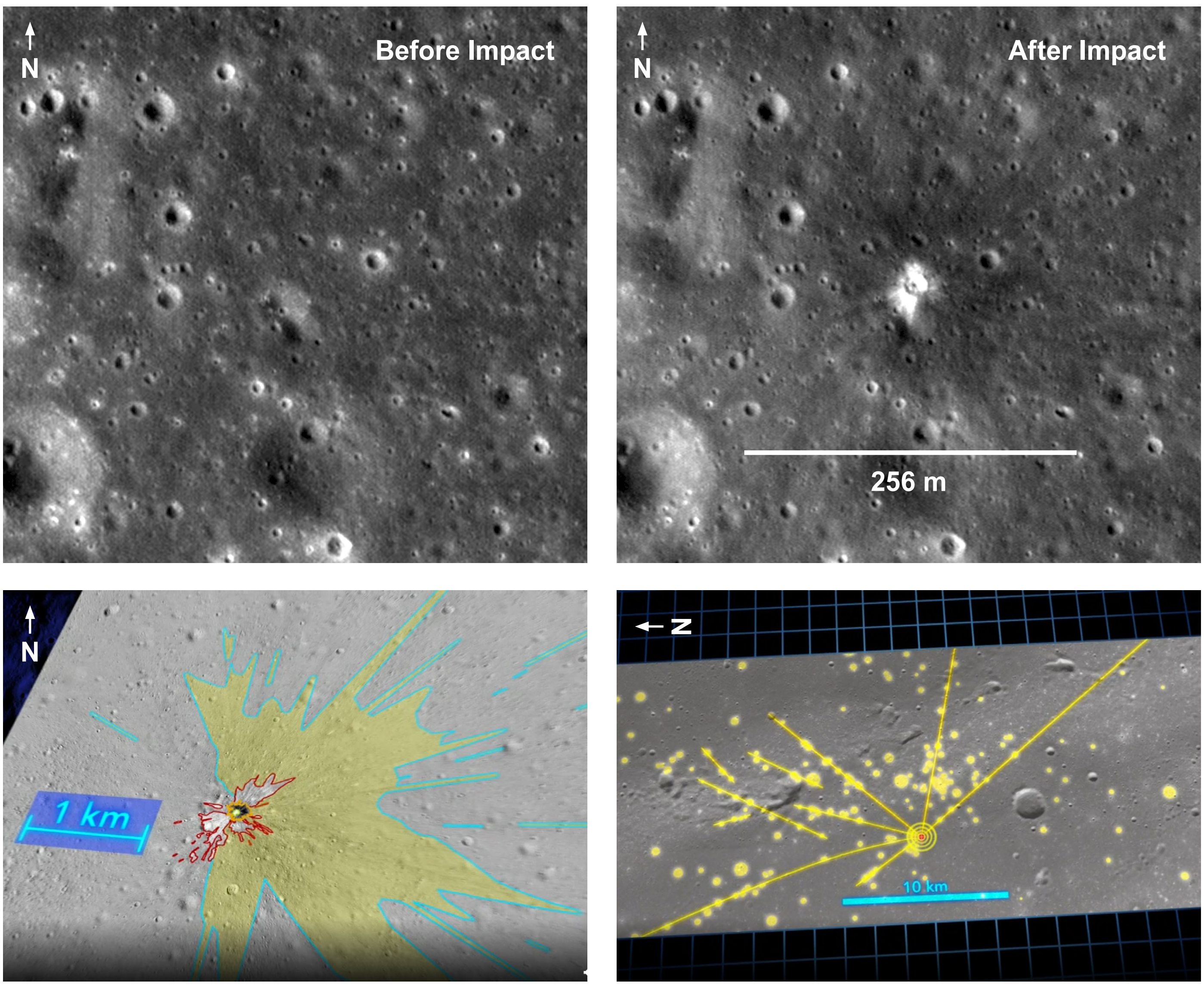
A multi-gas monitor operating in the ISS Kibo laboratory in 2014 (red circle) represents the first laser sensor to continuously measure and monitor gases on a spacecraft.

Protecting Lunar Assets from Meteoroid Impact Ejecta

Meteoroid impacts, which are common on the lunar surface, create ejecta of regolith that could be a potential threat to any crew or spacecraft operating on and near the lunar surface. To protect future lunar astronauts, vehicles, and habitats, NASA will need accurate modeling of the size, mass, and density of this ejecta, as well as its direction, velocity, and distribution. To that end, MSFC developed MeMoSeE*, or Meteoroid Model of Secondary Ejecta, which is an update to the current Apollo-era lunar ejecta model included in the Agency's Design Specification for Natural Environments (DSNE). The DSNE will be used in the design of future lunar systems such as the Artemis Program, Human Landing System, and Exploration Extravehicular Mobility Unit (xEMU).

An NESC team was asked to review MeMoSeE's primary impactor and ejecta modeling; debris transport equations; and contributions to computing risks to vehicles, habitats, and other objects on the lunar surface. Overall, the MeMoSeE model was found to incorporate the appropriate phenomenology for a DSNE design environment. Additionally, the team provided recommendations for model improvements that would help ready MeMoSeE for use in computing ejecta risk for future lunar missions. This work was performed by MSFC, JSC, GSFC, LaRC, Arizona State University, and Princeton University. NASA/TM-20220000562.

*The model has since been renamed Lunar Meteoroid Ejecta Engineering Model.

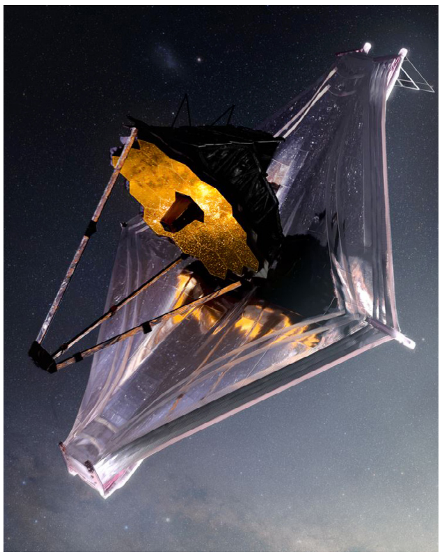


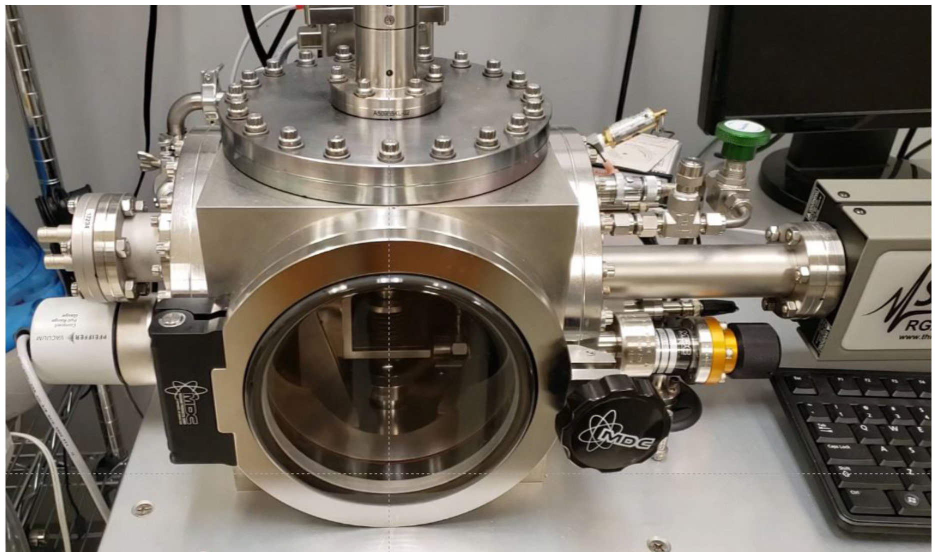
Top row: On March 17, 2013, the Lunar Reconnaissance Orbiter found a new impact crater measuring 61.7 feet in diameter. Bottom row: A measured change in surface brightness in addition to new markings on the lunar surface shows the extent to which material was ejected by the impact. More than 200 related surficial changes up to 19 miles away were noted. Credits: NASA/GSFC/Arizona State University

Evaluating Dry Film Lubricant Sensitivity to Humidity

Several of the James Webb Space Telescope's (JWST) complex mechanisms operate at cryogenic temperatures, which makes using liquid lubrication in the mechanical assemblies difficult. Instead, JWST uses forms of dry film lubricant (DFL) that are better suited for the extremes of the space environment. Prior to the telescope's launch in December 2021, the NESC led a team of materials and tribology experts to test a DFL's sensitivity to humidity as some JWST components would be exposed to humid conditions during integration and storage prior to flight.

The work involved performing tests on substrates with flight-like DFL coatings to evaluate their performance under simulated conditions. The results showed successful DFL life-test results and identified no risks or performance concerns for the JWST components using the lubricant. This work was performed by GSFC and GRC.





Top right: Spiral orbiter tribometer. Bottom: DFL on representative key mechanical interfaces and mechanisms within JWST's science instruments were tested using the tribometer at GSFC.

APOLLO-ERA GANTRY USED IN NESC TESTING

Update on In-Progress Work

A national historical landmark, LaRC's Landing and Impact Research facility (LandIR) vehicle structural testing complex, better known as the "gantry," continues to serve NASA and the nation as a unique venue for full-scale crash and impact tests on both land and water. Since the Apollo Program, the 240-foot high, 400-foot long, 265-foot wide, A-frame steel structure has been modified to take on new roles.

Over the last 3 years, the LandIR facility's staff led three unique test campaigns for the NESC in support of the Commercial Crew Program. The LandIR staff analyzed NESC test requirements then led the planning, instrumentation, design, and fabrication of ground support equipment and test execution.

NESC testing centered around lifting a swing mass with steel cables as high as 200 feet, then releasing the mass to swing pendulum-style to impart a specific amount of kinetic energy into critical components in a controlled and repeatable manner to test their robustness.

NESC SUPPORTS NASA'S COMMERCIAL CREW PROGRAM

The NESC has supported the NASA Commercial Crew Program (CCP) in the development, testing, and flight of its partners' crewed spacecraft.

SpaceX launched its sixth flight, Crew-5, of the Crew Dragon for NASA. Since beginning crewed flights to ISS, the NESC has assisted the CCP in flight readiness reviews and post-mission evaluations and continues to support refinements of various subsystems such as software and parachutes.

Boeing prepared for its first crewed flight, expected in 2023, following the successful Orbital Flight Test-2 of its CST-100 Starliner, which launched to ISS in May of this year. NESC has played an integral role in the testing and evaluation of many Starliner subsystems including avionics, environmental control and life support, software, propulsion, and power systems.

Top: SpaceX Dragon Endurance crew ship docked to the ISS on the Crew-5 mission, October 6, 2022.

Bottom: Boeing CST-100 Starliner crew ship approaching the ISS on Orbital Flight Test-2, May 20, 2022.

PRIORITY 2

IN-PROGRESS ASSESSMENTS

- CCP Landing Simulations
- Software Defect Density Analysis across NASA Projects and Programs
- Independent V&V of MAV Ascent Phase of Flight
- Self-Reacting Friction Stir Weld (SR-FSW) Anomalies
- NASA Exploration Systems Maintainability Standards for Artemis and Beyond
- SLS FTS Stray Voltage Anomaly
- SLS Core Stage Thick Plate
- Power and Propulsion Element Battery Safety Assessment and Pathfinder
- Space-Shielding Radiation Dosage Code Evaluation and Identification
- Pressurized Rover Red Team Review, JAXA and NASA Concepts
- Dragonfly Dynamic Stability
- Hot-Fire Testing of 5 lbf Class Reaction Control System Thrusters
- Exploration Systems Exterior Lighting Design Guidance
- Study of Material Sensitivities to N2O4/MON Exposure
- Oxidizer Tank Design and Qualification Assessment
- 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
- Frangible Joint Technical Support to SLS
- Parachute Dispersion Bridle Load Link Tech. Eval. Phase-1
- MPCV Launch Abort Vehicle Powered Aero Database Development using FUN3D
- SLS Prevalve Assessment
- Reaction Wheel Bearing Contamination
- Energy Modulator Webbing Shredding Testing
- MAV Buffet / Aeroacoustics Numerical Simulations
- LC-39A Pad Modification Evaluation
- MPCV COPV Damage Tolerance Life by Analysis Risk
- CFD Assessment of Ascent Abort Axial Force Anomaly
- Evaluation of Alternate Helium Pressure Control Component
- Trade Space Analysis: Balancing Crew and Mission Design Parameters
- Tube Test Coupon for COPV Mechanics
- Anaerobic Hydrogen Detection Sensor
- Orion Crew Module Side Hatch Analysis
- Qualification of Radiographic NDE Techniques
- CCP Post-flight Reference Radiation Environments
- Midpoint Monitoring in Batteries
- Material Compatibility and EAC Data for Metals in Hypergolic Propellants
- Autonomous Flight Termination System
- Hydrodynamics Support for the Orion CM Uprighting System
- Thermocouple Interference During High-Speed Earth Entry
- Peer Review of ESD Integrated Vehicle Modal Test, Model Correlation, DFI and Flight Loads Readiness
- Orion Titanium Hydrazine Tank Weld
- 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

- SLS SPIE (Spacecraft/Payload Integration and Evolution) B1B CDR Support
- Buffet/Aeroacoustic Analysis of SLS Core Stage Foam Repair for Artemis I
- Materials SME for MMPACT Review
- ESM Pressure Control Assembly Valve Model Update
- Ames Facility Electric Power Issues
- Balloon Program Flight Safety Risk Analysis
- Review of Spacesuit Electrical Models for Lunar Operations
- ESD Critical Event Assessment Reviews
- Gateway Type 2 D&C Standards ESA Equivalents Plan
- Suborbital Crew Qualification Approach and Risk Analysis
- Artemis xEMU Visor Inspection System Hardware
- Statistical Design of Experiments for ICEE Formulation
- MAV Mass Properties and Mass Growth Implementation and Margin Refinement
- Rotordynamic Analysis for Europa Clipper
- Ocean Color Instrument Engineering Test Unit
- Eval. Risk of an Alternative Pyro Lot Acceptance Test Plan
- SE&I Support to CCP DCRs
- Review of SLS FTS Battery Cell Out Test Procedure
- MAF Nonconformance Reporting and Corrective Action

IN-PROGRESS SUPPORT ACTIVITIES

- Orion Mass Gauging Development
- Artemis I Supplemental Parachute Imagery
- Display Management Computer Reset Anomaly
- HALO CDR SE SME Support
- MSR Orbiting Sample Model Review
- Composite Consult for New Launch Vehicle Application
- FSW and GNC SME Support for Psyche
- Mars Sample Return CCRS-OS Charging Support
- RST Radiation and Charging Support
- HLS GNC Landing System Sensor Milestone Review
- xEVA Design and Construction Support
- SLS Block 1B CDR Support
- Material Flammability in Lunar Gravity
- ESCAPADE Propulsion System Trade
- Lunar Ground Testing Guidebook
- Orion Reusability Evaluation
- Psyche Mission RAD750-V3
- SLS SE&I Programmatic Review
- OSAM-1 Assembly Joint Mechanism
- SubC Safety Review
- HLS Avionics Fault Tolerance
- Lunar Glove Thermal and Dust Risk Mitigation
- Contamination Control Engineer Consultant for GLIDE Mission
- Double Asteroid Redirection Test Solar Array Loads Issue Resolution
- Frangible Joint Technical Support to LSP
- Mars Sample Return MMOD Protection Review
- Independent SMEs for DOLILU Certification Review
- Operational Modal Analysis of Dynamic Rollout Test Data
- Sensor Anomaly Investigation Support
- Space Charging of Ocean Color Instrument Rotating Mechanism
- Support to CCP Launch Vehicle
- Orion, NDSB2, and Gateway Material Electrical Properties
- CCP Parachute Flight/Ground Tests & Vendor Packing/ Rigging Activities
- SLS Design Certification Review
- Bond Verification Plan for Orion’s Molded Avcoat Block Heatshield Design

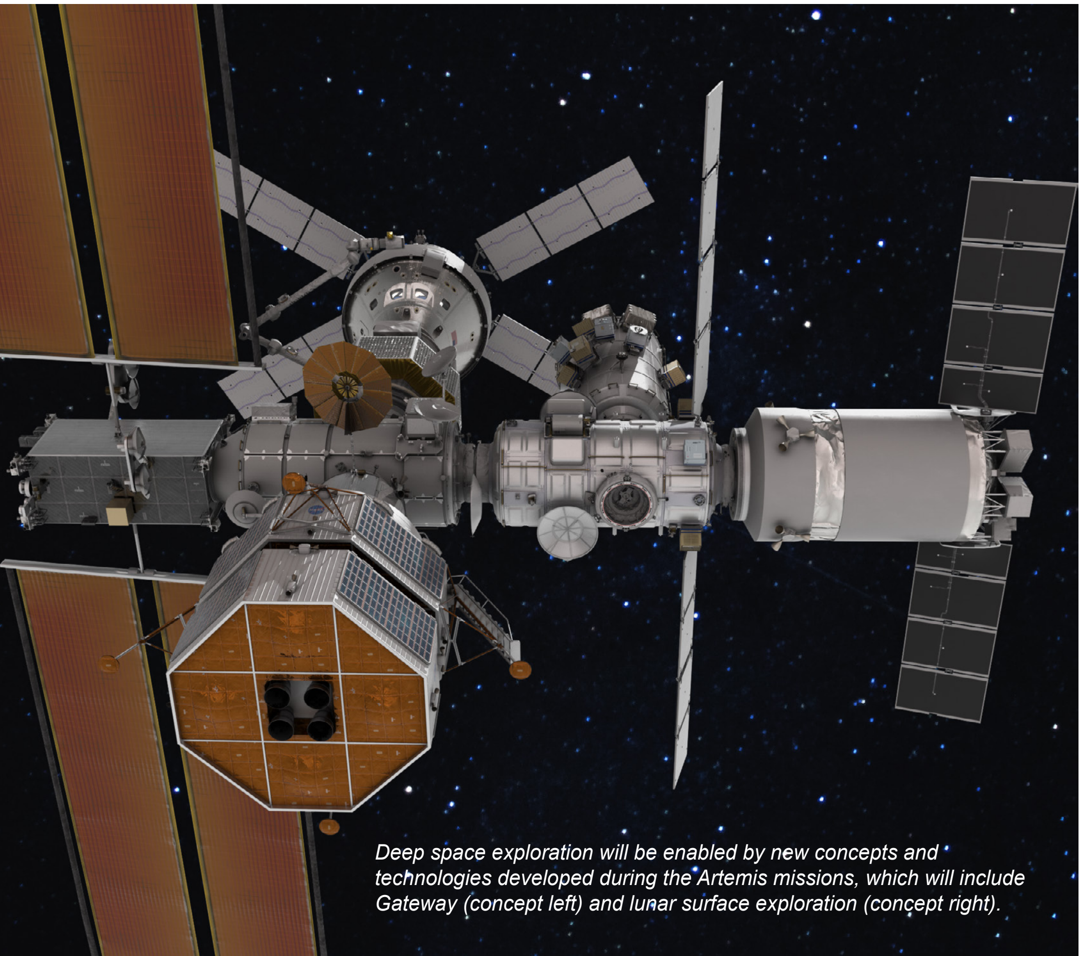
COMPLETED ASSESSMENTS IN FY22

PRIORITY 3: Problems Not Being Addressed by Any Project

Avionics Interoperability on Long Duration Missions

As NASA's crewed exploration missions move beyond low Earth orbit, the need for interoperable avionics systems becomes more important due to the cost, complexity, and the need to maintain distant systems for long periods. The previous NASA-developed and widely adopted standard for backplane-based chassis interconnect, cPCI, is over 20 years old and no longer supports modern architectures. SpaceVPX is an avionics board- and chassis-level international industry standard that addresses some of the needs of the space avionics community, but it falls short of an interoperability standard that would enable reuse and common sparing on long-duration missions and reduce nonrecurring engineering for missions in general. An earlier version of SpaceVPX, VITA-65, defined backplane and board-level profiles from multiple hardware/software vendors to ensure interoperability of their products, and the current version, VITA-78, incorporates fault tolerance features that are required by many spaceflight systems. But VITA-78 allows so much flexibility that interoperability between VITA-78-compliant modules cannot be assured.

An assessment was initiated to identify gaps in VITA-78 and provide guidelines on the use of, and extensions to, VITA-78 to enable avionics interoperability for future NASA missions. This work used multiple NASA use cases to assess requirements for SpaceVPX across crewed missions, science missions, and orbital and surface robotic systems. The NESC team also engaged with other agencies to learn about their interest in SpaceVPX, their strategies for implementing SpaceVPX-based systems, and their internal development efforts. Recommendations were made regarding the feature set and module profiles to support NASA SpaceVPX implementations, including working with the SOSA™ Consortium and other space-going agencies and industry to incorporate these recommendations into a future revision of VITA-78. Further, NASA should collaborate with the same partners to conduct follow-on studies to develop next generation avionics architectures beyond SpaceVPX. This work was performed by LaRC, GSFC, JPL, JSC, and Aspen Consulting Group.



Deep space exploration will be enabled by new concepts and technologies developed during the Artemis missions, which will include Gateway (concept left) and lunar surface exploration (concept right).

Developing Mission Architectures for Deep Space Expeditions

NASA's Moon-to-Mars objectives call for long-duration, deep-space crewed expeditions where long-term exposure to radiation and microgravity, communication delays and lack of resupply opportunities could combine to jeopardize mission success. In 2020, the NESC Chief Scientist and the NASA Chief Health and Medical Officer led a team of health, space environments, mission architecture, and human systems integration experts to research potential engineering solutions for some of the challenges presented by deep-space travel (specifically travel to Mars). Using a systems approach rather than one focused on individual countermeasures, they examined the trade space around integrated safety, health, and performance risks to identify high-potential risk mitigation strategies and characterize aspects of Mars mission architectures that render the lowest aggregated risk.

A "fast Mars transit" round-trip mission concept was studied using an innovative flight-dynamics approach to quantify the minimum total mission energy required for a Mars transit with total mission duration less than 400 days. This approach was shown to hold promise for sending humans to Mars and returning them safely with acceptable exposure to microgravity and minimal exposure to radiation using current or near-term technology. The fast transit concept would also result in fewer time-driven vehicle failures and enable sustainable deployment of humans and infrastructure to Mars on a regular cadence. Furthermore, they concluded that reliance on the low Earth orbit mission operations paradigm—i.e., one of near-complete real-time dependence on experts at Mission Control to manage the combined state of the mission, vehicle, and crew—is high risk given the communication delays and limited resupply of a Mars mission. Based on historical trends, it is highly likely that the crew will face a high-consequence problem of uncertain origin during Mars transit when ground support will be greatly reduced.

While it may be possible to reduce anomaly rates through improved reliability analysis and testing and to reduce anomaly impacts through added robustness, such mitigations address only known failure modes and known uncertainties. Therefore, a radical shift in the Human-Systems Integration Architecture that defines the operational paradigm, systems design, and human-systems interactions is needed to improve the risk posture to an acceptable level.

This work was performed by GSFC, MSFC, ARC, HQ, JPL, JSC, LaRC, KSC, Space Science Solutions, University of Alabama Huntsville, University of Hawaii, and Analytic Services, Inc.

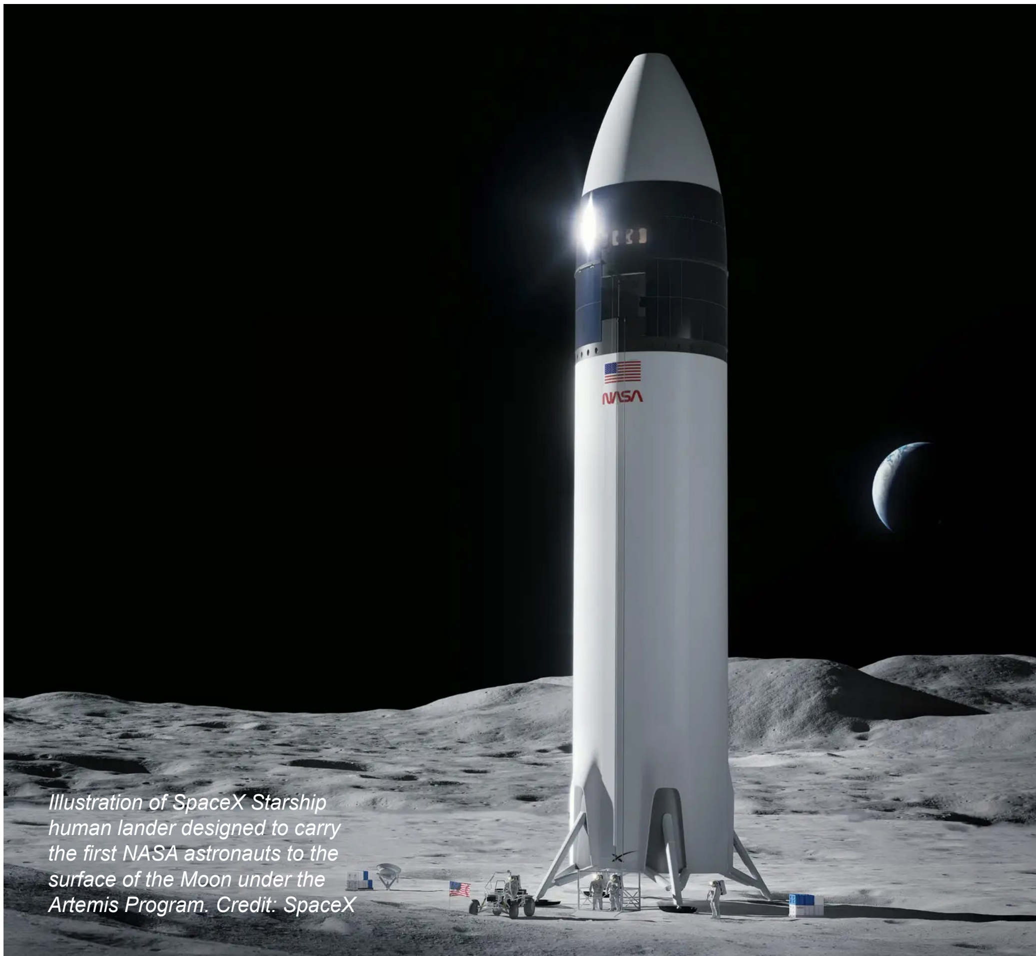
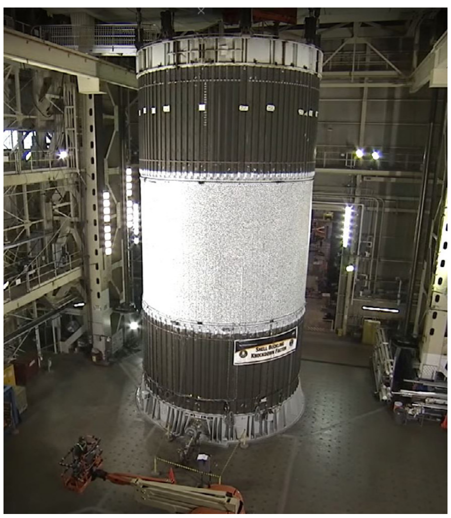


Illustration of SpaceX Starship human lander designed to carry the first NASA astronauts to the surface of the Moon under the Artemis Program. Credit: SpaceX

New Buckling Design Guidelines for Launch Vehicle Structures

In FY22, the NESC concluded its multi-year effort to revise decades-old buckling design guidelines and provide new data and insight into the buckling response of modern launch vehicle constructions. High-performance aerospace shell structures are inherently thin walled because of weight and performance concerns. Primary design considerations are the prevention of buckling, large magnitude displacements, large reductions in global stiffness, and collapse. Empirically based design recommendations, developed through the 1960s, were typically overly conservative for modern aerospace-quality shell structures.

The NESC's Shell Buckling Knockdown Factor (SBKF) Project, started in 2007, helped develop and validate new analysis-based knockdown factors (KDF) and analysis methods for selected metallic and composite launch vehicle structures. The SBKF team performed extensive design trade studies, subscale and full-scale structural testing, detailed test and analysis correlation, and development of KDFs and analysis methods. Reducing conservatism in KDFs and use of revised KDFs by SLS led to significant benefits to the core stage design in reduced mass, material cost, and design cycle time. Large-scale composite testing validated analysis approaches and identified important variables that influence the buckling response. As a result, *NASA SP-8007 Buckling of Thin-Walled Circular Cylinders, Revised August 1968* now includes updated design guidelines for buckling-critical cylindrical shells and descriptions of the history and state of the art for shell buckling. This work was performed by LaRC, MSFC, KSC, AFRC, GRC, ATK Aerospace, Michoud Assembly Facility, The Boeing Company, and Northrop Grumman Corporation. NASA/SP-8007-2020/REV2, NESC/TB-16-01.



The SBKF team tested both metallic shells (left images) and composite shells (far right).

Methods for Removal of Cadmium from High Purity Hydrazine

Since early 2020, the NESC has performed several deep-dive analyses into new production methods for high-purity hydrazine (HPH), the hypergolic liquid propellant used for rocket propulsion systems, auxiliary power units, and thrusters for satellites and spacecraft. The efforts have helped shed light on the quantities and chemical profiles of trace contaminants present in HPH following changes in the production process. Trace contaminants in HPH propellant can impact a wide variety of commercial, Department of Defense, and NASA missions. These analyses have provided best practices for performing an HPH elemental profile and identifying any extraneous unknown carbonaceous materials that might be present.

The NESC initiated a study to investigate methods to reduce specific problematic elements should HPH stocks require purification to meet programmatic needs. Additionally, purification methods were assessed for capacity to simultaneously remove extraneous carbonaceous content in the new HPH. Results showed that crystallization, sublimation, and vacuum-assisted distillation held the most promise for optimizing and upscaling. This work was performed by KSC, WSTF, MSFC, and DLA Energy. NESC/TB-22-08.

Method	Target Element Removal*	Carbonaceous Removal	Considerations
Crystallization	28%	Possible Reduction**	Supercooling
Sublimation	97%	Possible Reduction**	Supercooling
Vacuum-Assisted Distillation	99.7%	35%	Stablizer Potentially Necessary for Upscale
Ion Exchange Resin	97%	Additional Contamination	Increase in NVR and Exchange Ion Concentration
Alumino-Silicate Molecular Sieves	N/A***	N/A***	Dissolution into HPH

*Target Element Removal Rates for Non-Optimized Lab-Scale Demonstration
**Further Study Needed to Quantify Reduction
***Study Halted Prior to Full Evaluation Due to Non-Compatibility

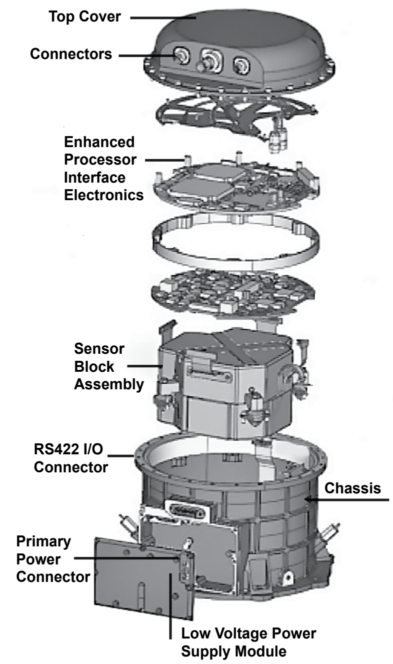
Summary of Laboratory-Scale Findings to Purify HPH

Miniature Inertial Measurement Unit Analysis

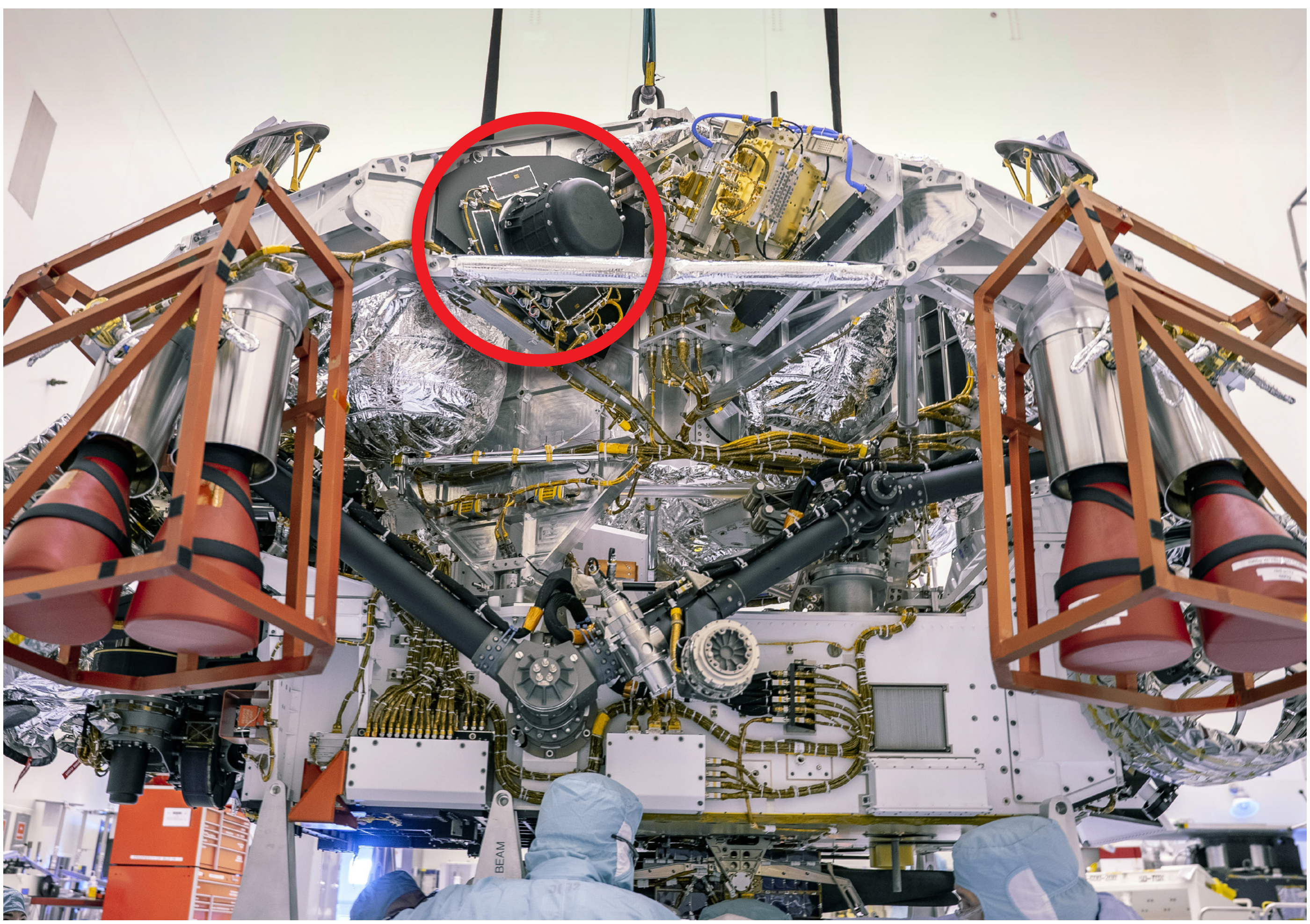
Inertial sensors provide the foundation for the guidance, navigation, and control (GNC) systems on most of NASA's spacecraft. The Honeywell miniature inertial measurement unit (MIMU) is a workhorse sensor and is commonly used on NASA spacecraft that fly in operational regimes ranging from low Earth orbit to planetary and deep space. The MIMU provides inertial reference data to the spacecraft's onboard GNC systems for maintaining precise orbit/trajectory control and payload instrument orientation.

The NESC was requested by the Space Science Mission Operations organization at GSFC to provide best practice operational guidance to operate the Honeywell MIMU since there were indications the MIMU lifetime is time- and temperature-dependent. A secondary goal was to capture best practices for accommodating/integrating the MIMU sensor hardware into spacecraft for missions in the design and development phases of their lifecycles.

The NESC team collected an extensive set of MIMU operational flight data from 12 different NASA space missions, selected to obtain data over a wide range of operating regimes (e.g., Earth orbiting, lunar orbiting, Mars orbiting, deep space) and primary mission durations. The team found that several missions have developed and implemented the use of an all-stellar (i.e., gyroless) or stellar-only attitude determination algorithm/flight software update to preserve MIMU operating life for essential attitude control and navigation operations. The large MIMU flight data set collected can serve as a resource for NASA to build upon for future examinations of MIMU performance by GNC engineers. See page 54 for further discussion. NASA/TM-20220012239.



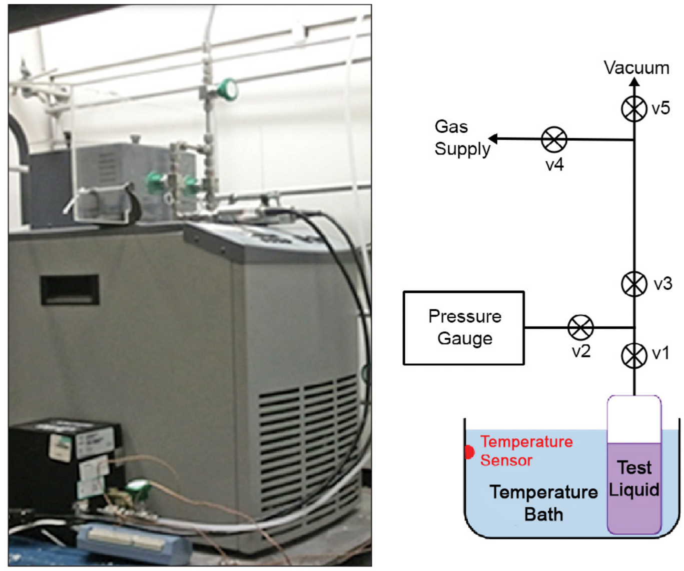
MIMU illustrated parts breakdown
Source: aerospace.honeywell.com



Mars 2020 powered descent vehicle (PDV) stacked onto the Perseverance Rover. A MIMU is visible near the top left of the PDV.

Testing Helium Solubility in Liquid Propellants

Helium is used as a pressurant gas for nearly all liquid propellant propulsion systems. Although the least soluble of commonly used pressurant gases, some amount of the helium will go into the solution of the liquid propellants, such as monomethylhydrazine (MMH) and nitrogen tetroxide (NTO), which are used in space applications. The amount of pressurant dissolved is temperature and pressure dependent, so at higher operating pressures, more helium can go into solution. As pressure drop occurs through the propulsion feed system, helium can evolve out of solution and remain as bubbles for extended periods, possibly causing off-nominal and sometimes damaging chugging and thruster damage.



Testing apparatus used at The Aerospace Corporation

This effort was focused on accurately predicting the amount of helium that can go into solution at flight pressures and temperatures, which is critical in avoiding instabilities during engine start. A previous NESC study (see page 16) focused on when and how much helium evolves out of solution. Most widely used publicly available data on the solubility of gases in MMH and NTO are based on measurements made during the 1960s, when testing at higher pressures was limited. The NESC team conducted helium solubility tests at The Aerospace Corporation with MMH and NTO at pressures and temperatures greater than in the prior NESC study and more relevant to in-space applications, establishing new relations for helium solubility. The data generated in this work should help propulsion system designers understand the helium solubility/evolution conditions associated with damaging instabilities, increasing life and system reliability. This work was performed by MSFC, GRC, JSC, WSTF, and The Aerospace Corporation. NASA/TM-20220013195, NESC/TB-22-07.

PRIORITY 3

IN-PROGRESS ASSESSMENTS

- “Know Before You Go” to Mars
- NESC PDV System Repair and Modernization
- Programmable Logic Device Guidance and Standard
- Unique Science from the Moon in the Artemis Era
- Phased Array Microphone System Development
- AACT Risk Reduction Project - Safe Life Category
- AACT Risk Reduction Project - in Situ Monitoring Category
- AACT Risk Reduction Project - Metallurgy Category
- Spacecraft Fire Safety Standard
- Galvanic Corrosion in Microfabricated Detectors & MEMs Devices
- NESC COG Technology Development
- Thermophysical Properties of Liquid TEA-TEB
- Test and Modeling to Predict Spacesuit Water Membrane Evaporator Failures
- Unconservatism of LEFM Analysis Post Autofrettage
- 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 MLG Fracture
- Parachute Reefing Line Cutter Modification and Qualification
- Need for Wireless EDL Instrumentation Validation
- Southern Hemisphere Meteoroid Environment Measurements

COMPLETED SUPPORT ACTIVITIES

- NDL Risk Assessment Panel
- Support to GRC HV Fault/Transient Anomalies
- Update Human Systems Integration Practitioner’s Guide
- Revising NASA-HDBK-4002A
- Lunar Lander Mentor Team
- Completion of NASA-HNBK-5010A

IN-PROGRESS SUPPORT ACTIVITIES

- Human System Interactions in Closed Breathing Systems
- TALOS Project
- Low Temperature Coefficient of Thermal Expansion Measurement Capability
- EPIC/Athena Assessment Group Tech Support
- Human Factors Support for OSAM-1

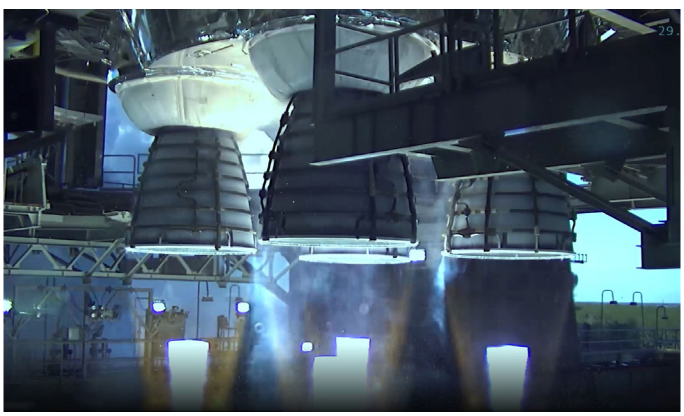
COMPLETED ASSESSMENT IN FY22

PRIORITY 4: Work to Avoid Potential Future Problems

Guidance for Spaceflight Propulsion System Filtration

Contamination has been accepted as the root cause of many spaceflight system anomalies. Some of these could have been prevented if an appropriate filtration approach had been specified and implemented. Currently, no standards exist for sizing, building, and verifying the performance of spaceflight propulsion system filters, and while component and system cleanliness standards exist, the interpretation of cleanliness-level applicability varies widely. There is no standard technique to determine how cleanliness levels are applied at a system level and how they correlate to filtration requirements.

In 2020, the NESC took on the task of defining a common approach to filtration terminology and developing guidelines for spaceflight propulsion and pressurant systems. The team evaluated filtration rating, contamination capacity, flow rate vs. pressure drop, differential collapse pressure, and filter housing performance to develop guidance for filtration system design. The key results from this work included identification of the major sources of particulate contamination and a guideline for the design of filtration systems. The assessment was a first step in a multi-step process. The guidance established by the team is recommended for all launch vehicle and spacecraft propulsion systems and may be applicable to a range of other systems. This work was performed by MSFC, JSC, GRC, GSFC, JPL, KSC, SSC, LaRC, WSTF, and The Aerospace Corporation. NASA/TM-20220004115, NESC/TB-22-02.



Contaminants in liquid propulsion systems must be controlled to increase operational reliability.
Left: Test firing of the SLS RS-25 core stage engines. Right: SLS core stage preparation for Artemis I mission.

PRIORITY 4

IN-PROGRESS ASSESSMENTS

- Design and Testing of Battleship Hypergolic Propellant Thruster
- Lessons Learned on DART NEXT-C Ion Engine
- FPMU Data Processing Algorithm Development/ Analysis
- BON GCR Model Improvements
- Wire and Wire Bundle Ampacity Testing and Analysis
- Solderless Interconnects and Interposers
- Electrical, Electronic, and Electromechanical Parts Copper Wire Bonds for Space Programs

COMPLETED SUPPORT ACTIVITIES

- Human Factors Support for OCE Project Factors Team

PRIORITY 5

IN-PROGRESS ASSESSMENTS

- Improved Hypervelocity Test Methodology Identification and Trade Analysis
- Updates and Modernization of the CEA Code
- Avionics Packaging Engineering Processes
- Frangible Joint Working Group
- NASA Quantum Sensing Capability
- Flight Mechanics Analysis Tools Interoperability

COMPLETED SUPPORT ACTIVITIES

- Reentry Aeroballistics Trajectory and Thermal Protection

IN-PROGRESS SUPPORT ACTIVITIES

- NEPP Industry Leading Parts Manufacturer Pathfinder

AMES RESEARCH CENTER

66 ARC Employees Supported NESC Work in FY22

ARMSTRONG FLIGHT RESEARCH CENTER

11 AFRC Employees Supported NESC Work in FY22

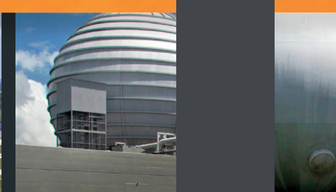
GLENN RESEARCH CENTER

73 GRC Employe NESC Work in



NESC AT THE CENTERS





JOHNSON SPACE CENTER

100 JSC Employees Supported NESC Work in FY22

KENNEDY SPACE CENTER

43 KSC Employees Supported NESC Work in FY22

LANGLEY RESEARCH CENTER

257 LaRC Em NESC Wo

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FY22

GODDARD SPACE FLIGHT CENTER

96 GSFC Employees Supported NESC Work in FY22

JET PROPULSION LABORATORY

100 JPL Employees Supported NESC Work in FY22

NASA EMPLOYEES SUPPORTING NESC WORK IN FY22

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MARSHALL SPACE FLIGHT CENTER

117 MSFC Employees Supported NESC Work in FY22

STENNIS SPACE CENTER

30 SSC Employees Supported NESC Work in FY22

NESC Chief Engineer: Kenneth R. Hamm, Jr.

66 ARC EMPLOYEES SUPPORTED NESC WORK IN FY22

AMES RESEARCH CENTER

The Ames Research Center (ARC) supports a diverse suite of capabilities for the NESC including advanced computing; software; aerodynamics testing; intelligent systems; aerothermal entry, descent, and landing (EDL) modeling; thermal protection materials; and human factors research. ARC personnel are represented on 19 NESC Technical Discipline Teams (TDT) and have supported more than a dozen independent technical assessments and studies including EDL modeling, dynamic stability assessments for Dragonfly and Mars Sample Return Earth Entry System, and a workshop on Safe Human Expeditions Beyond LEO. This year's profiled individuals demonstrate the diversity of experience present at ARC.

Dr. Cetin Kiris

Dr. Cetin Kiris, Branch Chief for Computational Aerosciences at ARC, has assisted the NESC since the Agency's early efforts to return the Space Shuttle to flight following the Columbia accident. Today, as a member of the Aerosciences TDT, he remains a key contributor to NESC assessments, bringing ARC personnel and capabilities to bear on technical issues.

In 2020, he helped the NESC evaluate modifications to NASA Launch Pad 39A to accommodate the Falcon Heavy rocket. The work involved enhancing computational fluid dynamics code to ensure no adverse effects would result. "We performed simulations on the original and modified launch pad configurations that helped give confidence in the modifications," said Dr. Kiris. More recently, he helped in understanding the dynamic stability of capsules like the Mars Sample Return Earth Entry System and the Dragonfly as they go through the transonic and subsonic regimes during EDL. "We have worked on validation studies for capsule flow such as the static and dynamic pitching moments and forces that are working on them," he said.

"NESC assessments are always challenging because they are related to safety. And they give me the ability to validate ARC capabilities and elevate that capability to the next level so I can apply it to other projects and programs."

Dr. Alonso Vera

Having served for more than a decade as Chief of the Human Systems Integration Division at Ames, Dr. Alonso Vera has spent much of his career understanding how humans interact with increasingly complex and intelligent systems. It was that expertise the NESC needed for its Safe Human Expeditions Beyond LEO assessment, an interdisciplinary study and work-shop focusing on the capabilities needed for astronaut health and safety on long-duration, deep space expeditions.

"For the past 60 years of human space flight, the majority of the tough problem-solving and decision-making has been car-ried out by ground control," said Dr. Vera. "We have not had Earth-independent crewed missions at all." Living on the Moon and Mars, astronauts will be responsible for everything from solving anomalies and handling emergencies to equipment maintenance and medical intervention with either time-lagged or no assistance from ground control.

"Through the NESC assessment, we went a long way to characterizing what activities during spaceflight are safety critical or time dependent and came up with a core set of recommendations of the research that needs to happen before these long-term missions begin. The process of identifying the issues and getting cross-Agency participation on the teams was something the NESC has perfected. We had the ability to look at our risks, assess the consequences, and look for mitigations. It was a very positive experience."

NESC Chief Engineer: Dr. W. Lance Richards

11 AFRC EMPLOYEES SUPPORTED NESC WORK IN FY22

ARMSTRONG FLIGHT RESEARCH CENTER

The Armstrong Flight Research Center (AFRC) provided engineering technical expertise for several NESC activities in FY22. AFRC engineers and instrumentation specialists from the Fiber Optic Sensing System (FOSS) team instrumented a CCP heatshield with a comprehensive array of 500 fiber optic strain sensors, which helped anchor analytical models to quantify structural margin during reentry. The AFRC FOSS team worked with the multi-organizational team to design the instrumentation layout, install the sensor array, support testing, and gather, reduce, and deliver the required dataset to meet the project goals. In FY22, AFRC pilots and life support specialists were also requested to provide expertise and consultation to the Department of Defense (DoD) in response to the 2022 National Defense Authorization Act. These efforts were in direct support of the nation's efforts to better understand the underlying reasons for physiological episodes in the DoD fleet of tactical aircraft.

Tony Chen

Mr. Tony Chen is an aerospace engineer in the Aerostructures Branch at AFRC. Since coming to NASA in 1999, his job has been to ensure flight structures are airworthy, from determining flight loads and performing stress analysis to conducting structural ground tests and participating in flight tests. For the past 6 years, Mr. Chen has been a member of the Structures Technical Discipline Team where he participates in monthly and annual meetings with structures experts across the Agency and the country.

"The regularly held meetings let team members learn from each other and establish collaborations," he said. "The platform also allows members to meet experts in the various areas within the structures discipline, and the hosted site visits provide opportunities to see how structures hands-on work is done at each participant's home facility. The information we receive and the partnerships we develop are tremendous in furthering our advances in the structures technical area."

He also enjoys talking with his structures peers about the many different projects they are working on. "I've learned that every center does things a little differently, and I can take that back and improve how we do business here at Armstrong."

Jonathan Lopez-Zepeda

An early-career engineer with the Advanced Systems Development Branch at AFRC, Electronics Engineer Mr. Jonathan Lopez-Zepeda is taking every opportunity to soak up NASA knowledge. His work often includes mechanical design integration, environmental testing, as well as systems engineering. Currently he is splitting his time between the CryoMag Project, an Early Career Initiative, and working with AFRC's FOSS Team.

Recently he had the opportunity to assist on an NESC assessment as the FOSS team instrumented the heatshield of a commercial provider's spacecraft to acquire strain measurements during an acceptance test program. The team uses fiber optics to measure strain, temperature, shape deformation, loads, and other key parameters to understand a structure's performance.

"My role was to shadow the team so that I can take the lead on the next project. Since I'm a new hire, I'm still learning the ropes and understanding the sensor installation, how that strain measurement data are collected, and how we make sense of it. I see how useful this technology can be for the industry and how important it is to get it out there," he said. "It's not something I expected to work on but has definitely been a cool project and team to be a part of."

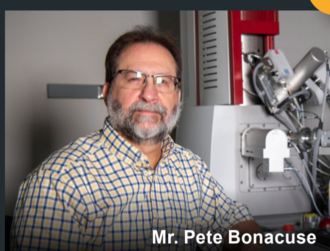
NESC Chief Engineer: Robert S. Jankovsky

73 GRC EMPLOYEES SUPPORTED NESC WORK IN FY22

GLENN RESEARCH CENTER

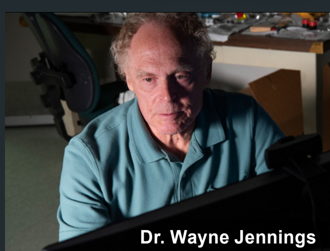
The Glenn Research Center (GRC) provided a broad spectrum of technical expertise to 27 NESC technical assessments/activities and 18 NESC Technical Discipline Teams (TDT). These activities supported all NASA mission directorates and several cross-cutting discipline efforts. The NASA Technical Fellows for Cryogenics and Loads & Dynamics, and deputies for the Cryogenics, Electrical Power, Thermal Control & Protection, Propulsion, Nuclear Power & Propulsion, and Software TDTs, are resident at GRC.

ASG Group

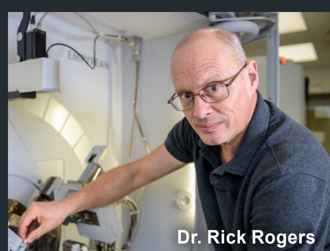


Mr. Pete Bonacuse

Dr. Anita Garg



Dr. Wayne Jennings



Dr. Rick Rogers

With only small samples of a failed engine component, GRC's Analytical Sciences Group (ASG) was able to determine the root cause of its failure. Using a series of sophisticated analytical tools, the group, led by Mr. Pete Bonacuse, found the answers in the microstructure of the failed material.

The forensic analysis began with scanning electron microscopy and energy dispersive spectroscopy that allowed Dr. Wayne Jennings to determine the microstructural makeup and detailed composition of the material down to the sub-micron scale. Next, Dr. Rick Rogers used X-ray diffraction to characterize and understand the proportion of different phases throughout the thickness of the complicated multi-layered coating and determine resulting product phases after reaction with the environment. Dr. Anita Garg followed with scanning/transmission electron microscopy to complete the analysis at the nanometer scale in regions where a very fine microstructure developed. Together, they revealed the reasons for the failure, which led to new inspection procedures for future engines.

"It's a real-life forensic analysis story," said Dr. Ronald Noebe, who collected and collated the ASG's data. "It took not only these high-tech tools, but more importantly the experts with decades of experience to reconstruct the history that led to the component's ultimate failure. This group was not only influential in resolving this particular problem, but the members of this group individually or together have supported other NESC activities this year and in the past."

Damir Ljubanovic

It was his passion for flying remote-controlled helicopters and a job repairing TVs and audio equipment that ultimately led Mr. Damir Ljubanovic to NASA. The self-taught aeromodeller specializes in power electronics and controls for the GRC Power Management and Distribution Branch where he has developed an advanced modular power system for use across multiple platforms such as those for Gateway and lunar assets as well as a portable equipment panel for astronauts to connect everything from computers to hair dryers. But his recent work with the NESC was a departure from space-bound power system development.

Mr. Ljubanovic was part of a team that built a Medical-Ceramic Oxygen Generator (M-COG) for which he developed the power, controls, and data acquisition systems. The M-COG was designed to provide medical oxygen for hospitals and clinics in remote settings where oxygen is not readily available.

"This need for medical-grade oxygen became so apparent during the Covid pandemic. So many people need oxygen and don't have it." Mr. Ljubanovic's father came from a small Croatian village where electricity and running water didn't arrive until the mid-1960s. "That was another reason I was excited to work on this M-COG project," he said. "It was an honor to help people here on Earth, since I'm usually developing space systems that fly away and never come back."

NESC Chief Engineer: Carmel A. Conaty

96 GSFC EMPLOYEES SUPPORTED NESC WORK IN FY22

GODDARD SPACE FLIGHT CENTER

The Goddard Space Flight Center (GSFC) supported a wide range of NESC work including 47 technical activities using 96 engineers, technicians, and scientists. Key assessments and support activities included Mars Sample Return (MSR) Micrometeoroids and Orbital Debris (MMOD) Protection Review, MSR Orbiting Sample Models Review, Avionics Packaging Engineering Processes and Best Practices, Balloon Program Flight Safety Risk Analysis, Subject Matter Expert Support for Psyche Independent Assessment Team, Materials Expertise Support for Lucy Project Anomaly Review Team, Recommendations on Use of Commercial-off-the-Shelf Guidance for NASA Missions, Verification of Testing Standard for CO2 Partial Pressure in extravehicular activity (EVA) suits, Honeywell Miniature Inertial Measurement Unit Operational Life Investigation, and Galvanic Corrosion in Microfabricated Detectors and Microelectromechanical Systems Devices. In addition, the NASA Technical Fellows for Systems Engineering, Mechanical Systems, and Guidance, Navigation, & Control, as well as the NESC Chief Scientist, reside at GSFC.

Scott Hull

Credit: Kristin Rutkowski

As the Lead Orbital Debris Engineer at GSFC, Mr. Scott Hull assesses the orbital debris risks to both spacecraft and the environment by performing risk assessments and debris simulations prior to launches and spacecraft reentry. “We have a small team, and I work on as many as 40 different missions, usually about 6 at a time.” Currently that list includes satellites in NASA’s Earth Observing System, Heliophysics missions that explore the sun, and the tracking and data relay satellite (TDRS) constellation of communications satellites.

Mr. Hull’s MMOD expertise has been vital to several NESC assessments, most recently with an MSR MMOD protection review, helping to evaluate plans for shielding the Earth Entry System and the detection systems that will protect it from damage. He has previously contributed to studies of the shielding of the JPSS-1 spacecraft, on-orbit anomalies potentially resulting from debris impacts, and detailed examination of NASA’s orbital debris and meteoroid environment models.

“I would never get to meet a lot of these folks if it were not for the NESC assessments. It’s an opportunity to work with the nation’s and even the world’s experts in some fairly esoteric topics, and I’ve learned so much from them. Every time we meet, I learn something.”

Marta Shelton

Ms. Marta Shelton specializes in communications, most often applied to small satellites. “As a big proponent of optical communications, I have been in studies exploring the feasibility of its infusion into science missions,” she said. Ms. Shelton designs antennas, participates in small satellite design reviews, and supports the Mission Design Lab. Her work in signal processing has translated well to several NESC assessments. Her contributions to the Pilot Breathing Assessment—she was the first to map time relationships between aircraft systems and pilot breathing to improve pilot safety—made her a perfect choice to analyze data on spacesuits for exploration missions.

“Carbon dioxide buildup is a concern on long duration EVAs, and while standards for ambient spaces have been established, gas flow and mixing is a little different in a smaller volume, enclosed, and pressurized spacesuit.” She led a data analysis team that poured through 20 hours of JSC human-in-the-loop test data and methods for future spacesuit requirements and acceptance testing. “To work and learn from the best minds from all NASA centers is truly a gift. NESC work takes me outside of well-defined branch work, broadens my horizon, and fulfills my never-ending curiosity towards science and technology.”

NESC Chief Engineer: Kimberly A. Simpson

100 JPL EMPLOYEES SUPPORTED NESC WORK IN FY22

JET PROPULSION LABORATORY

The Jet Propulsion Laboratory (JPL) provided technical leadership and engineering expertise to 25 new and ongoing NESC assessments and all 20 Technical Discipline Teams (TDT) in 2022. JPL's expertise in composite overwrapped pressure vessels (COPV), avionics, software, environmental monitoring, additive manufacturing, mechanical structures, and thermal analysis supported assessments for a variety of NASA's mission directorates. Significant contributions included assessment of electrical, electronic, and electromechanical (EEE) parts, COPV stress rupture analysis, wire and wire bundle ampacity testing and analysis, space radiation shielding, RAD750 failure investigation, and thermal testing in support of lunar glove thermal analysis. More than 50 JPL employees served on TDTs working with NASA Technical Fellows on advancement of Agency engineering initiatives. JPL provides leadership for the COPV Working Group, and the Space Environments TDT deputy resides at JPL.

Dr. Mark Balzer

After 24 years at JPL, Dr. Mark Balzer is widely known as a Mr. Fix-It. "I have deep knowledge and experience in mechanisms, structures, materials, lubrication, manufacturing, and detailed design," he said, which makes him a popular problem solver. A Principal Engineer in JPL's Mechanical Engineering Division, Dr. Balzer mentors engineers who design, assemble, and test space mechanisms, helps out in the Bearing Processing and Mechanisms Development labs he founded, and serves on design review boards, anomaly review boards, and tiger teams.

Dr. Balzer has been a member of the Mechanical TDT since 2008, working most recently on the Solar Array Drive Assembly for the Joint Polar Satellite System, a 2-stage gearbox for Orion and ISS, and the SLS Main Engine Prevalve clutches. He is member of the committees responsible for NASA-STD-5017 and NASA-STD-5020, and the standing review board for the Dynamic Radioisotope Power System.

"I love solving challenging problems, and the ones that rise to the NESC level are the most challenging of all," he said. "I live to learn and view every NESC project as an opportunity to work alongside subject matter experts in the various TDTs and learn things that don't appear in any textbooks."

Dr. Elan Borenstein

Aerospace Nuclear Safety Engineer Dr. Elan Borenstein is part of a team within JPL's Mechanical Systems Engineering, Fabrication, and Test Division that characterizes potential launch accident environments for NASA missions involving radioisotope power systems. "We specify the blast, fragment, and thermal environments from either liquid or solid propellant and perform aerothermal heating and reentry breakup analyses," he said of his group, which includes Dr. Don Li and Dr. Shervin Taghavi. They bring their experience to the Liquid Oxygen (LOX)-Methane Quantity-Distance assessment to define the possible hazards of LOX/methane propellants in the event of a potential launch accident.

"The NESC has the reach to organize the many stakeholders in a way that probably wouldn't be possible otherwise," Dr. Borenstein explained. "That makes the project a bit unique." The JPL group will bring their familiarity with working across multiple organizations to understand the variety of launch accident environments to this new task. He said the suite of tests that must be designed will be challenging, but he and his team are excited to bring their voices, needs, and concerns to the table. "We have been wanting to conduct these types of tests for many years, and now we have the opportunity."

NESC Chief Engineer: Joel W. Sills

100 JSC EMPLOYEES SUPPORTED NESC WORK IN FY22

JOHNSON SPACE CENTER

Diverse engineering personnel from the Johnson Space Center (JSC) and the White Sands Test Facility (WSTF) contribute to engineering analysis, design, test, and operations expertise to the ISS, the first launch of Orion and SLS, the Commercial Crew Program vehicles, the lunar Gateway elements and system, and the Extravehicular Activity (EVA) and Human Surface Mobility Program. Both JSC and WSTF personnel lead and act as consultants on assessment and support tasks including Soyuz landing reconstructions; occupant protection testing; SLS frangible joint investigations; multiple propulsion and lunar material investigations; and support the ISS EVA mobility unit investigation and the Russian PrK crack investigation team. The resident NASA Technical Fellows continue their mission with other Agency discipline leaders to strengthen technical community connections through joint sponsorship and participation in activities such as the Structures, Loads, Mechanical, and Materials Systems Early Career Forum and the Thermal and Fluids Analysis Workshop.

Joy Hamilton

Khadijah Shariff

As a chemist and an engineer at WSTF, Ms. Joy Hamilton has been instrumental in broadening the NESC's understanding of how propellants impact the materials NASA chooses for space exploration. She has provided theoretical calculation and modeling to determine the role of helium concentration in ignition fluid to mitigate hard engine starts; characterized the leak behavior of RP-1 propellant to mitigate risks to astronauts and ISS crew; and examined propulsion system sensitivities to monomethylhydrazine and nitrogen tetroxide exposure under different environmental conditions to help fill knowledge gaps.

Currently her focus is on defining the mixing hazards of liquid oxygen and liquid methane in storage and fueling, which has introduced her to explosives and cryogenics. "It's a benefit for me and WSTF to learn from this and help address an Agency concern for commercial vehicles and launch pad infrastructure," she said. "The NESC assessments have been incredibly important work. I was deeply affected as a young adult by the Columbia accident and knowing this work could help mitigate future accidents gives me a strong passion for my work. I can see the implications and effects these efforts will have for decades to come. From an NESC perspective, I'm really humbled by what we do."

Ms. Khadijah Shariff, a structural engineer, has participated in the Structures, Loads & Dynamics, Materials, and Mechanical Systems (SLAM^{2}S) Early Career Community since 2015. Now she is on the leadership team and is co-organizing the 11th Annual Early Career Forum, which is designed to allow early career engineers (ECE) to showcase their work, network with peers, and discuss technical issues with NASA's top leaders in each discipline. "SLAM^{2}S is a great development opportunity, and I'm happy to be a part of it," said Ms. Shariff. "ECEs from across the Agency get feedback and guidance from NASA Technical Fellows and mentors. Personally, I've learned about many different discipline areas I would have never learned about otherwise."

Recently, Ms. Shariff consulted on the model verification of the SLS mobile launcher. "It was a great experience to see how senior engineers handle large technical problems," and a chance to broaden her Artemis Program horizons beyond her work on the Orion crew module. She also helped in the analysis and testing of wire and wire bundle ampacity to understand the forces wires exert on each other as they go through temperature cycles. "This allowed me to see where thermal analysis and structural analysis intersect."

NESC Chief Engineer: Stephen A. Minute

43 KSC EMPLOYEES SUPPORTED NESC WORK IN FY22

KENNEDY SPACE CENTER

The Kennedy Space Center (KSC) provided technical expertise to 43 NESC activities and Technical Discipline Teams (TDT) in 2022. KSC personnel engaged in numerous NESC assessments including: hypergolic propellant contamination analysis; additive manufacturing risk reduction assessment for the Agency; spacesuit water membrane evaporator testing; and galvanic corrosion and degradation of metallic films on circuit boards. Likewise, the NESC provided technical support to KSC programs. The NESC provided the Commercial Crew Program with composite heatshield and parachute analyses. The NESC provided expertise in support of Exploration Ground Systems gaseous nitrogen facility supply issues; ground and flight systems helium contamination evaluation; and mobile launcher umbilical clearance analysis. 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 laboratories to evaluate anaerobic hydrogen sensor development and hydrazine synthesis and contamination analysis for the Agency.

Leonard Duncil

A 35-year NASA veteran, Mr. Leonard Duncil is part of the Environments and Launch Approval Branch of the Agency's Launch Services Program where he works to understand the internal and external flow dynamics of the rocket environment. The breadth of his experience makes him an asset to the Aerosciences TDT, where he enjoys opportunities to solve NASA's aerodynamic-related technical challenges.

Recently, Mr. Duncil assisted in the depressurization modeling of a business jet being modified at LaRC to include a window in the aircraft's floor. "This problem was similar to the work we do to determine the pressure differentials between the compartments of a spacecraft and its fairing," he said. "We have modeling capability that looks at how the fairing reacts to depressurization and responds to changes in external pressure during transonic flight." Mr. Duncil brought those models to bear to help his LaRC peers understand the delta pressure across the aircraft's floor and the velocities at the vent connections between the floor and the cabin as air exits the new window. "It's like a puzzle every day. The TDT leverages the capability of the Agency, which has been a great learning experience and helped me grow as an engineer. And in turn, the TDT connects us with people who can help us solve problems within Launch Services."

Dr. Eliza Montgomery

When Halley's comet last made an appearance, Dr. Eliza Montgomery was 10 years old, and she has been hooked on space ever since. Today she is the KSC Corrosion Technical Lead and an Agency-wide subject matter expert in corrosion and electrochemistry. Her work spans NASA projects and programs and the environmental control and life support community. As manager of the KSC Corrosion Engineering Lab, she has performed testing for NASA, its commercial partners, and the Department of Defense. The depth and breadth of her experience has made her invaluable to many NESC assessments, including a recent evaluation of biocide compatibility with hardware for deep space travel.

"We were working to figure out if certain biocides would corrode the interior of future potable water systems and the Exploration Extravehicular Mobility Unit (xEMU)," she said. "I also worked an assessment to determine the health of current ISS EMU sublimators, understanding how pitting could affect their remaining life spans." Her expertise extended to evaluating corrosion of heatshields as well. "For every assessment that I work, I don't come in knowing everything," she said. "So it's been a way for me to grow technically on corrosion and electrochemistry subjects. And that folds back into my regular job and improves it. It's been a positive influence."

NESC Chief Engineer: Mary Elizabeth Wusk

257 LARC EMPLOYEES SUPPORTED NESC WORK IN FY22

LANGLEY RESEARCH CENTER

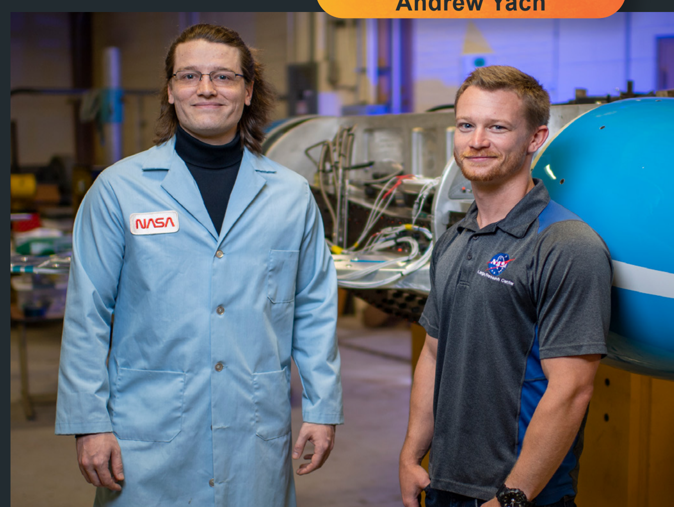
The Langley Research Center (LaRC) continues to provide subject matter experts for NESC technical activities. With the successful launch of Artemis I and the continued success of the Commercial Crew Program, LaRC celebrates the culmination of 170 NESC Artemis-related assessments and the additional 31 assessments in support of the Commercial Crew Program. LaRC's technical activities are reducing risk in NASA's human exploration missions as well as broadening opportunities of discovery aboard the ISS. Furthermore, LaRC's workforce has fabricated ground and flight hardware and led multiple ground and wind tunnel tests, including completing the Aerodynamic Buffet Flight Test, demonstrating the versatility of LaRC's workforce and assets. In FY22, over 257 LaRC employees engaged in 42 assessments, supporting the NESC's mission to perform value-added independent testing, analysis, and assessments of NASA's high-risk projects.

Jonathan Austin

As the CCP Loads Subsystem Manager in the Loads, Induced and Dynamics Environments group, Mr. Jonathan Austin is a key contributor to the NESC and is now technical lead for NESC frangible joint (FJ) assessments. NASA uses the small pyrotechnic joints to assist in spacecraft vehicle staging and fairing separation, and the assessments have helped the Agency test and evaluate their reliability, particularly the FJs used on human-rated vehicles. Before FJs, Mr. Austin brought his aerospace engineering expertise to an ascent cover separation assessment and reviews of thermal protection systems.

"I enjoy the experiences I'm getting through the assessment work," he said. "NESC provides me opportunities to see a wide breadth of issues, and the technical challenges are always difficult and interesting. You get to see how a diverse team works through technical challenges and comes up with unique solutions," a skill he has leveraged in his daily CCP work. "The experiences I have gained through problem solving and interacting with multiple disciplines helps me talk through technical issues with our commercial partners. The NESC does great work—I appreciate the integrity of the teams and the focus on safety, and the value they add to the programs. I'm glad I get to participate in these assessments and help ensure a safe environment for our astronauts."

Cody Pierce and Andrew Yach



When a failed brake system took LaRC's Transonic Dynamics Tunnel out of service for 3 years, contractors Mr. Cody Pierce, Wind Tunnel Test Engineer, and Mr. Andrew Yach, Engineering Technician, were part of the team who brought the tunnel back online. Operating since the 1960s, the wind tunnel has hosted testing that identified and solved many of NASA's aeroelastic issues. It is a highly sought-after facility at LaRC as well as for NESC assessments. "The eddy current brake system controls the speed of our main drive, and replacing the necessary parts was a huge project," said Mr. Pierce, who works with tunnel customers to prepare test plans and objectives, run tests, and ensure the necessary data are collected. Once repairs were finished, Mr. Pierce put the tunnel through a series of tests. "We wanted to ensure everything was working properly before we reopened the tunnel for customers."

Mr. Yach's group was involved in troubleshooting and repairs for the lubrication system. "It involved a lot of trial and error," he said. "The wind tunnel has a great support network of knowledgeable people with varying backgrounds. It was a rewarding challenge." Both were new to the wind tunnel, but each hit the ground running as soon as they arrived. "It was like a crash course," added Mr. Pierce. "It was time to learn how everything is done and start playing a part."

NESC Chief Engineer: Steven J. Gentz

117 MSFC EMPLOYEES SUPPORTED NESC WORK IN FY22

MARSHALL SPACE FLIGHT CENTER

The Marshall Space Flight Center (MSFC) provided engineer, scientist, and technician subject matter expert support to 44 NESC technical activities involving exploration systems development, space operations and environmental effects, science, and crosscutting discipline activities. Some of the more significant efforts included composite shell buckling, additive manufacturing, model-based systems engineering, high-temperature insulation, advanced chemical propulsion, modeling and simulation of launch vehicle/spacecraft interfaces, and human factors task analyses. The NASA Technical Fellows for Propulsion, Space Environments, Environmental Control & Life Support, Flight Mechanics, and Systems Engineering, and the Technical Discipline Team (TDT) Deputies for Propulsion, Nuclear Power and Propulsion, Materials, Space Environments, Loads & Dynamics, Nondestructive Evaluation, Cryogenics, Flight Mechanics, Sensors & Instrumentation, and Software are resident at MSFC.

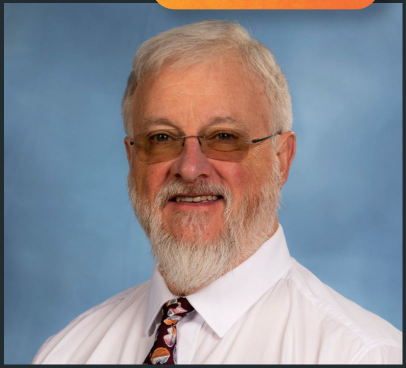
Dr. William Cooke

As the lead of NASA's Meteoroid Environment Office (MEO), Dr. William Cooke has brought his experience in assessing and predicting meteoroid environment risk to many NESC assessments, from studying the potential of micrometeoroid damage to wire harnesses on the James Webb Space Telescope to participating in reviews of NASA's orbital debris model. Most recently he has been part of the NESC team supporting upgrades to the Southern Argentina Agile Meteor Radar (SAAMER) meteoroid monitoring facility. The MEO will use data collected from SAAMER to better model meteor shower activity. "It's interesting to see new radar equipment being used to monitor the meteoroid environment and realize how valuable it can be in helping mitigate the risk to spacecraft and astronauts," he said. As a long-time contributor to NESC assessments, Dr. Cooke said, "All of them are challenging and they let me focus on very specific problems. Plus, they allow me to meet a variety of people both inside and outside of NASA."

Scott Tashakkor

Software supporting NASA's missions comes in many different forms, complexities, and safety criticalities. Mr. Scott Tashakkor uses his knowledge of aerospace and computer engineering disciplines to balance the needs of projects and provide software assessments. "I love the NESC's mission and challenges it takes on." He has supported assessments of life support systems, defect densities in software, and software architecture reviews. "Each assessment allows me to help a project accomplish its goal safely while learning and sharing knowledge about systems." He is a member of the NESC Software TDT, lead of the TDT's Software Architecture Review Board, and a member of several other software sub-teams, and he supports NASA's adoption of artificial intelligence and machine learning techniques. "I feel honored to help the NESC and NASA. It is a dream."

Harry Wise



A 40-year veteran of NASA programs, Mr. Harry Wise brought his considerable expertise in materials and processing to an NESC review of a commercial provider's environmental control and life support (ECLS) systems. The senior materials engineer spent several months reviewing documents, drawings, and material lists for ECLS subsystems to ensure designs were robust, verifications were in place, and requirements had been met. "I am familiar enough with the materials that I will notice when items that provide evidence of a solid design might be missing," he said, a familiarity that comes from years of designing spaceflight hardware for the Space Shuttle, satellites, and flight experiments. "It is flattering to be on such a distinguished team," he said of the NESC. Though much of his work was a solitary endeavor of pouring over documents, he said, "The strength of the team comes in when cross-cutting issues are identified and resolved as a team."

NESC Chief Engineer: Michael D. Smiles

30 SSC EMPLOYEES SUPPORTED NESC WORK IN FY22

STENNIS SPACE CENTER

Expert technical support was provided to the NESC by the Stennis Space Center (SSC), including subject matter expertise in software evaluation, test operations, and data analysis and modeling. NASA Data Acquisition System (NDAS), software developed by SSC for engine test data acquisition, and the expertise of the SSC NASA and contractor experts were utilized to evaluate and improve errant software code for the NESC Thruster Advancement for Low-temperature Operation on Space (TALOS) Assessment. SSC also provided the data analysis and modeling technical lead for the liquid oxygen-methane assessment. SSC also supplied technical expertise and facilities at the A-1 Test Stand for upcoming NESC phased-array microphone system testing.

Alex Elliot

Software Subject Matter Expert Mr. Alex Elliot has worked in the SSC Test Complex for more than 20 years and facilitates software development through process and policy improvements. Currently he works as software developer on the NDAS Project and is part of the electrical design team for the Space Launch System Exploration Upper Stage Green Run testing. Through the NESC, he also represents SSC in the NASA Software Working Group, participating in Agency surveys and data-gathering calls, and reviewing changes to the governing NASA policy requirement.

Recently, he had the opportunity to assist the TALOS Project with a quick-turnaround code review. “My team and I reviewed software code for the test facility and test article and provided a report with recommendations. We also used automated tools to perform static code analysis and cyclomatic complexity assessments to identify problematic areas. We helped focus attention and domain knowledge on their issues and suggested ways to improve,” he said.

“Working on NESC projects has given me the opportunity to experience engineering at other centers, sometimes even in other disciplines. I get to see how other teams operate and uniquely solve common problems and can bring that solution back to my own work. I also get to meet and interact with peers outside of my normal circles and learn about interesting new projects.”

Kristopher Mobbs

A software engineer, Mr. Kristopher Mobbs works as the Project Manager for the NDAS in SSC’s Engineering and Test Directorate. He guides the evolution of the NDAS as well as designs new software used to operate and capture critical data during rocket engine tests.

“NDAS provides a common platform that allows a standardized approach to data acquisition at SSC,” he said. That unique capability was key to helping an NESC team tasked with determining the cause of a low-pressure vent and loss of communications during testing of the TALOS Project.

“My role was as liaison between the NESC and NDAS teams, but it was the whole NDAS team who came together to provide the TALOS Project with the support they needed. It was a critical need for them.”

The effort was Mr. Mobbs’s first NESC project involvement. “What I witnessed was a multi-center, multi-level team focused on identifying a problem and providing a solution. It was nice to see people working with that level of efficiency across the Agency and in a quick-paced, laser-focused way. It gave me an understanding that the approach to a solution is often bigger than what we do at an individual center. It was great to be a part of the solution.”

NESC KNOWLEDGE PRODUCTS

Capturing & Preserving Critical Knowledge from NESC Assessments and Support Activities

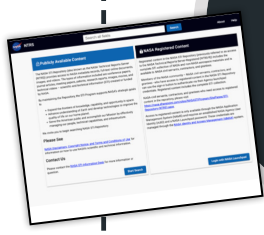
The NESC is engaged in activities to identify, retain, and share critical knowledge in order to meet our future challenges. To disseminate that knowledge to engineers—within NASA, industry, and academia—the NESC develops a wide variety of knowledge products that can be readily accessed including technical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

TECHNICAL PAPERS & CONFERENCE PROCEEDINGS

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

ASSESSMENT ENGINEERING REPORTS

ntrs.nasa.gov



Detailed engineering and analyses generated from each assessment available as Technical Memorandums (TM)

NESC ACADEMY

Live & On-Demand Videos

A library of more than 800 videos containing interviews, tutorials, lectures, and lessons learned relevant to current NASA issues and challenges.

nescacademy.nasa.gov

DISCIPLINE COMMUNITIES OF PRACTICE

nen.nasa.gov

Led by NASA Technical Fellows and other subject-matter experts, houses tools and resources shared by the NASA engineering community

TECHNICAL BULLETINS

Critical knowledge captured from NESC assessments in the form of new engineering information or best practices in a one-page format

NESC ASSESSMENTS AND SUPPORT ACTIVITIES

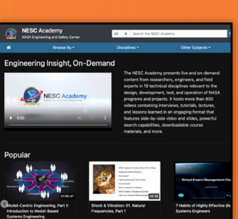
nesc.nasa.gov

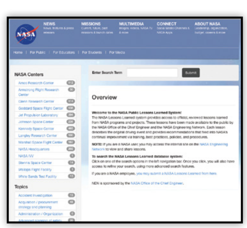
NESC TECHNICAL UPDATES

Annual summary of NESC technical activities including lessons learned, technical bulletins, innovative techniques, discipline features, journal articles, and publications

LESSONS LEARNED

Captured knowledge or understanding gained on NESC assessments that would benefit the work of others





LLIS

Agency-Level Lessons Learned Information System (LLIS)

llis.nasa.gov

Critical Knowledge Released in FY22

No. 22-01

The NESC performed testing to determine if high-speed video techniques can be used to predict the onset of flow-induced vibrations in bellows. A comprehensive test matrix was established to determine if Motion Magnification and Digital Image Correlation can be used to determine the onset of FIV in...

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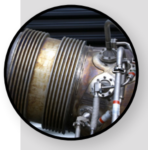

DETECTING FLOW-INDUCED VIBRATION IN BELLOWS

No. 22-02

The NESC performed an assessment of existing filtration standards and guidance documents for propellant and pressurant systems. The assessment included a vendor survey to better understand concerns about filtration systems, defined a common set of filtration and contamination-related...

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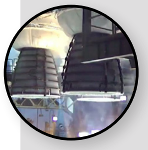

REVISITING FILTRATION STANDARDS AND DEFINITIONS FOR SPACEFLIGHT PROPULSION AND PRESSURANT SYSTEMS

No. 22-03

Analytical and experimental evidence shows that fast-moving dynamic pressure fluctuations caused by valve actuation, fluid-system priming, fluid discharge, vibration, and flow disturbances can elicit adverse structural response and must be considered in the spaceflight pressure system design and verification process.

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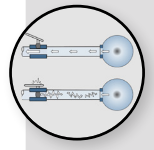

TREATMENT OF TRANSIENT PRESSURE EVENTS IN SPACEFLIGHT PRESSURIZED SYSTEMS

No. 22-05

Launch vehicle ascent stability analyses typically rely on a combination of frequency and time domain analyses. Frequency domain analysis uses a sequence of high-fidelity linear models with constant parameters spanning the ascent trajectory. Complementary time domain analysis is performed using high-fidelity, nonlinear 6-DOF simulations...

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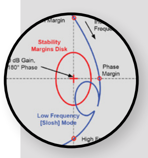

LAUNCH VEHICLE FLIGHT CONTROL STABILITY MARGIN REDUCTION CONSIDERATIONS

No. 22-06

Slosh dynamics pose a stability concern for human-rated launch vehicles during ascent. Historical perspectives on the treatment of slosh dynamics, newly developed rules of thumb, the utility of flight data, and methods for analyzing and dispositioning slosh instability risks should be considered when linear stability margins are lower than typically...

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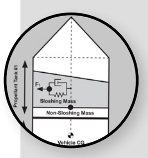

TREATMENT OF SLOSH STABILITY MARGIN REDUCTIONS FOR HUMAN-RATED LAUNCH VEHICLES

No. 22-07

A test program to characterize the solution of helium in nitrogen tetroxide/mixed oxides of nitrogen (NTO)/(MON) and monomethylhydrazine (MMH) at anticipated flight-representative pressures/temperatures was completed. Updated relations for helium solubility in MMH and NTO were generated and documented...

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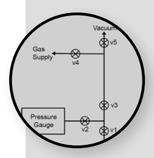

HELIUM SOLUBILITY IN MMH AND NTO

TECHNICAL BULLETINS

Critical knowledge captured from NESC assessments in the form of new engineering information or best practices in a one-page format.

nasa.gov/nesc/technicalbulletins

No. 22-04

Uncertainty quantification provides statistical bounds on prediction accuracy based on finite element model uncertainty. An alternate method for UQ, called the Hybrid Parametric Variation combines a parametric variation of the Hurty/Craig-Bampton fixed-interface modal frequencies with a nonparametric...
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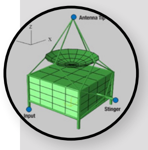

UNCERTAINTY QUANTIFICATION OF REDUCED ORDER STRUCTURAL DYNAMIC MODELS

No. 22-08

Hydrazine and its derivatives are used ubiquitously in liquid propulsion systems. In smaller thruster systems, contaminant build up has historically caused flow decay and consequently, performance losses. Many of these contaminants are not controlled by the current revision of MIL-PRF-26536, the high purity hydrazine procurement...
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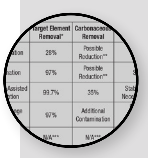
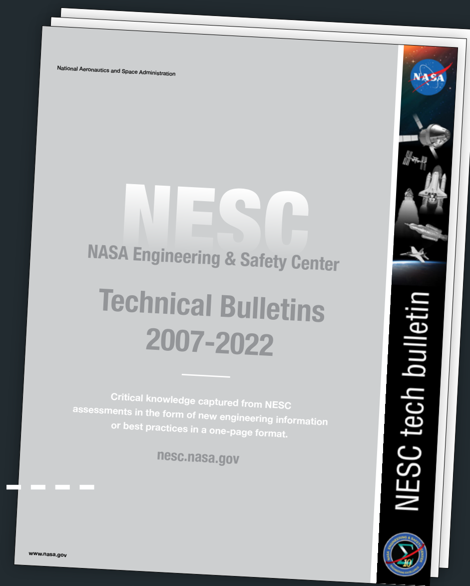


CONTAMINANT REDUCTION IN HIGH PURITY HYDRAZINE



Scan to see all NESC Technical Bulletins in one easy-to-read document.

LESSONS LEARNED

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

llis.nasa.gov

LLIS ENTRY 31403:

Released August 2022

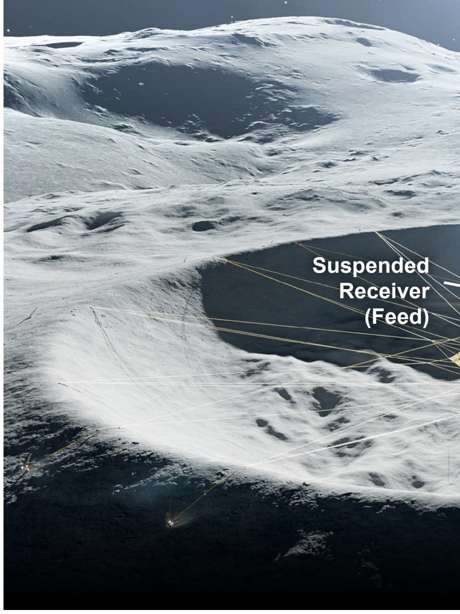
Controlling Triboelectrification Effects on Spacecraft Ethernet Cabling

LLIS ENTRY 31801:

Released October 2022

AIAA/ANSI Standard S-120A-2015_R2019, Mass Properties Control for Space Systems

SCIENCE
Dr. Azita Valinia,
NESC Chief Scientist



HOW DO WE SUSTAIN HUMAN EXPLORATION IN THE ARTEMIS ERA?

Planning is underway at NASA for returning humans to the Moon, followed by human missions to Mars. Astronauts will again venture outside the protective shield of the Earth's magnetosphere, this time for durations of months to several years, where they will be vulnerable to long-term exposure from radiation and microgravity or low gravity environments. Keeping the astronauts safe and healthy during these long-term expeditions is an enormous challenge and so is the enormous price tag that comes with accomplishing such a grand feat. So what will keep such endeavors sustainable after the novelty of "been there" and "done that" wears off? The answer is simple: Science! Making groundbreaking discoveries spanning pure and applied sciences as a key part of Artemis goals provides a long-term sustaining rationale, beyond just exploration for its own sake. The success of the Hubble Space Telescope (HST) servicing missions to upgrade and repair the telescope to advance astrophysics is a shining example of what can be accomplished when NASA human exploration and science programs partner towards a common goal.

The Moon – A Platform for Science

Scientific exploration, whether of the Moon itself, or the use of the Moon as a platform for scientific studies, will play a great role in fueling sustainable human exploration. For example, since the beginning of the space age, the Moon has been proposed as a platform for astronomical observatories. With the NASA Artemis plan to return humans to the lunar surface in the mid-2020s, there is renewed interest in using the Moon as a unique location for scientific studies ranging from observing our solar system to studying the early universe before the first stars were born. Great opportunities lie ahead to advance ground-breaking science using the synergy between human and robotic scientific exploration. For this reason, a workshop, *Unique Science from the Moon in the Artemis Era*,[1] bringing together stakeholders from science, engineering, technology, and human exploration communities was sponsored by the NESC in June 2022 to accomplish the following:

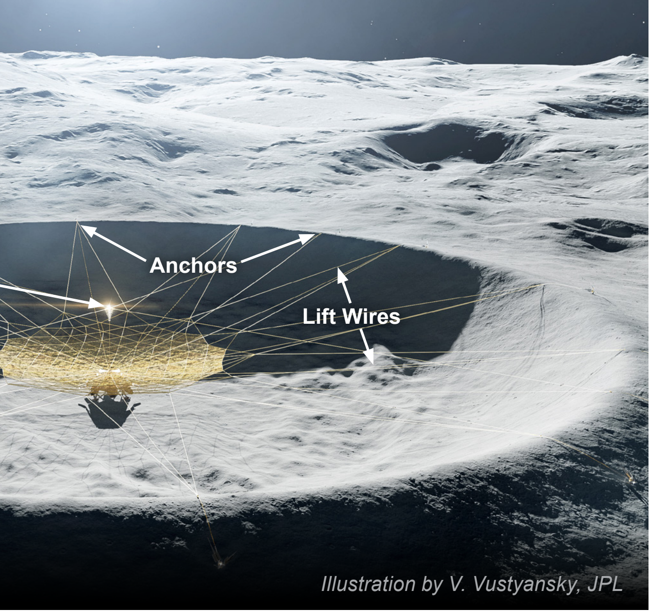
- Explore leveraging Artemis-era infrastructure to conduct unique science experiments and observations from the lunar surface and maximize return on investments,
- Advance synergistic approaches between human and scientific robotic exploration, and
- Identify/address key engineering challenges and risks.

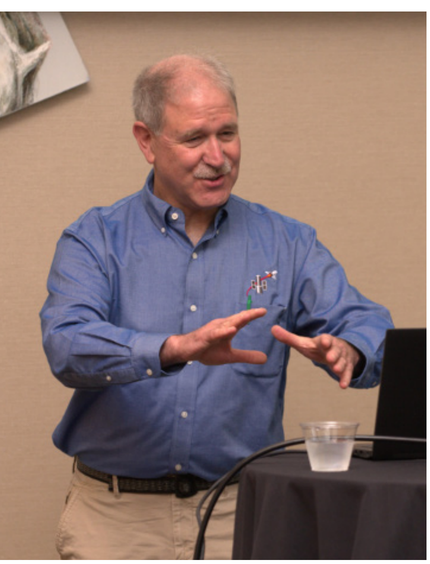
Over 400 attendees participated in the hybrid workshop that was held at KSC and online. The workshop began by identifying unique and compelling astrophysics science studies that can only be accomplished from the surface of the Moon. Among the possibilities, the workshop focused on studies that NASA has already funded to robotically place a low-frequency radio telescope on the far side of the Moon[2] to study the Dark Ages of the Universe (the epoch before the first stars were born) and radio emissions from the Sun and exoplanets orbiting nearby stars. One of these studies focused on placing a low-frequency radio telescope (Lunar Crater Radio Telescope[3]) inside a lunar crater. If built as proposed, it will be one of the largest radio telescopes in the solar system and would enable tremendous scientific discoveries in cosmology. While it is feasible that such a telescope could be assembled robotically, leveraging the Artemis infrastructure has the potential to be more efficient and cost effective.

Achieving Synergy Between Human and Robotic Exploration

A key element of the NESC workshop was to identify how the human exploration program can be leveraged to achieve ground-breaking science. There have been past successful examples of this, with the most spectacular being the Space Shuttle launch of the HST and subsequent servicing missions. More recently, this has been accomplished via science experiments attached to the ISS. For a future lunar base camp with science facilities, there are analogies with the Amundsen-Scott South Pole Station in Antarctica, which provides a hub for scientific activities, including telescopes to study the cosmic microwave background and neutrino experiments.

Exploiting the infrastructure provided by the human exploration program will have major benefits both in cost savings to the science program and its sustainability (e.g., via potential upgrades and repairs of facilities). As demonstrated by HST and the ISS, there is the potential for major groundbreaking science to be achieved when the human and science programs work together. Currently, science requirements are retrofitted to the capabilities of the early Artemis missions. This is understandable given that early missions are to demonstrate basic capabilities, but this limits the science return. Just as the later Apollo missions made science a driving goal with increased capabilities,





the workshop concluded that we must be vigilant to ensure that science requirements are not afterthoughts for Artemis missions in the 2030s and 2040s. It is critical that architectural elements to enable ground breaking science be included in the Artemis requirements at an early stage of the Artemis Program.

A focus of the workshop was the synergy between human and robotic scientific exploration. The presence of humans on the lunar surface is an opportunity to deploy, repair, and upgrade any scientific instruments and observatories there. It is essential to optimize the role of robotics versus humans and to only use the latter where appropriate. A key feature is to ensure that telescopes that have been robotically landed and deployed, or those that have been manufactured in situ, are designed to be serviced. In a keynote speech, former astronaut John Grunsfeld discussed the lessons learned from HST and the ISS and made the compelling point that having standards (e.g., using the same bolt sizes and accessible connectors, and providing easy access) is crucial. This provides the ability to recover from unexpected events and failures, as well as upgrade existing facilities with new technology, ensuring sustainability.

Meeting the Engineering Challenges & Risks

Engineering challenges and risks associated with synergistic human and robotic exploration was another discussion focus of the workshop. While the lunar surface environment is challenging with dust contamination, large thermal swings, and extreme shadows at the lunar poles, and power generation and storage technologies will need to be developed, no showstoppers to using the Moon as a platform for science observatories were identified, but careful planning is needed. For example, adequate low-frequency radio frequency interference testing, screening, and shielding must be considered and standardized for all spacecraft and payloads that will be visible from the lunar radio quiet zone.

In summary, to ensure sustainability of the human exploration program and provide added return on investment, the workshop concluded that integration of science requirements into the Artemis Program at an early stage is a must. Otherwise, human exploration that does not include science as one of the primary objectives is a missed opportunity and is likely to result in the exploration program not being sustainable.

Top: Illustration depicting the concept of the Lunar Crater Radio Telescope on the far side of the Moon. Middle: Astronaut John Grunsfeld servicing HST. Bottom Left: Grunsfeld giving the keynote speech on synergy between science and human exploration. Bottom Right: NESC Workshop, "Unique Science from the Moon in the Artemis Era", held July 2022 drew over 400 participants at KSC and online.

1. https://www.nasa.gov/nesc/workshops/Unique-Science-from-the-Moon-in-the-Artemis-Era
2. https://www.nasa.gov/directorates/spacetech/niac/2020_Phase_I_Phase_II/lunar_crater_radio_telescope/
3. Observations of the radio band below 30 MHz cannot be made from the ground due to absorption from the Earth's ionosphere. These observations can only be made from the far side of the Moon since the Moon acts as a physical shield that isolates the telescope from radio interference from sources on and around the Earth's orbit.

PROPULSION
Dr. Daniel J. Dorney,
NASA Technical Fellow
for Propulsion (Retired)

NESC HELPS FILL GAPS IN PROPULSION KNOWLEDGE

After 22 years, Dr. Daniel Dorney, the NASA Technical Fellow for Propulsion, retired in August. Before he left, he reflected on a few of the more than 30 propulsion-related activities he led for the NESC and how expanding NASA's propulsion discipline would be key to driving future exploration.

Seven-year-old Daniel Dorney was awestruck when Apollo 11 landed on the Moon, and he decided right then he would build his own, full-size Saturn V rocket. While collecting supplies, e.g., scraps of wood, wire, and bolts, he penned a letter to NASA Lewis (now NASA Glenn) requesting the rocket's plans. A NASA engineer kindly replied that the plans couldn't be shared, but Dorney wasn't deterred. He sent a follow up letter with the plea, "But I really need the plans." The same engineer responded, but this time with a blueprint for a kid-friendly rocket that required easier to find materials like juice cans and glue.

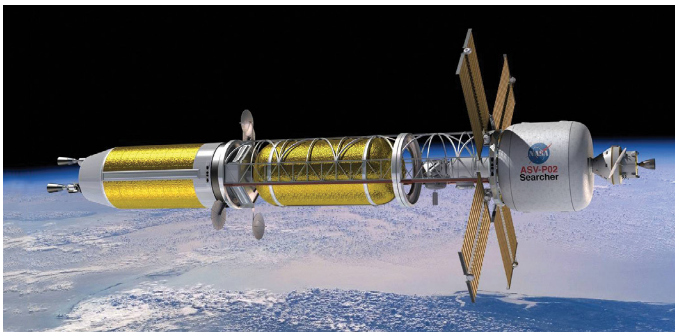
"That engineer took the time to answer not only one of my letters but two," said Dr. Dorney. "That got me interested in astronomy, which got me interested in aerospace engineering."

Whether by correlation, causation, or coincidence, Dr. Dorney ended up at NASA, ultimately serving as the Commercial Crew Program Launch Vehicle Chief Engineer and working the console for the first orbital test of the SpaceX Falcon 9 booster and Dragon 2 spacecraft. He was then competitively selected by the NESC to be the Agency's Propulsion Technical Fellow.

In the last four years, Dr. Dorney has led more than 30 technical activities for the NESC, resolving propulsion anomalies with flight programs, delving into issues that have plagued the propulsion community since the Apollo era, and researching future technologies like nuclear propulsion that may help propel mankind to Mars and beyond.

First launch of the SpaceX Crew Dragon

One of his first assessments addressed the unexpected loss of an O-ring[1] supplier that affected many NASA programs including Orion, Commercial Crew, and Mars 2020, which used O-rings in many of their pumps and valves. Dr. Dorney assembled a team of experts to look at replacement materials, an effort that took them to the White Sands Test Facility (WSTF) to assess the compatibility of the proposed alternates with NASA propulsion systems. “This assessment was so timely, and our results generated requests from all over the world because it was a question so many were trying to figure out.”



Nuclear electric and thermal propulsion systems may be required for future Mars missions (conceptual spacecraft shown above).

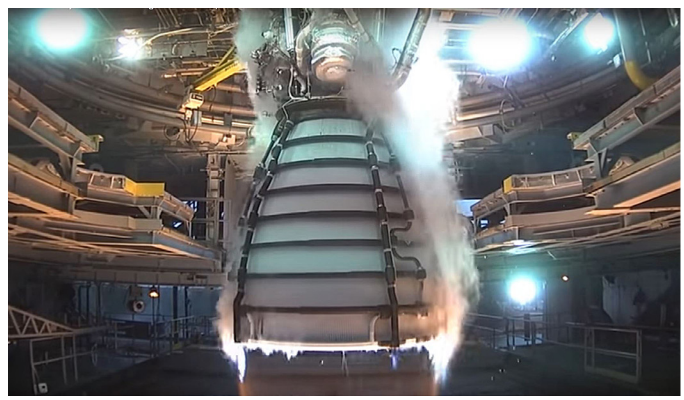
His plate stayed full, analyzing gas generator baffles, determining fundamental autoignition characteristics of isopropyl alcohol and ethanol,[2] performing transient combustion modeling, and characterizing the thermal performance of insulation. Programs requested his help to find answers to various valve and thruster issues. In 2020, he began an evaluation of nuclear electric and thermal propulsion systems, both technologies being considered for Mars missions planned for the 2030s. “The assessment was a balancing act. We found some of the smartest people in nuclear propulsion with each half of the team supporting one type of propulsion.” The team helped determine technology maturity, find technology gaps, and guide architecture design and investment focus for Mars missions. “We ended up with a good final product and are still getting requests for that report.”[3]

Dr. Dorney also focused on addressing propulsion issues that have puzzled the propulsion community for decades with studies in material sensitivities, understanding cavitation[4] in hydrogen peroxide, filtration[5] standards for pressurized propulsion systems, helium solubility in propellants, using techniques like motion magnification to analyze gimbaled bellows,[6] and updating and modernizing codes for combustion analysis.

Most recently, his team assessed the effects of pressure spikes on materials in hypergolic engines. “Pressure spikes and transients have been an issue for many programs and the issues have persisted since the Apollo Program.” While programs have found work arounds, a real solution was needed. “As providers look to reuse engines and components, there is a potential for accumulated damage from these spikes,” he said.

Testing and modeling of a hypergolic engine provided data on a material’s capability to withstand pressure spikes and the magnitudes that would cause material damage. To broaden the scope, he initiated an assessment to design, build, and test a highly instrumented 10-lbf class hypergolic thruster to pinpoint the origin and root cause of these pressure spikes. The results would be available to any organization using these types of thrusters.

“I’ve tried to focus my recent efforts on propulsion testing. A lot of people think we’ve done all we can with launch vehicle engines, that we understand everything with chemical propulsion, but there is still a lot more to be done. If we’re going to become interplanetary travelers, we have to work on ways to get to Mars in under 6 months and change the paradigm from here to the Moon. We need propulsion to get us further out much faster. I don’t think there is any part of the propulsion portfolio that we should stop investing in.”



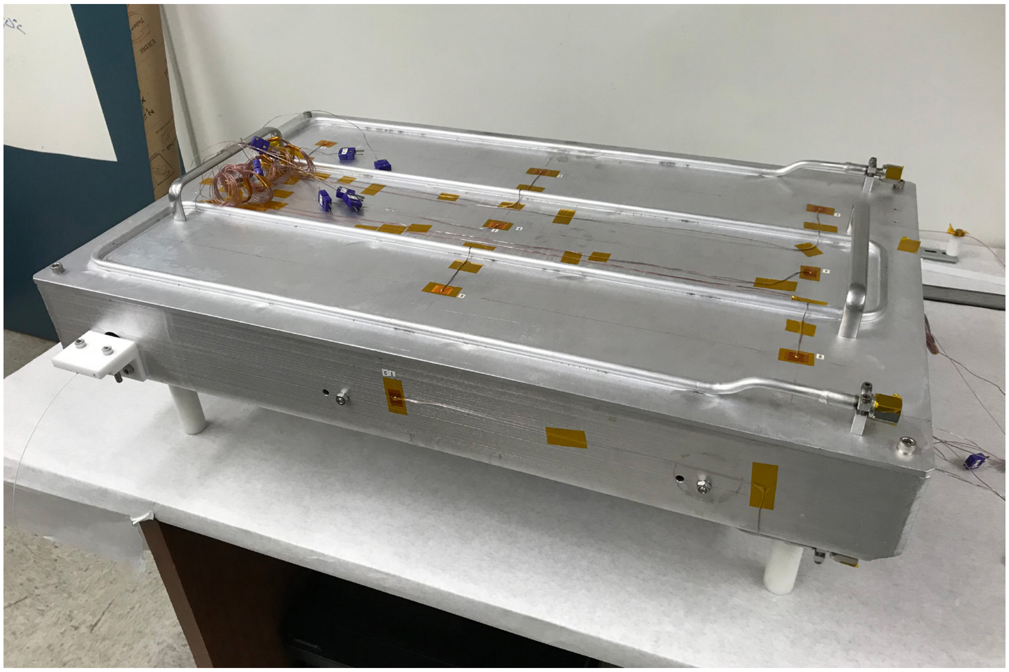
Propulsion testing is a crucial step in launch vehicle development.

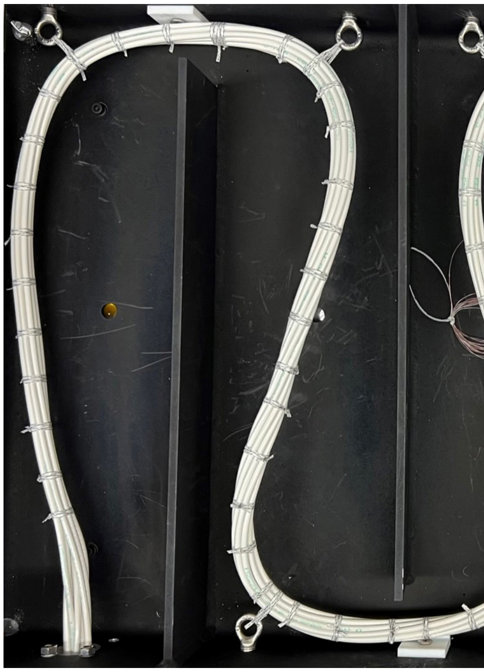
After four years as the propulsion Technical Fellow, Dr. Dorney said it was time to retire. “In this position, 3 to 4 years is a good amount of time. Now it’s time to have the benefit of someone who has a different outlook and skill set so that the propulsion community gets to see another point of view.”

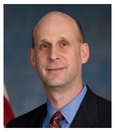
While the awestruck 7-year-old’s homemade Saturn V didn’t much resemble the one that landed on the Moon, it did likely launch his career in propulsion and put him on a road to the aerospace industry, a tenured engineering professorship, and ultimately to NASA. But what propelled him most were the people he worked with along the way.

“I have a broad colleague base,” he said, from his technical discipline team to the U.S. military and within academia. “I get a lot of questions that I don’t always know the answer to, but I know who will know the answer. And that is huge.”

1. NESC Technical Bulletin No. 20-04: Alternative O-Rings for Hypergolic Propellant Systems.
2. NESC Technical Bulletin No. 20-05: Determination of Autogenous Ignition Temperature of Isopropyl Alcohol and Ethanol.
3. Assessment of the Technical Maturity of Nuclear Electric Propulsion and Nuclear Thermal Propulsion Systems. NASA/TM-2020-5006807.
4. NESC Technical Bulletin No. 21-01: Experimental and Computational Study of Cavitation in Hydrogen Peroxide.
5. NESC Technical Bulletin No. 22-02: Revisiting Filtration Standards and Definitions for Spaceflight Propulsion and Pressurant Systems.
6. NESC Technical Bulletin No. 22-01: Detecting Flow-Induced Vibration in Bellows.







THERMAL CONTROL & PROTECTION
Steven L. Rickman, NASA Technical Fellow for Thermal Control & Protection

RE-ARCHITECTING THE NASA WIRE DERATING APPROACH

Phase II: Wire and Wire-Bundle Ampacity Testing and Analysis

Design of wiring for aerospace vehicles relies on an understanding of current carrying capacity (i.e., ampacity) of individual wires or wires in bundles. Limiting current flow in wires is required to prevent exceedance of wire temperature limits due to resistive heat dissipation. Exceeding the wire temperature rating can result in electrical, physical, and/or chemical degradation of the wiring insulation and conductor, which could lead to a catastrophic failure.

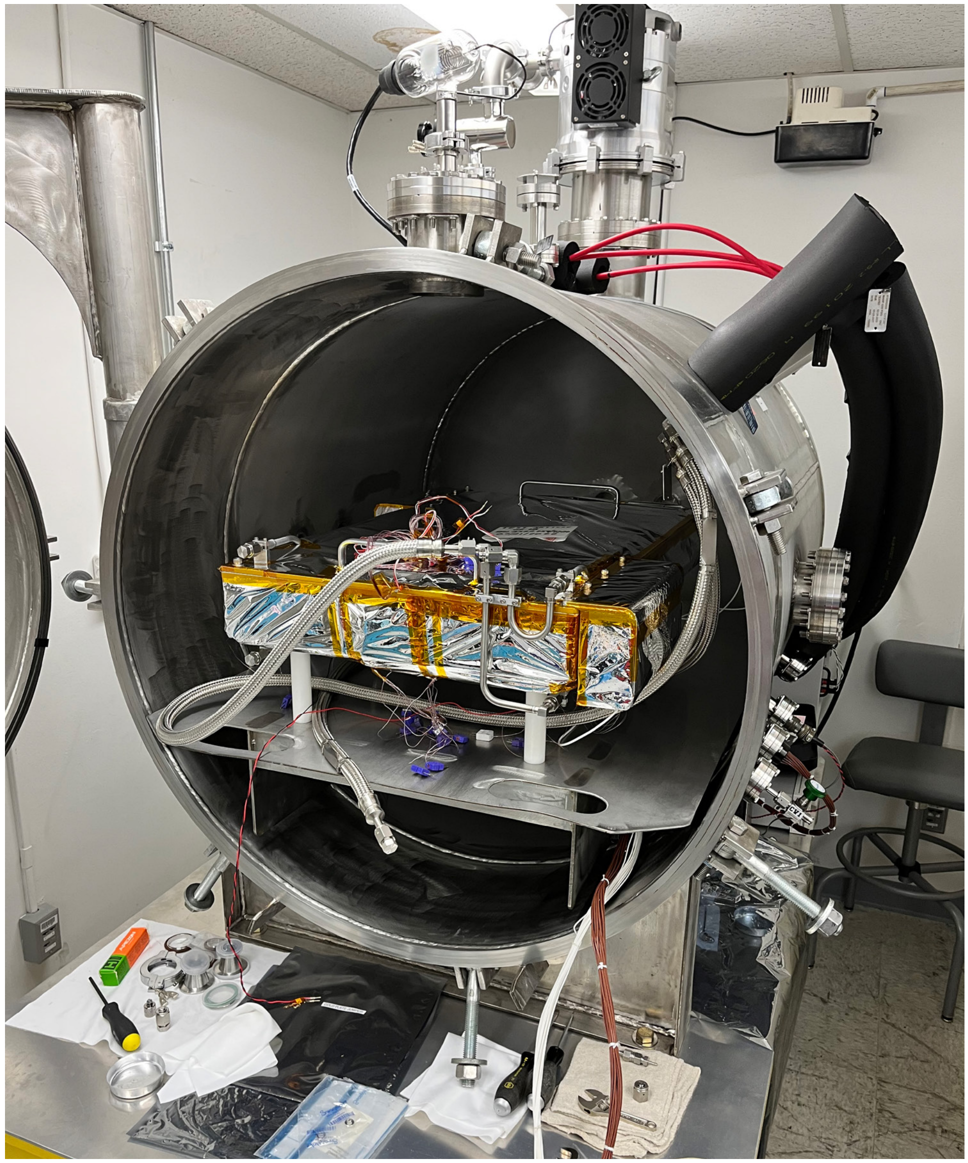
Under current practice, designers rely on standards to derate allowable current flow. But these standards are based on empirical data that are no longer available for review and can add or underestimate the margin. A model-based solution is therefore desired.

In 2018, the NESC completed a successful pathfinder study to determine the feasibility of using physics-based wire and wire-bundle thermal models as a potential replacement to the standards. A physics-based model might offer more predictive capability using variables such as bundle size; environment temperature and pressure; and wire conductor alloy, plating, insulation jacket weight, and type.

A follow-on study began in 2021 and aims to extend the testing, model development, and correlation with the goal of developing a tool to aid designers in wire selection and sizing.

Using Design of Experiments (DOE) techniques, an efficient wire and wire-bundle test matrix has been developed. Key wire properties for test articles such as resistance per unit length and wire jacket infrared transmissivity have been measured. Wires and wire bundles are undergoing testing at the Jet Propulsion Laboratory in a custom vacuum chamber with a temperature-controlled shroud.

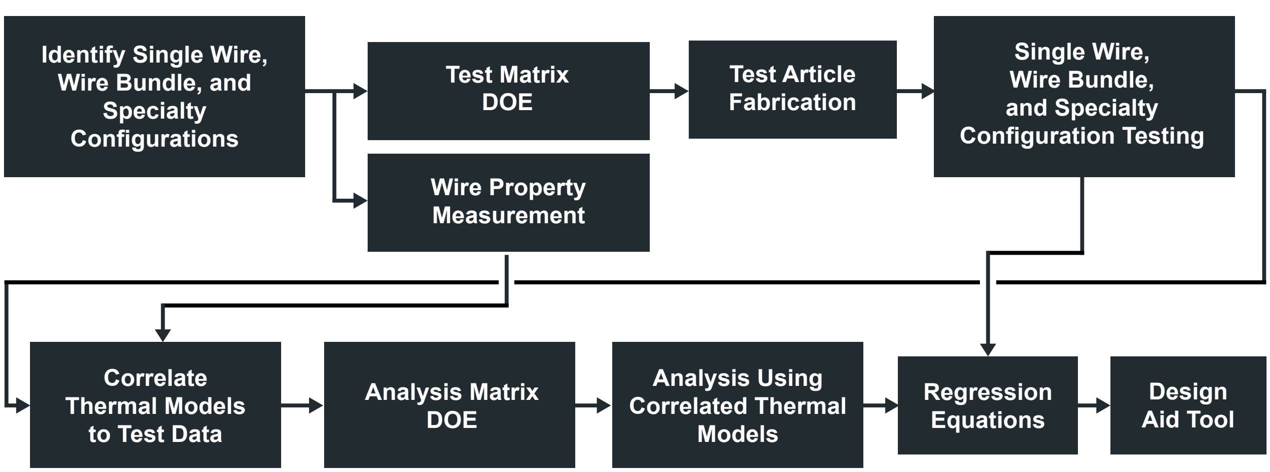
Test articles are subjected to a variety of pressures ranging from high vacuum to one atmosphere and temperatures ranging from -50°C to +70°C. Temperature data obtained during testing are being used to correlate physics-based thermal models for both single wires and wire bundles. The ultimate goal is to use these correlated models to develop regression equations for use within a tool to aid designers in wire sizing. This work is being performed by JPL, MSFC, GSFC, JSC, KSC, and LaRC.



Left: Temperature-controlled shroud

Middle: Wire-bundle test article within shroud (lid removed)

Right: Thermal-vacuum test configuration showing insulated shroud in vacuum chamber



Overall Development Strategy

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

THE 2022 GNC DISCIPLINE YEAR IN REVIEW

The NESC GNC Technical Discipline Team (TDT) conducted numerous activities in the course of 2022 in support of the NASA Mission Directorates. Discussed below are three noteworthy highlights and a look into the future of the GNC discipline at NASA.

Extending Inertial Measurement Unit Operational Lifetime Study

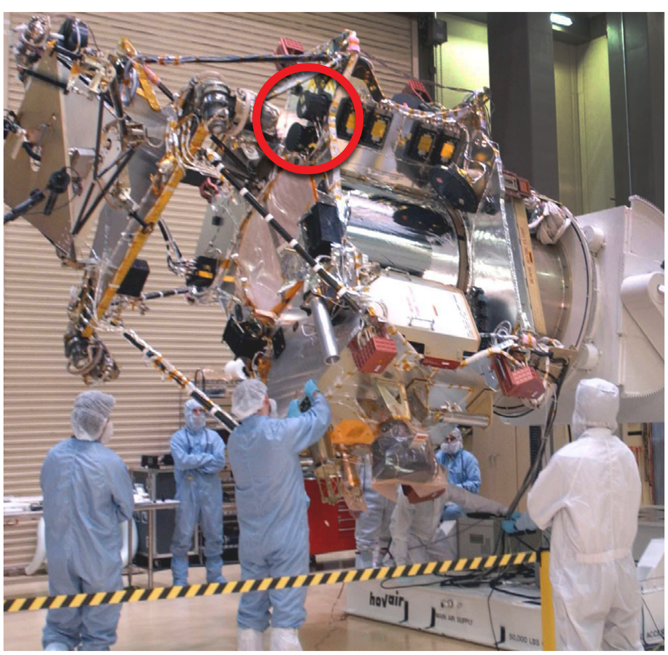
Inertial sensors provide the foundation for the GNC systems on most of NASA's spacecraft. Inertial measurement units (IMU) are highly-integrated assemblies of inertial sensors, including gyroscopes to measure angular motion/rates, accelerometers to measure translational forces, and associated electronics. One such spacecraft IMU is the Miniature Inertial Measurement Unit (MIMU), produced by Honeywell International Inc., which employs ring laser gyroscope (RLG) inertial sensor technology. The MIMU is a workhorse sensor commonly used on NASA spacecraft that fly in operational regimes ranging from low Earth orbit to planetary and deep space. It is a fully self-contained three-axis strapdown, radiation-hardened sensor system that provides inertial reference data to the spacecraft's onboard GNC systems for maintaining precise orbit/trajectory control and payload instrument orientation.

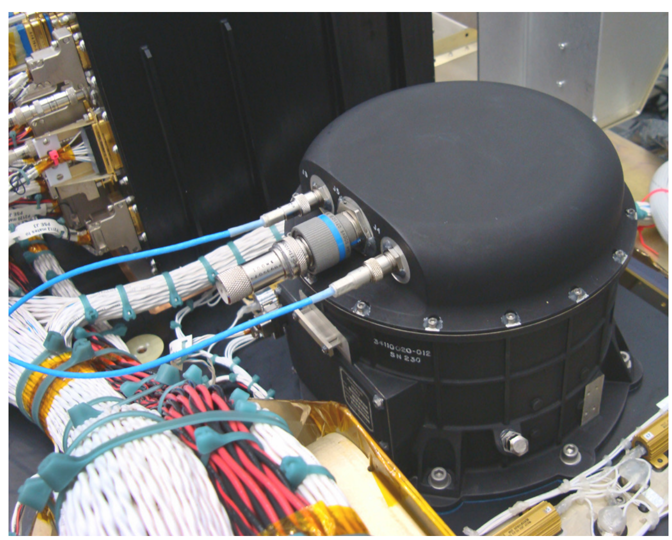
Framing a Suspected Temperature Issue

There have been indications that the MIMU lifetime is operating temperature-dependent. Thus, the Space Science Mission Operations (SSMO) organization at GSFC requested the NESC to determine any best practices that could maximize the MIMU operating life. The SSMO is the key stakeholder, along with Exploration Systems Development and Space Operations Mission Directorates. In response, an NESC team performed the MIMU Operational Life Investigation,[1] to achieve two goals: formulate recommendations for MIMU operational best practices for spacecraft mission operations teams, and capture best practices for GNC design teams for accommodating/integrating the MIMU sensor hardware into spacecraft.

MIMU Data Collection, Analysis, and Modeling

Confirming the suspected temperature dependence was challenging since MIMU flight data have been retained within programs and projects, which limits the ability to analyze systemic operational performance. In spite of the challenges, the NESC team collected an extensive set of MIMU operational flight data from 12 different NASA space missions, selected to obtain data over a wide range of operating regimes (e.g., Earth orbiting, lunar orbiting, Mars orbiting, deep space),





Left: MIMUs on the Mars Reconnaissance Orbiter spacecraft shown during assembly and integration. Above: Lunar Reconnaissance Orbiter MIMU sensor hardware mounted on spacecraft panel in flight configuration during pre-launch Integration and test.

operational usage, and primary mission durations. The team analyzed the collected data sets to identify trends or patterns of successful MIMU operation. Open literature covering RLG inertial sensor technology was also studied to understand both laser failure modes and failure mechanisms of neon depletion within RLGs.

A primary discovery is that MIMU RLG laser intensity monitor (LIM) telemetry, which is a direct measure of RLG laser optical power, is the fundamental indicator of gyroscope health and should be monitored and trended from each of the three RLGs during the mission. The flight data from multiple missions indicated that the MIMU LIM telemetry measurements vary over time in direct relation to the RLG operating temperature.

A model using a linear curve fit has been developed by JPL flight operations analysts and can be used to estimate the relationship of RLG operating temperature versus RLG LIM. This leads to a direct temperature detrending approach where a given average RLG operating temperature is assumed, removing the LIM effect due to temperature fluctuations. In general, detrending removes the effects of a trend from a data set, revealing differences from any long-term direction, allowing periodic or other patterns to be identified.

Temperature-detrended LIM data typically show a period of increasing value followed by an inflection point where the time rate-of-change (i.e., the slope of the LIM curve) becomes increasingly negative, eventually leading to a critical end-of-life (EOL) point where the RLG lasing ceases and the inertial data are not usable for GNC algorithm processing. Calculating the derivative of the smoothed temperature detrended LIM can be used to alert spacecraft operators that the temperature-corrected LIM has begun to trend downward toward a potential EOL condition.

MIMU Findings and Recommendations

Based on the collected data and the detrend modeling effort, the team found the RLG lifetime remains static and does not degrade if the unit is powered off for long periods (e.g., months). Additionally, it is critically important for spacecraft mission operators to monitor and detrend the LIM telemetry from each of the three RLGs in a given operating MIMU device to assess the LIM telemetry over time. But it does not yet appear possible to precisely predict when the LIM EOL inflection point will occur as a function of MIMU operating hours.

An important finding is that several missions examined in this study have developed and operationally implemented the use of an all-stellar (i.e., gyroless) or stellar-only attitude determination algorithm/flight software update to preserve MIMU (or any other IMU) operating life for essential attitude control and navigation operations. In conclusion, this large MIMU flight data set and modeling performed by the team can serve as a valuable resource for NASA to build upon for future examinations of MIMU performance by GNC engineers.

SLS is a liquid-fueled launch vehicle. Mitigation against fuel slosh instabilities is included in the flight control system.

NESC Technical Bulletins Published on Launch Vehicle Flight Control Stability

The GNC TDT invested significant time and energy to capture the best practice knowledge that emerged from a recent NESC GNC assessment concerning launch vehicle stability.[2] The TDT generated two NESC technical bulletins to capture these best practices.

The first focused on Launch Vehicle Flight Control Stability Margin Reduction Considerations[3] outlining industry standard stability margin best practices. It also provided recommendations for the treatment of deviations from these standard launch vehicle stability margins due to vehicle flexibility, slosh dynamics, aerodynamics, and other undesired dynamics or coupling.

The second bulletin captured best practices for the Treatment of Slosh Stability Margin Reductions for Human-Rated Launch Vehicles.[4] Propellant slosh dynamics pose a stability concern for human-rated launch vehicles during ascent. The bulletin provides historical perspectives on the treatment of launch vehicle slosh dynamics along with some newly developed rules of thumb and observations concerning the utility of flight data. Furthermore, it outlines several methods for analyzing and dispositioning slosh instability risks that should be considered when launch vehicle flight control linear stability margins are lower than typically accepted for human-rated systems.

continued on next page....

Successful Planetary Defense Test

Members of the GNC TDT provided specialized technical support to the successful asteroid-impacting Double Asteroid Redirection Test (DART) mission performed by the Johns Hopkins University (JHU) Applied Physics Laboratory (APL)[5].

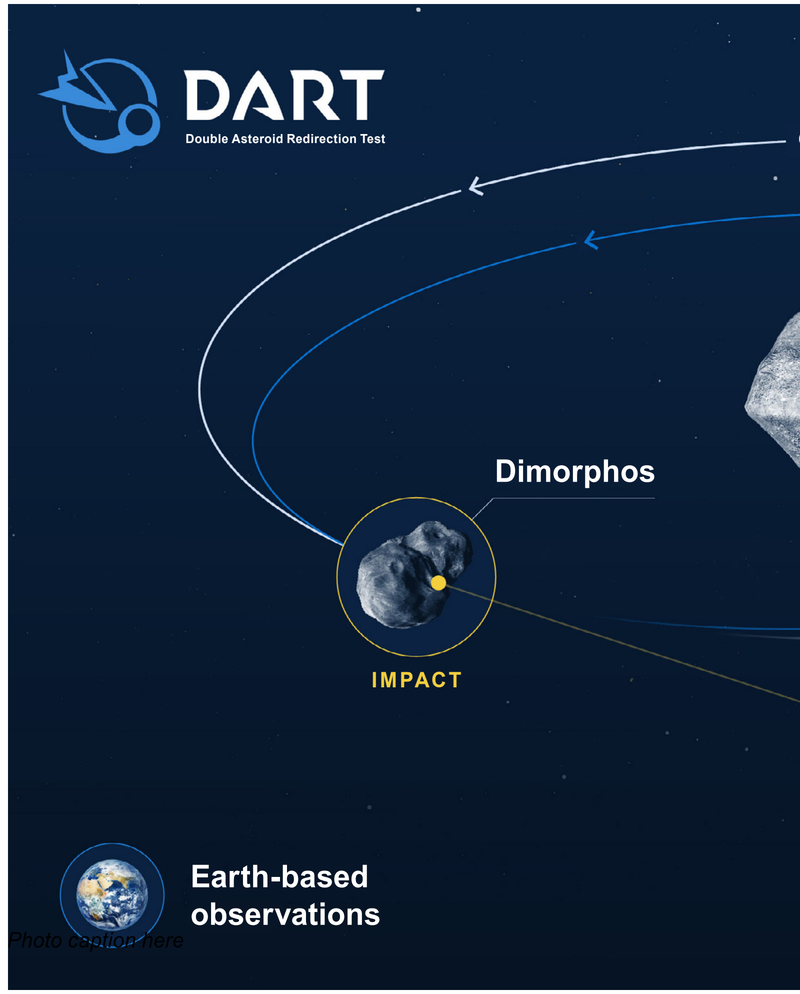
Mitigating the Risk of Star Tracker Noise

The NESC supported multiple risk reviews including a star tracker sensor noise sensitivity evaluation as part of the prelaunch Flight Readiness Review. The DART spacecraft required accurate attitude knowledge during its terminal phase (i.e., the final 4 hours of the mission) to ensure asteroid intercept. The star tracker sensor on DART provided fundamental spacecraft attitude measurements that were critical to the performance of the on-board SmartNav optical guidance system used to target the asteroid. Prior to launch, it was identified that DART's asteroid impact performance was very sensitive to star tracker sensor noise. The GNC TDT evaluated the DART star tracker noise sensitivity during the terminal asteroid intercept phase of the mission and participated in in-depth technical reviews of the DART star tracker noise model used in the simulation of impact performance. They worked closely with APL GNC engineers to review in-flight star tracker data collected from another mission flying a similar star tracker. It was observed that impact performance was not sensitive to sensor white noise, but rather to time-correlated noise (i.e., random walks).

The NESC subject matter experts pointed out the criticality of focusing on revising the time-correlated features of the star tracker noise model. This emphasis was necessary given the DART spacecraft's on-board attitude determination filtering was not able to significantly reduce these time-correlated random walks. Updating the star tracker noise model was necessary to ensure the most accurate simulation-based predictions of the orientation and motion of the spacecraft during the terminal phase just prior to impacting the asteroid. The NESC performed a prelaunch risk evaluation and recommended that the DART GNC team cease any further noise model changes until actual in-flight star tracker calibration data could be obtained from the spacecraft and analyzed. The NESC also encouraged the flight operations team to perform opportunistic optical navigation tests prior to the actual asteroid intercept phase to evaluate the influence of star tracker sensor noise under realistic conditions.

Solar Array Dynamics Modeling and Simulation

Prior to launch, the NESC provided technical support to perform a quick-response risk assessment of a late-occurring DART spacecraft solar array dynamics issue. A multi-disciplinary NESC team from the GNC and Loads and Dynamics TDTs considered the technical issue, performed sufficient modeling and simulation of the solar array dynamics, and provided APL with independent flight rationale for proceeding with the launch.



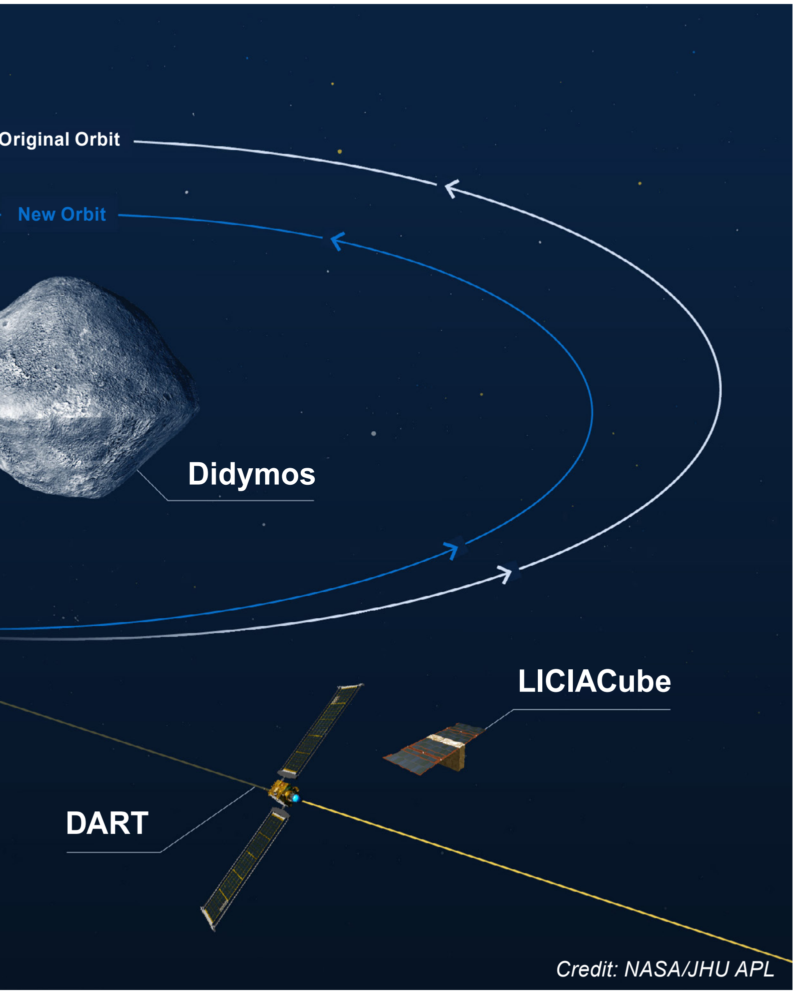
Above: DART impact infographic. Top Right: Asteroids shown before and after DART
Telescope and James Webb Space Telescope of Dimorphos ejecta about 4 hours aft

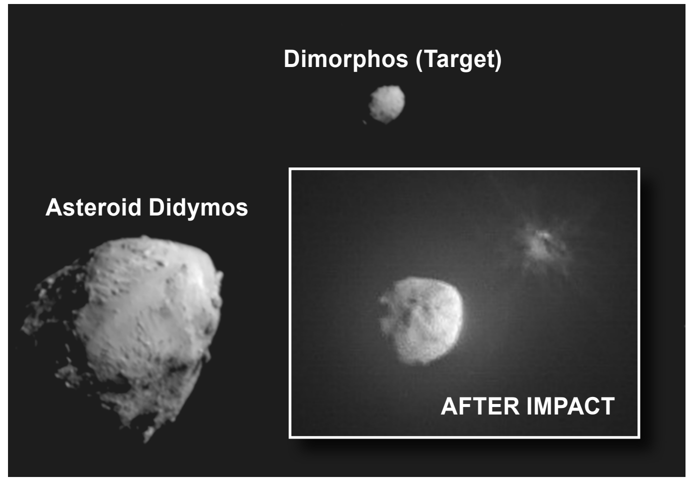
Results

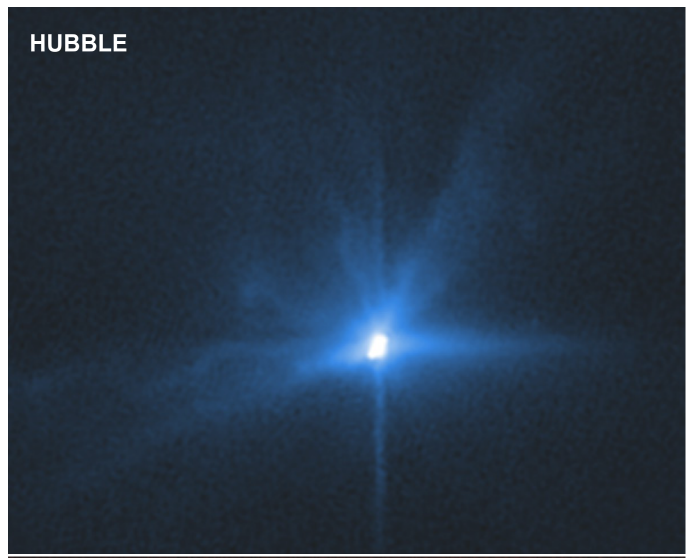
The NESC was pleased to support the DART mission demonstration of planetary defense. One week after the September 26 impact, the orbital period of Dimorphos around its parent body, Didymos, had decreased from 11 hours and 55 minutes to 11 hours and 23 minutes, indicating the kinetic impact successfully altered the asteroid's orbit.

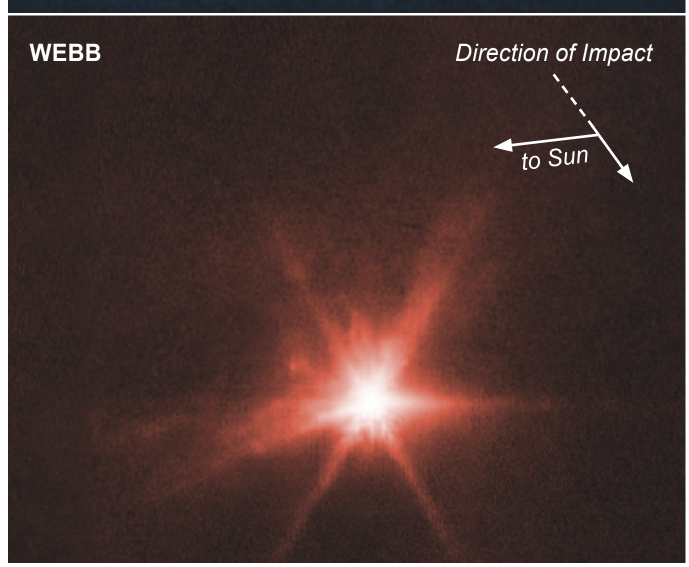
Looking Ahead for the GNC Discipline

The mission-pull demand for more autonomous operational capabilities is on the rise across all NASA's Mission Directorates. Consequently, the GNC TDT has adopted "Autonomous GNC" as its strategic vector providing the team a future focus on the system architectures, technologies, and engineering methods for implementing autonomous capabilities. As part of its annual assessment of the GNC discipline's state of health, the TDT has observed that aerospace GNC systems are growing more complex. To address this "curse of complexity," the TDT has identified the strategic need for the GNC discipline to enhance its ability to support more complex system interfaces and dynamic interactions. For example, current verification









impact. Middle and Bottom Right: Simultaneous images from Hubble Space
er impact.

and validation (V&V) approaches and processes are not adequate to cope with the evolving GNC architectures and topologies being driven by autonomy. The TDT is currently working to understand where the existing gaps are in NASA's V&V capability and to prioritize tool and method development needs for V&V of advanced GNC algorithms. The next generation of GNC engineers at NASA will need to create robust and resilient system architectures that structure and integrate emerging technologies (e.g., for autonomous onboard maneuvering) across multiple disciplines. These engineers will need to be equipped with modernized design methods and tools that allow the convergence of a multidisciplinary design-optimization process. Model-based design synthesis approaches that can simultaneously satisfy multiple dynamic system stability and performance requirements will likely be at the heart of the solution process for future autonomous GNC systems.

1. Miniature Inertial Measurement Unit (MIMU) Operational Life Investigation, June 2022. NASA/TM-20220012239
2. NESC Report "Treatment of Launch Vehicle Flight Control Stability Margin Reductions for Crewed Missions with Emphasis on Slosh Dynamics," June 2022.
3. NESC Technical Bulletin No. 22-05, "Launch Vehicle Flight Control Stability Margin Reduction Considerations," August 2022.
4. NESC Technical Bulletin No. 22-06, "Treatment of Slosh Stability Margin Reductions for Human-Rated Launch Vehicles," August 2022.
5. NESC Support of Double Asteroid Redirection Test (DART) Mission.

NONDESTRUCTIVE EVALUATION (NDE)
Dr. William H. Prosser,
NASA Technical Fellow for Nondestructive Evaluation

NDE SURVEY EXAMINES THE ORIGIN OF DETECTABLE FLAW SIZES USED IN SPACECRAFT HARDWARE

WHAT IS STANDARD NDE?

A standard NDE flaw size is intended to represent the largest flaw size that may be missed by most qualified inspectors for a specific NDE method. The benefit of tabulating standard NDE flaw sizes is to avoid the requirement that every inspector perform POD demonstrations, which can be resource intensive.

Dr. William Prosser has spent his NASA career looking for flaws. As the NASA Technical Fellow for NDE, he and his team have an arsenal of nondestructive tools like X-ray radiography, ultrasound, and dye penetrant inspection for detecting the cracks and imperfections in the metals and welds of spacecraft. Along with the inspection tools, the NDE and structures communities rely on NASA Standard 5009B, where the NDE detection capability requirements can be found for NASA systems or components that are considered fracture critical.

"The standard specifies how well we can reliably detect various flaw sizes with our different NDE methods," said Dr. Prosser. But where did the flaw sizes found in 5009B—the ones used to determine whether a spacecraft will survive its load environments—originate? The question had never been rigorously explored until recently, when Dr. Prosser and a team of NDE experts needed to test the results of a new flaw size probability of detection (POD) method and found some inconsistencies they couldn't explain. What resulted was a deep dive survey of the NASA flaw size origin story that took Dr. Prosser and his team back 50 years to 1973. "It ended up being an archaeological project we never expected."

What Prompted the Survey

NDE technologies have advanced in the past 5 decades, allowing the detection of smaller and smaller flaw sizes. X-ray technology, for example, has evolved to a fully digital platform, eliminating the need for film. "Digital radiography has different characteristics than film and may provide different levels of reliable flaw detection capability," explained Dr. Prosser.

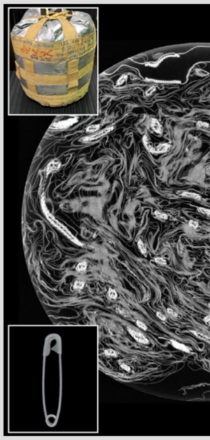
A BRIEF INTRODUCTION TO NDE:

NDE techniques are a variety of measurement techniques used to gain information about a material or structure without damaging it.

Some commonly used NDE techniques include ultrasonic testing, radiographic inspection, dye penetrant, computed tomography and eddy current testing. NDE techniques can be used to measure material properties such as conductivity and elastic stiffness, density, assess dimensions and structural configuration, and to detect indications of damage such as cracks and disbonds. Since the component being inspected is not damaged, it can then be used in its intended application.

NDE techniques can be used at a variety of points during a component's manufacture and lifetime to include screening of initial raw materials, inspection of machined and assembled components, and after intervals of usage. Some NDE methods can also be used for real time, in-situ structural health monitoring of components.

Microfocus CT Scanner
A computed tomography system located at LaRC that uses X-rays to generate volumetric radiographs.



Computed Tomograp
A parachute pack und
tomography to examin
signs of potential dam

"But the detectable flaw sizes for radiography in 5009B are still based on film from testing performed five decades ago." It left his team wondering if spacecraft designers were adding more weight and mass than necessary because only certain minimum flaw sizes were thought to be reliably detected. That led to Dr. Prosser and his team developing new POD methods to ensure designs based on results from the new technologies continued to have the appropriate levels of conservatism.

"It's something the NESC has wanted to address for a while," said Dr. Peter Parker, a NASA statistician and member of Dr. Prosser's NDE POD team. "We wanted to propose a new POD method that would fill the technology gap. The majority of NASA spaceflight system designs rely on these flaw sizes, and this new method will have broad impact."

Researching the Flaw Size Timeline

The concept of NASA's NDE flaw sizes originated in the early 1970's with the Space Shuttle Program (SSP) and were documented in the Orbiter Fracture Control Plan (OFCP). From there, the flaw sizes made their way into the fracture control requirements for payloads that were used for the Shuttle, then to Marshall Space Flight Center Standard 1249, and ultimately into NASA-STD-5009.

The specific origin of the initial flaw sizes in the OFCP, though, was more anecdotal. History suggested the flaw sizes were linked to a series of POD test programs performed by Shuttle prime contractors, which were combined and jointly analyzed by C.R. Bishop of Rockwell International, who in 1973 published a formative document titled "Nondestructive Evaluation of Fatigue Cracks."

Because none of the referenced standards provided details or references to the flaw size data sources, the team consulted with people involved in the SSP. They revealed that while some flaw size values were based on the quantitative analysis performed by Bishop, others were based on undocumented engineering judgement or unnamed data sources. More recent analysis showed the rudimentary methods used by Bishop were nonconservative in estimating POD parameters in most cases and that a key mathematical error had been made.

Why Does this Matter Now?

Since NASA has used these flaw sizes without failures for more than a half century, what could a historical survey reveal that would matter decades later? For Dr. Prosser and the NDE and structures communities, the findings were significant.

"We have been using results for a long time that we thought were conservative values for detectable flaw sizes. When those data are viewed with modern analysis, there is a degree of conservatism, but it's not as high as we originally thought," said Dr. Prosser. That understanding will ultimately better inform structure design. But just as important, he said, is that "this historical study reminds us how important independent reviews are to ensuring mistakes don't get passed on."

These checks and balances are a tenet of the NESC Review Board, which approved in September 2022 the final paper documenting what Dr. Prosser's team found during the NDE survey. "In addition to better analysis and reviews, we need to make sure that when we write standards, we provide good references and documentation on where values come from," said Dr. Prosser. "The sky is not falling because of what we

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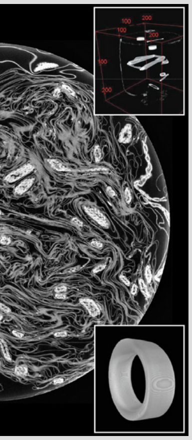

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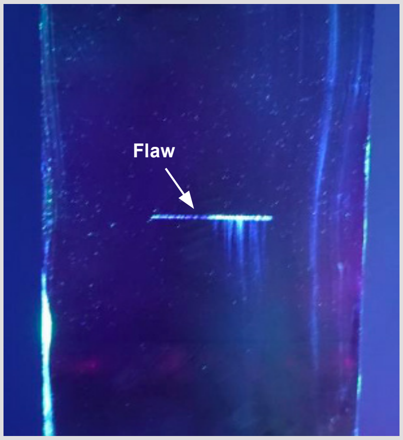
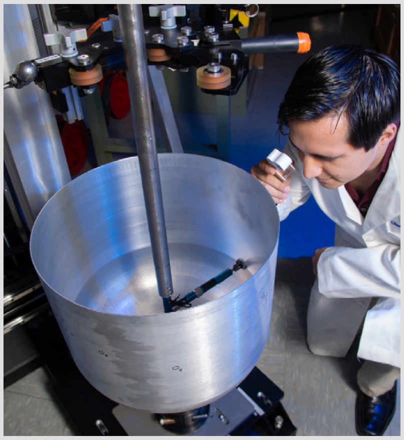
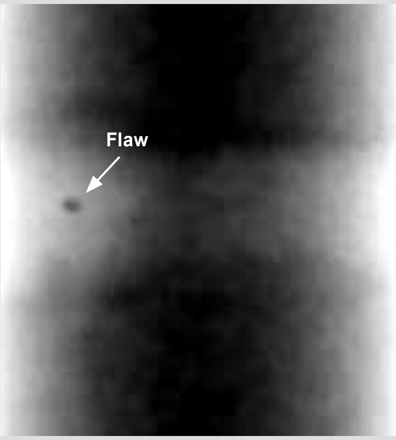


Dye Penetrant
Example of a flaw induced in Inconel test specimen examined using dye penetrant.



Eddy Current
A crack on surface of a pressure vessel examined after an internal eddy current through-wall nondestructive inspection.



Digital Radiography
A flaw in an MPCV crew module orbital tube weld detected using digital radiography.

found, but it certainly points to how we want to do things going forward." The survey also confirmed the importance of optimizing how POD testing is done. "Bishop used more than 400 flaws in the original study, which is above and beyond what we would do in a POD test today," Dr. Prosser said. This is why Bishop's 1973 report, though nonconservative in hindsight, was such an important legacy document. "They were figuring out how to assess the reliability to find flaws with NDE techniques, which was something no one had done before. They had to invent the methodology to analyze the data."

Today, generating 400 cracked specimens for a POD study would be cost prohibitive, so optimizing the test has become a key POD objective. With a better understanding of NASA's flaw size origins, the NDE community can focus on a specific range of flaw sizes that requires fewer crack specimens.

"Cost has been a perceived barrier in conducting a standard NDE study," added Dr. Parker. "Our proposed POD method is smaller, making it more approachable and something engineers may be more willing to pursue," he said, by providing guidance on the numbers of specimens, flaws, and inspectors required, leveraging knowledge of NDE methods and more modern NDE analysis approaches in use now.

The next step would be spreading the word, not only on the historical findings but also the new POD method. "The ultimate user of this information is the fracture control community," said Dr. Prosser. "These numbers get used. When you are designing spacecraft, you have to show that the structure is going to survive without failing. Knowing the loads and cycles expected, you have to assume there is a certain flaw you didn't find with your inspection, and you have to show it will survive a certain number of lifetimes for conservatism. These flaw sizes are key in doing that kind of analysis."

This survey was the motivation for development of the first documented methodology to conduct a NASA standard NDE study that will be referenced in NASA-STD-5009C. This methodology would also enable the updating the standard NDE flaw sizes and specification of standard NDE flaw sizes for methods not included in NASA-STD-5009B.

A Survey of NASA Standard Nondestructive Evaluation (NDE)
https://ntrs.nasa.gov/citations/20220013820

Guidebook for the Design and Analysis of a NASA Standard Nondestructive Evaluation (NDE) Probability of Detection (POD) Study
https://ntrs.nasa.gov/citations/20220013822

EVOLUTION OF NASA'S STANDARD NDE FLAW SIZES

NASA STANDARD NDE LINEAGE SPANS NEARLY 50 YEARS

1973

Bishop Study is Published

- First known reference to estimate the flaw size a large proportion of inspectors would reliably detect for common NDE methods: radiographic, ultrasonic, eddy current, dye penetrant.
- Each method included: 164 aluminum alloy specimens, 420 fatigue cracks, and 5-7 inspectors.

1974

Bishop Study Supports Space Shuttle OFCP Development

- Introduces term "standard flaws."
- Defines standard/special NDE concepts.
- Sets flaw size limits.

1985

MSFC Publishes MSFC-STD-1249
Standard NDE Guidelines and Requirements for Fracture Control Programs

- Expands on OFCP concepts.
- First detailed tabulation of standard/special NDE flaw sizes for multiple flaw geometries.

1988

OFCP Concepts Carry Forward to Fracture Control Requirements for Shuttle Payloads

2008

NASA Publishes NASA-STD-5009
Nondestructive Evaluation Requirements for Fracture-Critical Metallic Components

- Extracts standard NDE flaw sizes from MSFC standard with minor modifications.
- Further defines special NDE.

2022

NESC Team Conducts Survey of NASA Standard NDE

- Runs Bishop data through today's accepted analysis processes revealing non-conservatism.
- Publishes "Guidebook for Planning and Analyzing NASA Standard NDE POD Studies."
- Survey referenced in forthcoming NASA-STD-5009C that revises standard NDE flaw size descriptions.

NEW TRANSIENT FINITE ENERGY SHOCK PREDICTION METHODOLOGY

In a major departure from prior methodologies, a physics-based shock prediction method has been created, executed, and compared against test results. Traditionally, shock response spectra (SRS) prediction has been extremely challenging. It has been consistently considered a top challenge by the Loads and Dynamics TDT, most NASA centers, and industry.

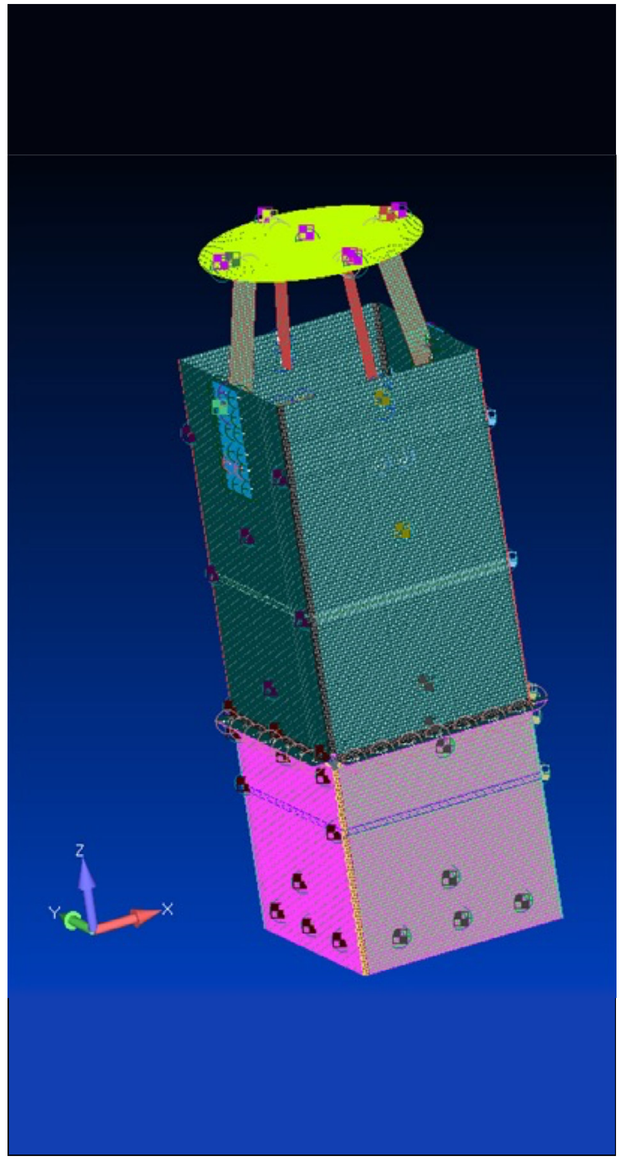
Despite being required by many aerospace projects, NASA and industry recognize that current shock predictions are reliant on the analysts performing them and are unreliable. It is typical, but not desired, to have open programmatic and potential technical risks related to shock prediction and margins late in the design cycle. Therefore, government and industry will benefit from improved shock prediction, not only for design, but also for risk mitigation.

Transient Finite Energy (TFE) is formulated by decoupling the impulsive shock input from propagation through the structure. It is considered physics based because it solves for an actual physical input forcing function called the TFE forcing function (TFE FF). Physically, a shock source behaves as an impulsive force applied to a structure, or a sudden release of strain energy within a structure. The basic shape of the shock source force impulse is best modeled by a half sine. The physical phenomenon can be explained as a sudden expansion and contraction of the system, due to the half sine impulse.

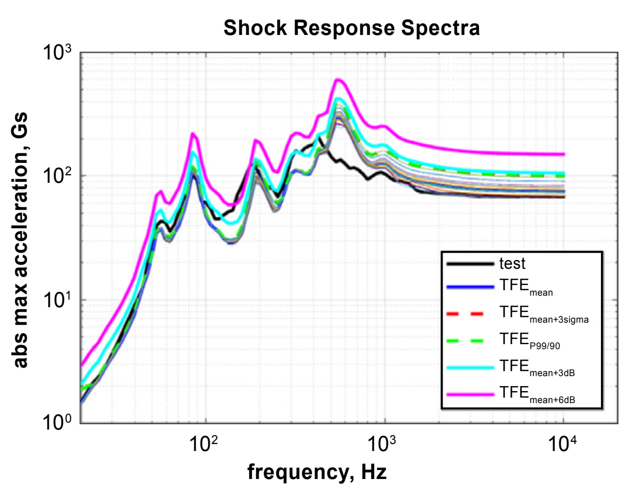
The TFE FF is calculated by connecting three domains: SRS, Fourier spectra, and time. A shock synthesis is performed over the input SRS. The resulting time history is transformed to the frequency domain via a Fourier transform and multiplied by the driving point apparent mass of the structure at the shock source location. The resulting force spectrum is inverse Fourier transformed to obtain the TFE FF time history. A Monte Carlo simulation is then performed applying the TFE FFs and calculating the mean SRS response. A dynamic uncertainty factor (DUF) is then added.

There are two TFE calculation modes: TFE FEM/analysis and TFE test based. TFE analysis uses an FEA transient analysis solution or steady-state transfer accelerations for prediction, compared to the TFE test-based mode, which uses transfer accelerations produced by a hammer tap. FEM-based TFE has been validated and envelopes SRS measurements with reasonable DUFs (1.4 and 2.0 for 3 and 6 dB, respectively). The NESC report, "Transient Finite Energy (TFE) Predictor" is available from ntrs.nasa.gov.

For more information contact daniel.s.kaufman@nasa.gov and arya.majed@appliedstructuraldynamics.com.



Finite element model of notional satellite (above) and its SRS using this TFE shock prediction methodology (below)



TECHNICAL PAPERS, CONFERENCE PROCEEDINGS, AND TECHNICAL PRESENTATIONS

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6. Kaufman, D. and Majed, A.: Applying Accelerance Decoupling to Remove the Test Stand Influence from an Integrated Large Structure Modal Test. Presented by Sills, J.: Spacecraft and Launch Vehicle Dynamic Environments Workshop, El Segundo, CA, June 21, 2022.

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Based on NESC Activities

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8. Eaton, C. and Mesmer, B.: Selection of Technical Measures: A Preliminary Comparison Among U.S. Government Agencies. AIAA Scitech 2022 Forum, January 14, 2022.
9. Campo, K.; Teper, T.; Eaton, C.; Shipman, A.; Bhatia, G.; and Mesmer, B.: Evaluating the Perceived Value of MBSE Through Evidence in Literature. 2021 ASEM International Annual Conference and 42nd Annual Meeting, October 28, 2021.
10. Eaton, C. and Mesmer, B.: When Do Measures Fail? Understanding the Pitfalls of Technical Measures in Engineering Design Through Case Studies Illustrating Goodhart's Law. RAM XIII 2021 Training Summit "Recharge Yourself," December 1, 2021.
11. Teper, T.; Campo, K.; Eaton, C.; and Mesmer, B.: Qualifying the Value of Life-Cycle Process Models to System Development. RAM XIII 2021 Training Summit "Recharge Yourself," December 1, 2021.
12. Campo, K.; Teper, T.; Eaton, C.; and Mesmer, B.: Model-Based Systems Engineering: Investigating Reliability and Maintainability. RAM XIII 2021 Training Summit "Recharge Yourself," December 1, 2021.
13. Patel, S.; Eaton, C.; and Mesmer, B.: The Impact of the Faster, Better, Cheaper Movement at NASA on Perceptions of Failure and Success of NASA Projects. RAM XIII 2021 Training Summit "Recharge Yourself," December 1, 2021.
14. Glandon, K.; Eaton, C.; and Mesmer, B.: Improving Reliability through Failure Classification: Possible Implementation Paths. RAM XIII 2021 Training Summit "Recharge Yourself," December 1, 2021.
15. Perner, D.; Patrick, J.; and Mesmer, B.: Leveraging SysML for Reliability Analysis with Category Theory. RAM XIII 2021 Training Summit "Recharge Yourself," December 1, 2021.
16. Wilson, S.: Assessing the Risk of Electrical Arc on the International Space Station. Quality and Productivity Research Conference, June 14-16, 2022.
17. Driscoll, A.: Experimental Design for Composite Pressure Vessel Life Prediction. Quality and Productivity Research Conference, June 14-16, 2022.
18. Wilson, S.: Statistical Engineering at NASA. Engaging Data Science in US National Labs and Government Agencies, NCSU Hot Topics in Data Science Webinar Series, June 17, 2022.
19. Campo, K.; Teper T.; Advised by Eaton, C.; Mesmer, B.: Qualifying the Value of Model-Based Systems Engineering as Perceived in Academic Literature. Posters on the Hill, April 26-27, 2022.
20. Eaton, C. and Mesmer, B.: When a Measure Becomes a Target, It Ceases to be a Good Measure: Considering Measure "Laws" in Engineering Contexts. UAH Research Week Graduate Poster Session, March 7, 2022.
21. Perner, D.: Capturing Aerospace System Complexity with Category Theory. UAH Research Week Graduate Poster Session, March 7, 2022.
22. Teper, T.; Campo, K.; Eaton, C.; and Mesmer, B.: Perceived Value of MBSE In the Aerospace Industry and Supporting Evidence. UAH Engineering Week Engineering Showcase, February 22, 2022.
23. Eaton, C. and Mesmer, B.: Hidden Design Decisions: Selecting Technical Measures. SERC Annual Research Review Doctoral Students Forum, November 4, 2021.
24. White, C.: Reexamining the Logical Foundation of Engineering Decision Making Under Uncertainty. SERC Doctoral Student Forum 2021.
25. Teper, T.; Campo, K.; Eaton, C.; and Mesmer, B.: Perceived Value of MBSE In the Aerospace Industry and Supporting Evidence. 14th Annual Wernher von Braun Memorial Symposium, October 12, 2021.
26. Perner, D.: Capturing Aerospace System Complexity with Category Theory. 14th Annual Wernher von Braun Memorial Symposium, October 12, 2021.

THERMAL CONTROL & PROTECTION

1. Rickman, S.: Re-Architecting the NASA Wire Derating Approach, Electrical Wiring Science and Technology Meeting, December 2021.
2. Rickman, S.: Fractional Thermal Runaway Calorimetry, American Institute of Chemical Engineers Design Institute for Emergency Relief Systems Spring Meeting, May 2022.
3. Rickman, S.: Introduction to Orbits, Rice/Envision Aerospace and Aviation Academy, June 2022.
4. Rickman, S.: Form Factors, Grey Bodies, and Radiation Conductances, Thermal and Fluids Analysis Workshop (TFAWS) 2023, September 2022.
5. Walker, W.; Bayles, G.; Johnson, K.; Brown, R.; Petrushenko, D.; Hughes, P.; Calderon, D.; Darst, J.; Hagen, R.; Sakowski, B.; Smith, J.; Poast, K.; Darcy, E.; Rickman, S.: Evaluation of Large-Format Lithium-Ion Cell Thermal Runaway Response Triggered by Nail Penetration using Novel Fractional Thermal Runaway Calorimetry and Gas Collection Methodology. J. Electrochem. Soc. 169 060535.
6. Dimpault-Darcy, E.; Darst, J.; Walker, W.; Rickman, S.; Anderson, N.; Khurana, C.; Drolen, B.; Bayles, G.; and Bilc, Z.: Systems and Methods for Measuring a Heat Response of a Battery Cell in Thermal Runaway. U.S. Patent 11,201,358, December 14, 2021.

NASA TECHNICAL MEMORANDUMS

1. NASA/TM-20220005732 Max Launch Abort System Project Flight Test Vehicle Design, Analysis, and Flight
2. NASA/TM-20220010298 Space Launch System Liftoff Clearance: Artemis I Flight Readiness Analysis Cycle 1
3. 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 (Rev 1)
4. NASA/TM-20220010939 Uncertainty Models for the Hybrid Parametric Variation Method of Uncertainty Quantification
5. NASA/TM-20220012197 Validation of the Method Used to Develop Acoustic Transfer Functions of the Space Launch System Booster Nozzle Volume
6. NASA/TM-20220002215 High Reynolds Number Wind Tunnel Investigation of the Ascent Aerodynamic Characteristics for a 1.75-Percent Scale Space Launch System
7. NASA/TM-20220004115 Filtration of Spaceflight Propulsion and Pressurant Systems
8. NASA/TM-20220012239 Honeywell MIMU Operational Life Investigation
9. NASA/TM-20210022984 International Space Station United States Destiny Laboratory Optical Window Seal Assessment
10. NASA/TM-20220000586 International Space Station Extravehicular Mobility Unit Sublimator Corrosion
11. NASA/TM-20220000562 Lunar Meteoroid Ejecta Model Review
12. NASA/TM-20210023030 Helium Evolution from Helium-Saturated Hypergolic Propellants
13. NASA/TM-20220002905 Safe Human Expeditions Beyond Low Earth Orbit
14. NASA/TM-20220013983 SpaceVPX Interoperability Assessment
15. NASA/TM-20220002233 Motion Magnification for Gimbaled Bellows
16. NASA/TM-20220013375 NESC GN&C TDT Best Practices: Design Requirements for Satisfactory Handling Qualities of a Piloted Spacecraft
17. NASA/TM-20220003648 Guidebook for Assessing Similarity and Implementing Empirical Transfer Functions for Probability of Detection Demonstrations for Signal Based Nondestructive Evaluation Methods
18. NASA/TM-20220013820 A Survey of NASA Standard Nondestructive Evaluation
19. NASA/TM-20220013822 Guidebook for the Design and Analysis of a NASA Standard Nondestructive Evaluation Probability of Detection Study
20. NASA/TM-20210022275 Treatment of Pressure Transients in Space Flight Pressurized Systems
21. NASA/TM-20220013195 Helium Solubility in Monomethylhydrazine and Nitrogen Tetroxide

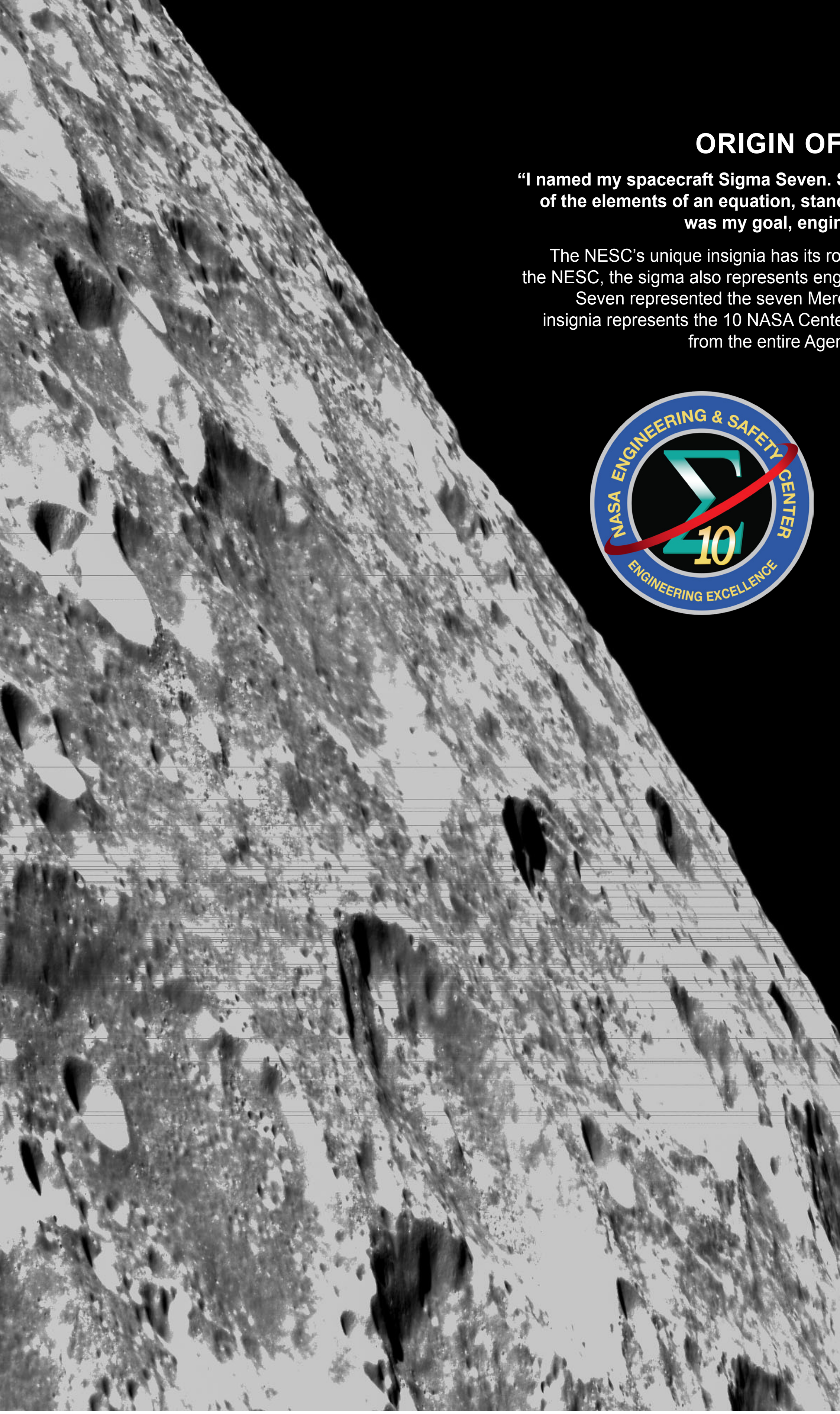
DID YOU KNOW?

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.

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



On the sixth day of the Artemis I mission, Orion's optical navigation camera captured black-and-white images of craters on the Moon.

NASA Engineering & Safety Center
NASA Langley Research Center
Mail Stop 118
Hampton, VA 23681

NESC.NASA.GOV

National Aeronautics and
Space Administration
Langley Research Center
Hampton, VA 23681
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