National Aeronautics and Space Administration

NASA Engineering & Safety Center TECHNICAL UPDATE

2020

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

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

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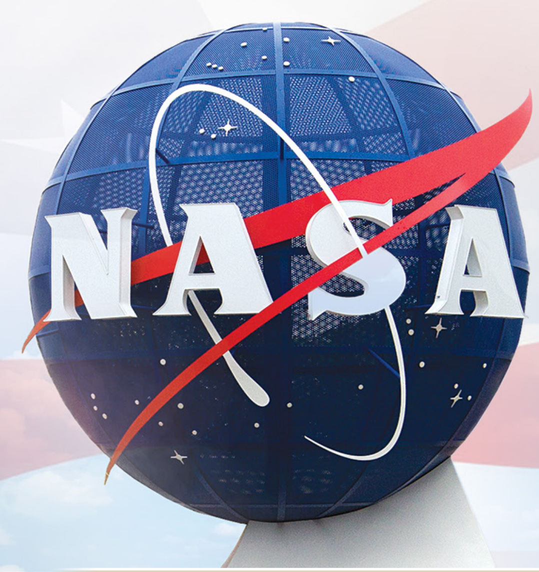


Find your local NESC contact through the NASA Enterprise Directory.

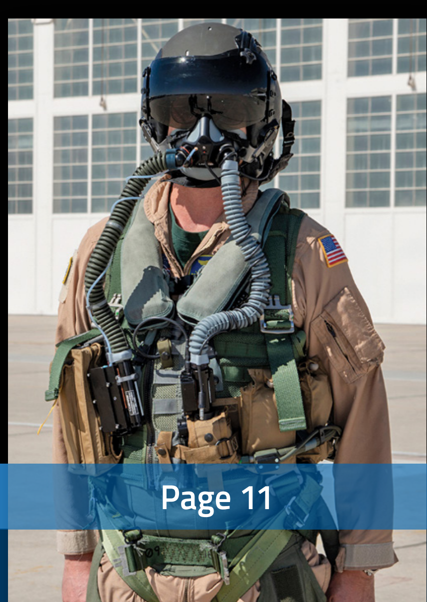
From NASA Leadership

Stephen Jurczyk
NASA Associate Administrator

"This year has been difficult for our nation and the world on many levels. Although there have been many challenges, I am proud to be a part of an Agency that sets a positive example and inspires our global community. Through the difficulties, NASA has made progress in developing the systems for the first mission of the Artemis program – successfully completing system testing of the Orion spacecraft including structural test article and space environmental testing to verify the spacecraft is ready for Artemis I. The agency also completed the prerequisite system test cases for the 'test like you fly' SLS Core Stage Green Run test that is the final hot fire test to clear the Core Stage for Artemis I. We have selected partners to join us in developing the Human Landing System; we have worked with our commercial partners in enabling test flights and have successfully launched Americans from U.S. soil to the International Space Station for the first time since 2011; and we launched the Perseverance rover to Mars for a February landing. Through all of this, the NESC has provided crucial support in enabling many of NASA's achievements. Through specialized expertise and guidance, rigor in providing technical excellence, and determination to reduce the risk to our astronauts, the NESC has been there to provide critical independent technical assessments to support NASA programs."

Ralph R. Roe, Jr.
NASA Chief Engineer

"We at NASA have grown and adapted this year to a new normal. We have worked from home, and we have utilized technological advances to do this work successfully. We have committed to the health and safety of our personnel, while ensuring that our NASA family can enable NASA's mission under new constructs. The NESC has shown incredible agility in its determination to provide the best support to NASA's programs. This 2020 Technical Update illustrates its tenacity in solving a broad range of difficult technical problems, while capturing knowledge and lessons learned to pass along to the NASA engineering community. From its work in supporting the Artemis missions and enabling American astronauts to again launch from U.S. soil, to the development of numerous engineering reports and technical bulletins from these efforts, the NESC continues to provide exceptional technical expertise to the Agency. The NESC reached a major milestone this year by surpassing 1000 technical assessments and support activities. This speaks volumes to the value the NESC has brought to NASA's programs and projects. As our work environments continue to change, so will the NESC adapt and bring new approaches to achieve NASA's mission."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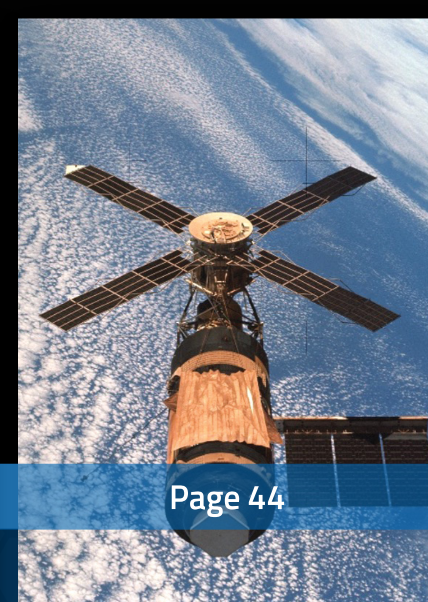
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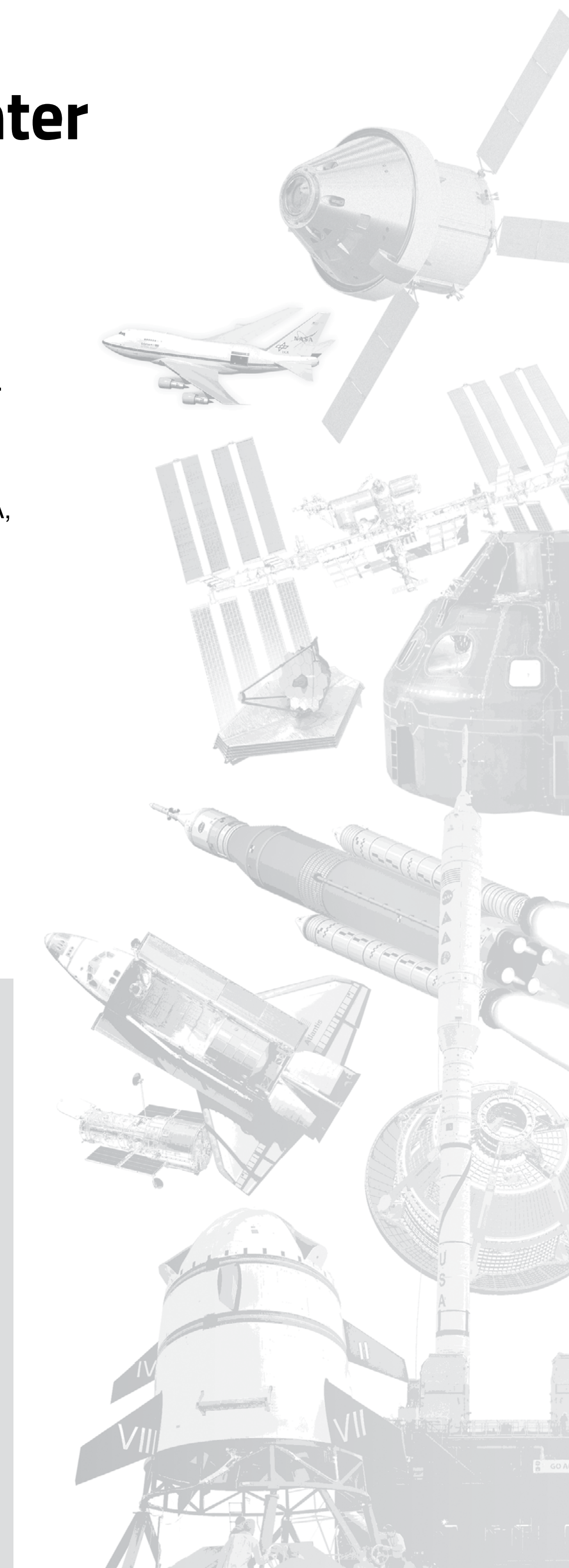
NASA Engineering & Safety Center



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.

Engineering Excellence

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

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.

The NESC Insignia Origin

"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

Artist Cece Bibby painting Sigma Seven logo on Mercury spacecraft with Astronaut Wally Schirra, 1962.

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

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

Promoting Engineering Excellence, Independence, and Objectivity

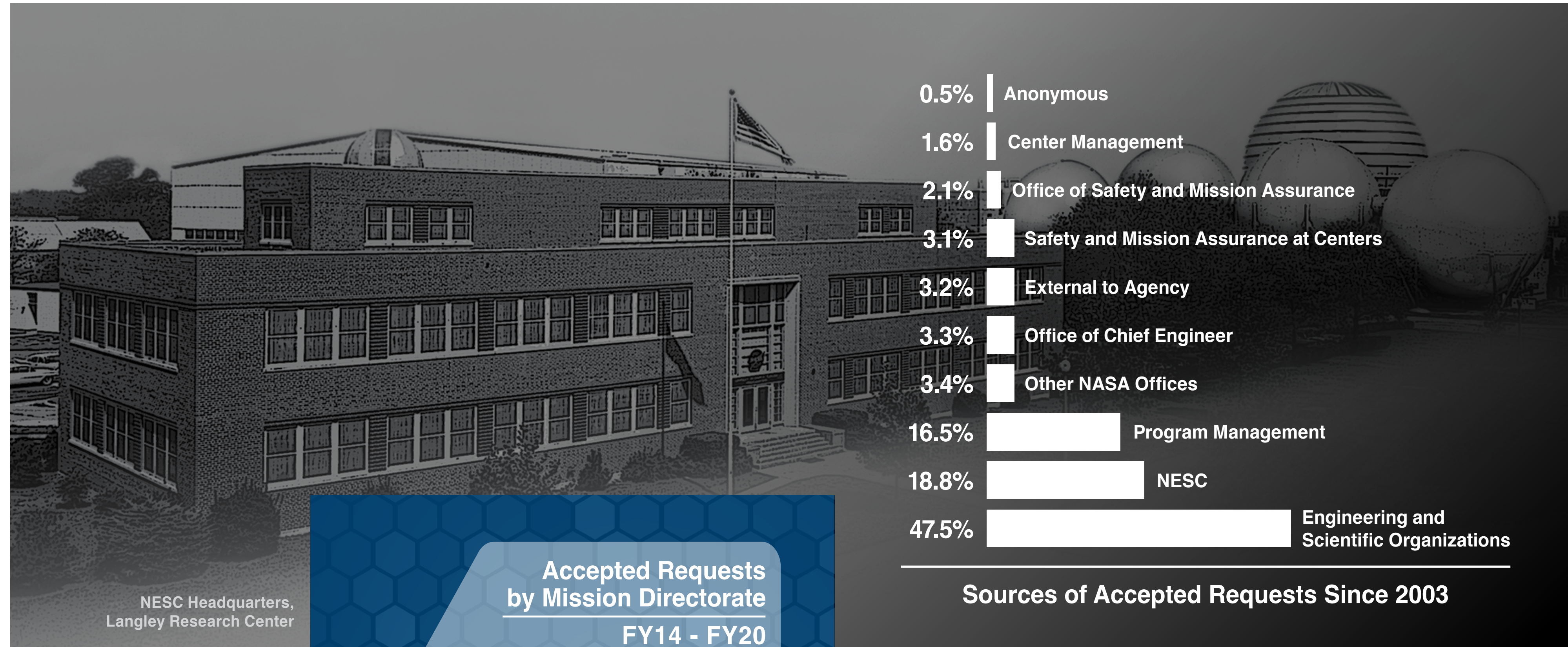
NASA has been impacted by the challenges of 2020 like everyone else and has had to reassess how to perform its mission. The NASA Engineering and Safety Center (NESC) has adapted along with the rest of the Agency. Fortunately, the NESC is built to adapt. The foundation of the NESC is people, so where the people are – in the office, in the lab, at home – is where the NESC is. During this difficult year, NASA has continued to move forward, and so has the NESC.

The NESC's mission is to provide the Agency with a unique resource promoting engineering excellence, independence, and objectivity. The strength of the NESC is its ability to rapidly reach out to industry, academia, the government, and all of NASA, to secure technical and scientific expertise needed to solve the Agency's most difficult problems. This ability not only brings the knowledge and experience to where the problems are, but also enables the NESC to proactively build diverse teams by drawing from such a broad base. The need for this type of organization – one that provides an independent voice and a source of resources to bolster safety through engineering excellence – was recognized after the Columbia accident.

The NESC's technical expertise resides in the NESC Technical Discipline Teams (TDTs). TDTs comprise engineers and scientists from across the country who join NESC Assessment Teams when there is a need identified through a request to the NESC. Assessment teams are formed in the spirit of the traditional "tiger team," which are short-duration, efficient, and assembled to focus on a specific problem. The 20 discipline-specific TDTs are each led by a NASA Technical Fellow. The Technical Fellows are NASA's senior technical experts and stewards of their respective disciplines.

The Technical Fellows constitute part of the NESC core team, along with the Principal Engineers, NESC Chief Engineers, Management and Technical Support Office, NESC Integration Office, and NESC Director's Office. The Principal Engineers lead many of the assessments, primarily those that are large and require coordination among several different disciplines. The NESC Chief Engineers reside at each of the ten NASA Centers, coordinate Center support to assessments, and serve as each Center's NESC point of contact. The Management and Technical Support Office provides the contracting, budgeting, and other business support for the NESC and its assessments. The NESC Integration Office coordinates programmatic and technical integration for the NESC.

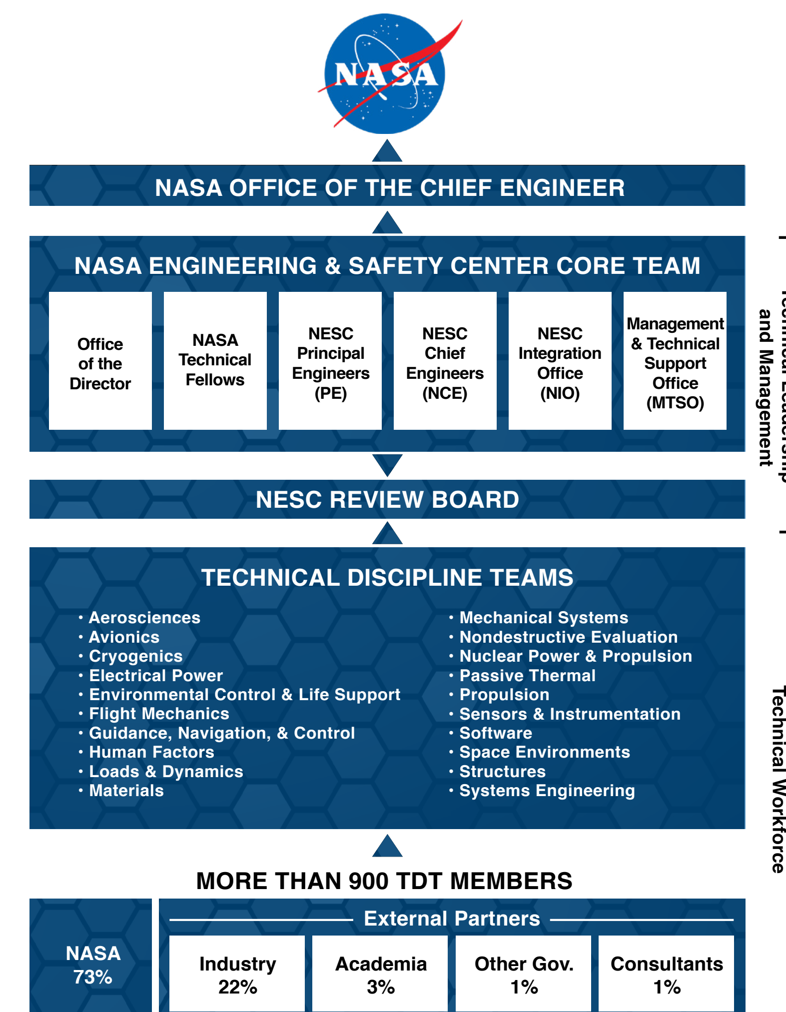
The hallmarks of the NESC are that every assessment is documented in a final report, and each final report must be approved by the NESC core team through the NESC Review Board (NRB). The NRB formalizes a diverse peer-review process by bringing all of the experiences, knowledge, and backgrounds of the core team members together to critique, enhance, and ultimately strengthen each product. The NESC has adapted to the challenges of 2020 by relying on this diversity and flexibility built into the organization. The NASA Administrator communicated this year that NASA demonstrates "the value of equal opportunity, diversity, and inclusion to our mission accomplishment." The NESC exemplifies the Administrator's message by demonstrating that the NESC's foundation of technical excellence is strengthened by making diversity a priority.



NESC Headquarters, Langley Research Center

1004 ACCEPTED REQUESTS SINCE 2003, 84 IN FY20

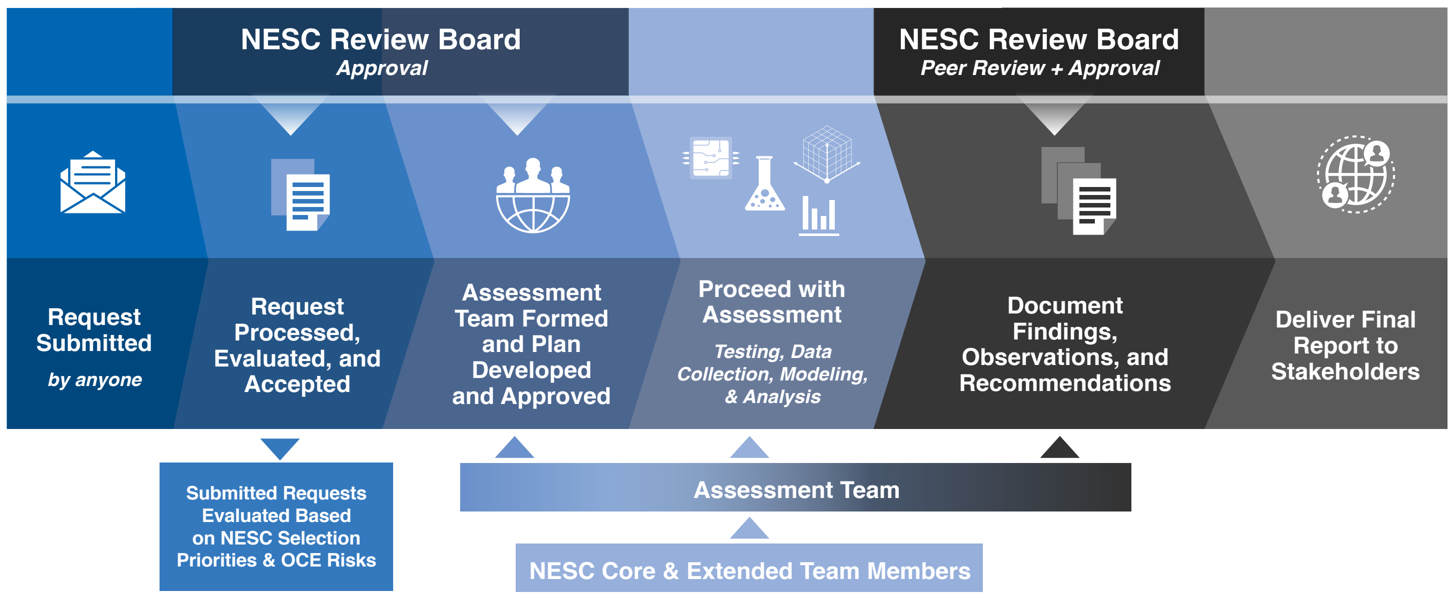
Data as of September 30, 2020



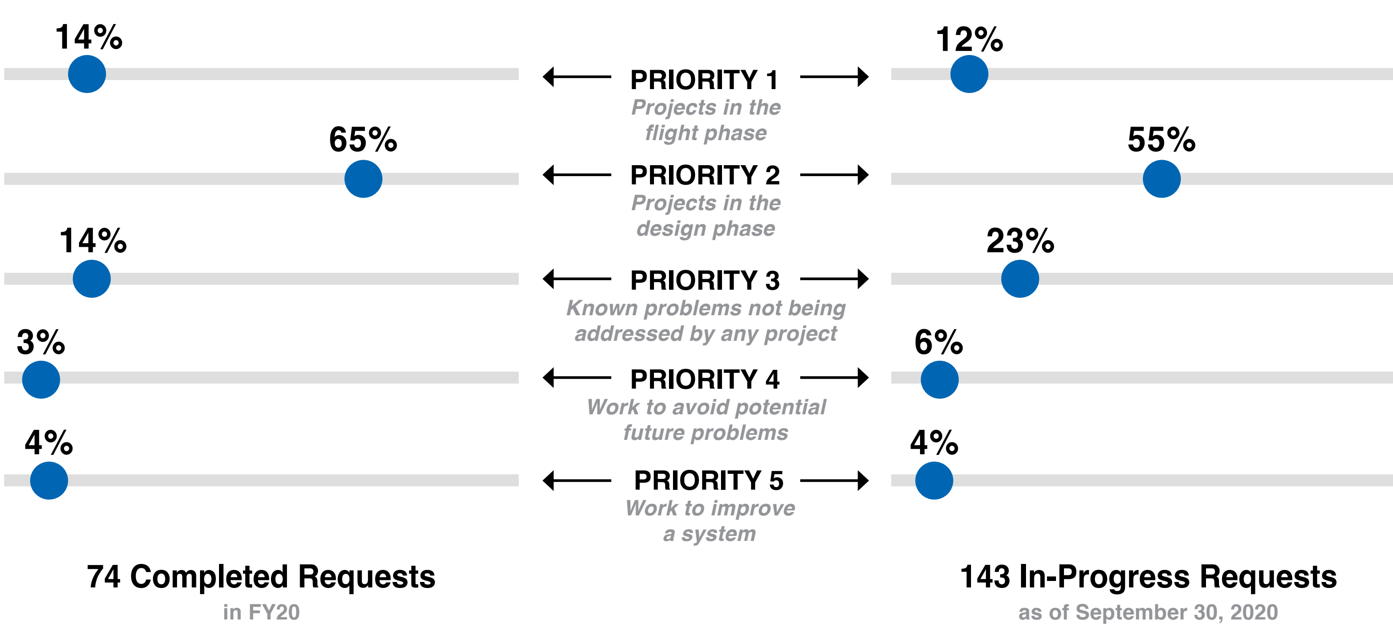
Assessments & Support Activities

Assessments typically include independent testing and/or analyses, the results of which are peer reviewed by the NESC Review Board (NRB) 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 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.



Priority 1 Completed Assessments

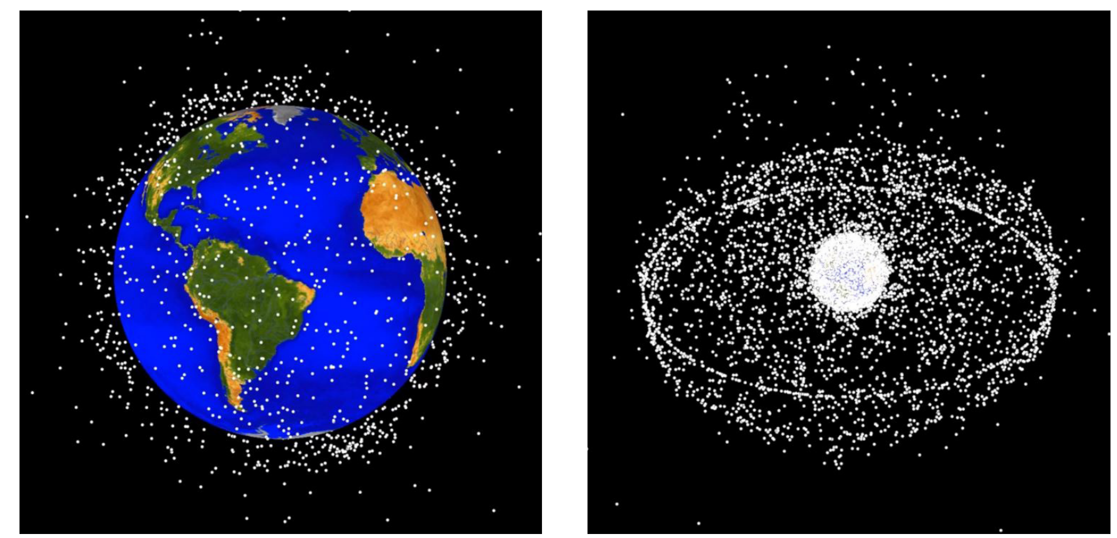
Projects in the Flight Phase

Evaluation of the ORDEM3.1 Software Release

The Orbital Debris Engineering Model (ORDEM) is NASA's primary tool for modeling the Earth's orbital debris environment and enables spacecraft designers to calculate the risk of meteoroid and orbital debris (M/OD) impacts to their spacecraft. After development of the latest version, ORDEM3.1, NASA's Orbital Debris Program Office requested the NESC to peer-review and exercise the new software to evaluate its performance and operational characteristics.

ORDEM categorizes orbital debris particles by size, material density, relative velocity, and direction, and also includes orbital parameters such as altitude and inclination. Version 3.1 focused on updates to these debris populations with the latest available measurement data to better inform debris impact risk assessments. The NESC team reviewed documentation and data and ran multiple test cases using specific orbits and starting years. The team examined trends in the resulting data, compared results to previous versions of ORDEM, and performed a typical M/OD risk assessment to examine ORDEM3.1's effect on predicted debris penetration risks. The team also identified areas where model predictions may be improved.

This work was performed by GSFC, JPL, LaRC, and MSFC.

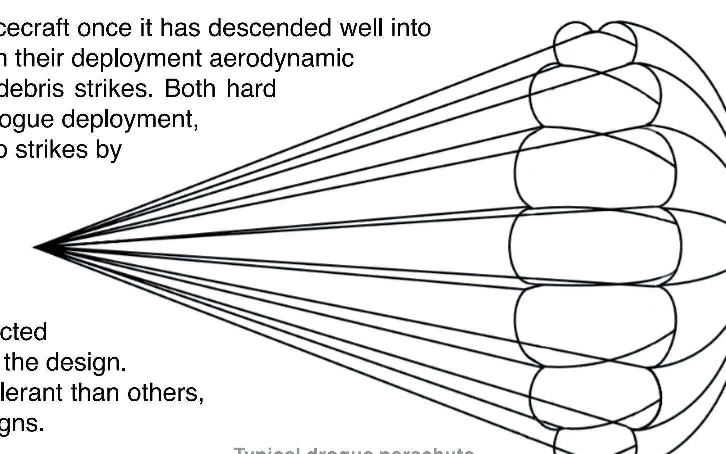


Orbital objects > 10 cm diameter in 1970 (left) and 2019.

Evaluating Impact Tolerance of Softgoods on Drogue Parachutes

Drogue parachutes serve to stabilize and decelerate a spacecraft once it has descended well into the atmosphere. While drogues are designed to be robust in their deployment aerodynamic environments, they have varying degrees of tolerance to debris strikes. Both hard and soft debris can be liberated from a spacecraft during drogue deployment, but little data exist that quantify drogue damage tolerance to strikes by soft debris such as blanket insulation.

The NESC sponsored testing at Southwest Research Institute's blast and impact facility to assess the damage tolerance of a modern drogue parachute to soft debris of different sizes and velocities. More than 15 tests were conducted to evaluate impact tolerance and quantify the robustness of the design. Some drogue elements were shown to be more damage tolerant than others, which can be used to improve the robustness of future designs.

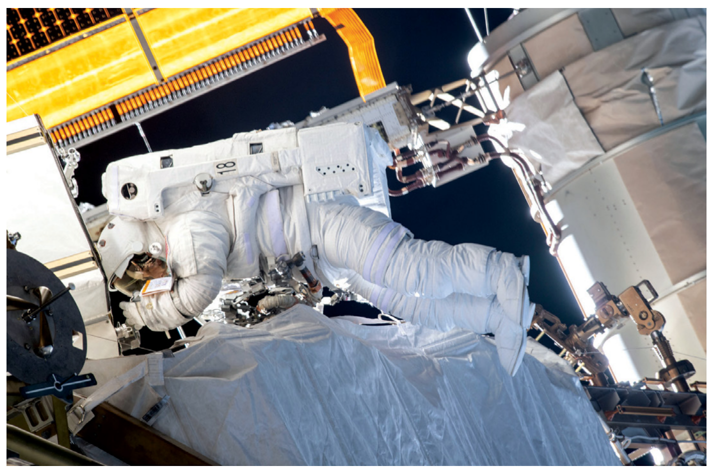


Typical drogue parachute.

Assessing Risk of ISS RPCM Hot Mate/Demate During EVA

Positioned at multiple locations along the International Space Station's (ISS) main truss are banks of circuit breaker devices referred to as remote power control modules (RPCM). Currently, when ISS equipment configurations change, these devices need relocating or replacing via an extravehicular activity (EVA), and can require a shutdown of critical ISS systems while astronauts perform the work. Shutting down large portions of ISS systems, however, carries operational risk to ISS and its crew, both while they are powered down and when bringing the systems back online. Therefore, the ideal approach would be to remove/replace the RPCMs while powered on, known as a hot mate/demate, but is not without risk to the EVA crew. To characterize the potential hazard, the ISS Program requested the NESC evaluate risk of potential molten metal generation due to electrical arcing during the mate/demate, and molten metal impacts on the EVA Mobility Unit (EMU). The NESC team conducted arcing tests at the Air Force Research Laboratory, MSFC, and GSFC, where EMU materials were exposed in vacuum to molten metal drops up to the maximum diameter possible based on the energy present in a potential arc. Testing and analysis revealed that these molten metal particles were unlikely to cause severe or catastrophic EMU damage.

This work was performed by AFRC, GSFC, JSC, KSC, LaRC, and MSFC. NASA/TM-2019-220421



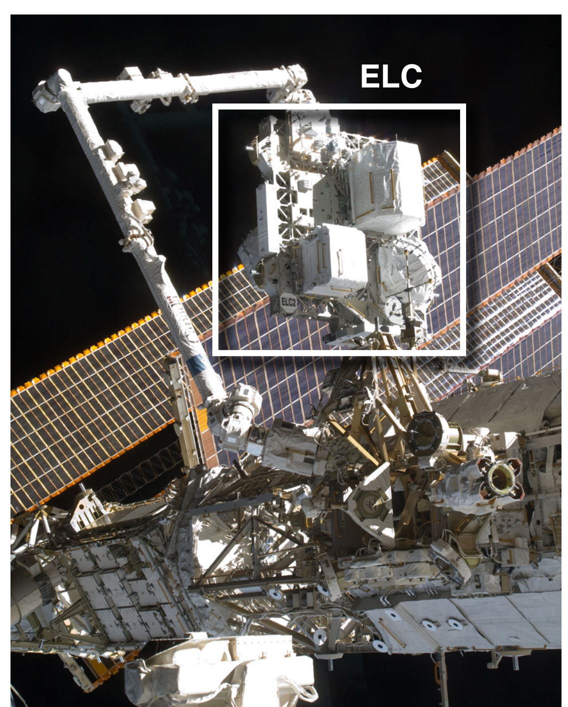
NASA astronaut Christina Koch installs Li-ion batteries in an ISS power system upgrade.

French astronaut Philippe Perrin examines the Canadian RPCM.

Express Logistics Carrier Reverse Capacitor Follow-on Testing

In an earlier assessment, the NESC investigated the effects of reverse-polarity installation of polarized capacitors possibly installed on the Expedite the Processing of Experiments to the Space Station (ExPRESS) Logistics Carrier (ELC) onboard the ISS. Subsequent to this work, the GSFC Safety and Mission Assurance (S&MA) team performed additional testing on similar capacitors under the same electrical configuration tested by the NESC team, but with an additional drying to simulate vacuum exposure time prior to application of reverse-bias testing. This more faithfully replicated the part history prior to powering up the ELC on orbit. This testing configuration indicated an increased capacitor life prediction than did the initial testing. As a result, the ISS Program tasked an NESC/Aerospace Corporation team with confirming the updated test results and the impact to previous capacitor life predictions. The assessment team conducted tests on capacitors of varying pedigree and corroborated the behavior seen by GSFC S&MA testing, leading the NESC team to conclude the initial life predictions were overly conservative. The new findings as well as data from other capacitor testing will serve as a reference for future studies of reversed-biased capacitors of this type.

This work was performed by KSC, JSC, GSFC, and The Aerospace Corporation.



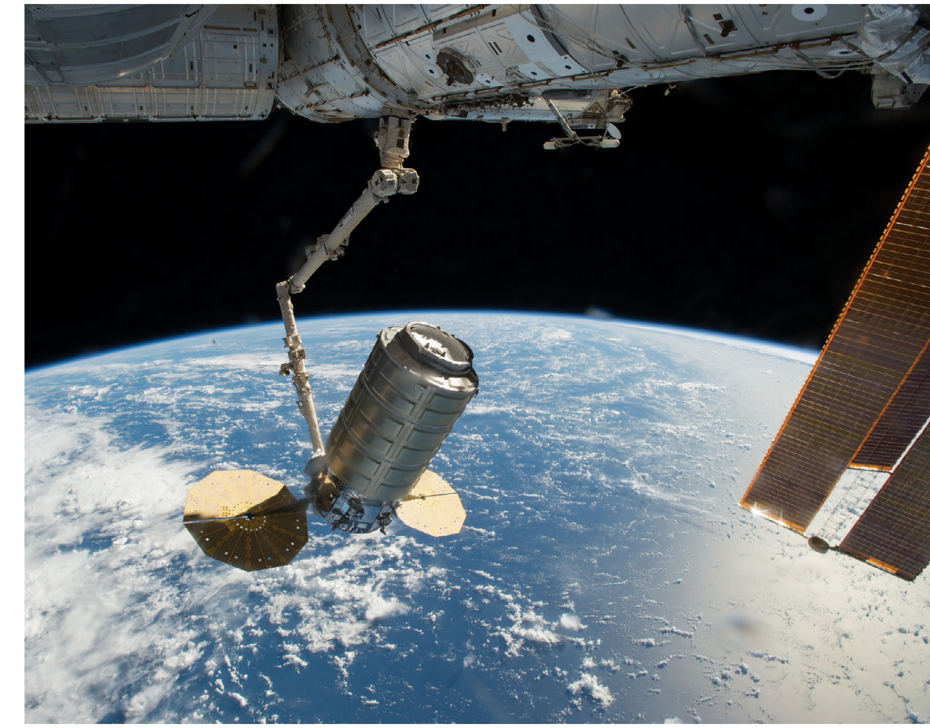
ELC-2 prior to its placement on the S3 truss.

Preventing Vibration-Induced Damage to ISS Cargo

To ensure soft-stowed payloads reach the ISS with no vibration-induced failures, NASA began to use a special ISS cargo software tool to calculate the attenuated random vibration environments and foam compression strain that foam-wrapped cargo will see in flight. Prior to the cargo tool's widespread Agency use, the NESC performed a comprehensive evaluation of the theoretical basis behind the tool's design, construction, and operation, and reviewed the results of another provider's tool for comparison with the ISS cargo tool results.

The assessment team reviewed isolation material testing, tool construction and supporting methodology, and current payload packaging and common isolation materials. The NESC team provided guidance for improving assessments of foam packing and test methods.

This work was performed by GRC, MSFC, JSC, and LaRC. TM-2020-5001542



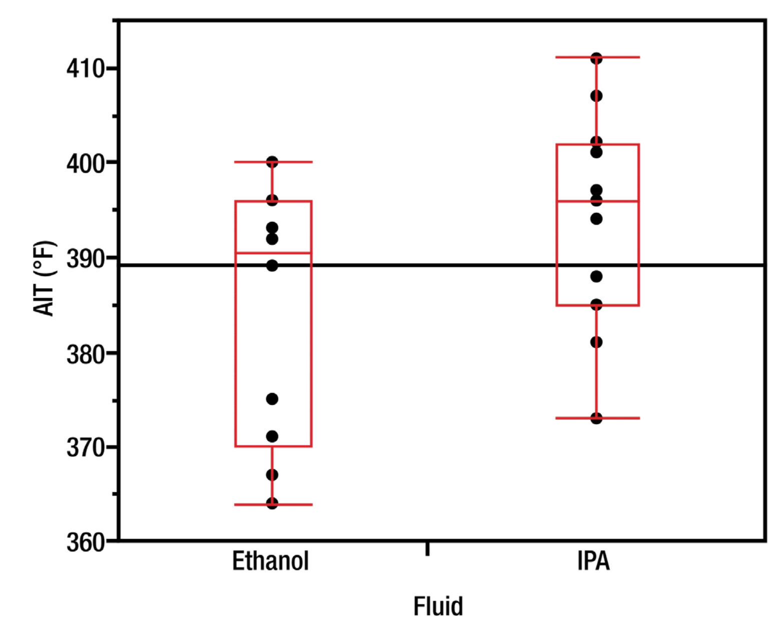
Orbital ATK's Cygnus cargo spacecraft carried with more than 5,100 pounds of cargo and research equipment on its fifth commercial resupply flight to the ISS.

Determining Autoignition Temperatures of IPA and Ethanol

Isopropyl alcohol (IPA) and ethanol are used extensively to clean and flush propulsion systems. When a commercial propulsion system designer requested NASA provide its available data on the autogenous ignition temperature (AIT) of IPA in a pressurized, pure oxygen environment, existing data were found to be focused primarily on the AIT of IPA in air, at lower pressures than the designer required. This led the NESC to experimentally determine the AITs of both IPA and ethanol in gaseous oxygen at various pressures.

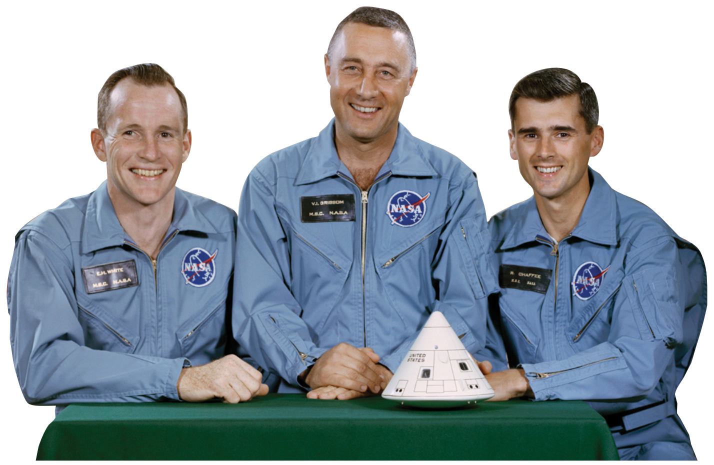
Tests in oxygen were performed at the White Sands Test Facility at pressures up to 2,200 psi (15.2 MPa), which allowed comparisons with previous data and provided new data at relevant propulsion system operating conditions. The assessment team analyzed the test replicants to understand method-dependent variability and establish statistical significance. The tabulated data, which includes the associated pressure increases upon ignition, were provided to the appropriate programs and projects across NASA. See NESC Technical Bulletin 20-05 page 40.

This work was performed by MSFC and WSTF. NASA/TM-2020-5004683, TB-20-05



Box and whiskers plots of AIT data.

Human Spaceflight Mishap Recurring Causes Study



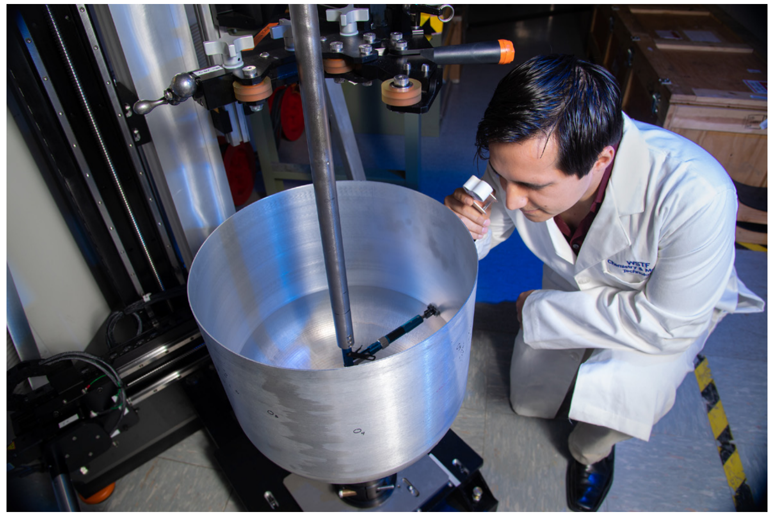
From left, astronauts White, Grissom, and Chaffee lost their lives in a January 27, 1967 fire in the Apollo Command Module during testing at the launch facility.

Major mishaps and significant close calls have marred the start of every human spaceflight program since three American astronauts were lost in the 1967 Apollo-1 fire. To understand the recurring cause trends from mishaps that occurred during flight tests and early operations, the NESC and NASA Safety Center studied eight mishaps during the Apollo, Soyuz, Skylab, Space Shuttle, and Constellation Programs, as well as commercial suborbital systems. The goal was to identify recurring causes to proactively reduce the risks of serious mishaps before upcoming NASA and commercial missions.

The study identified systemic, or underlying, issues that, if addressed, would have a maximum impact on reducing the frequency and/or severity of incidents, especially during flight tests and early operations. The nine most frequently recurring cause types were analyzed in detail. The final report summarized what was learned, compared the results to historical safety reports, provided a review of the analysis results by a cadre of human spaceflight subject matter experts, and discussed how findings can be used in developing effective mishap risk reduction strategies. See page 42-44 for a more in-depth article.

This work was performed by KSC, GRC, and ARC. NASA/TM-2020-220573

Upgrading COPV Liner Inspection System



Materials engineer Edgar Reyes of WSTF visually inspects a crack identified on the outer surface of a pressure vessel following an internal eddy current through-wall nondestructive inspection.

A composite overwrapped pressure vessel (COPV) undergoes pressure cycles where the metallic liner experiences plastic deformation, and so flaw detection in the liner is critical. The NESC recently upgraded its Multipurpose Pressure Vessel Scanner (MPVS), which is a robotic, nondestructive evaluation system used to detect critical surface and near-surface indications on COPV liners. The MPVS provides inspection capability and flaw mapping to a pressure vessel's interior and exterior mold line surfaces. It was developed as an improvement to existing COPV liner dye-penetrant inspection methods. The MPVS could allow manufacturers to screen out cracks that have grown to unacceptably large sizes, potentially threatening spacecraft crew and mission success.

As a follow-on to MPVS, the NESC assisted in a complete characterization of the system's capability and the investigation of additional capabilities needed by the COPV community. This included addressing concerns with crack-detection capabilities on liner domes of varying thickness, refining eddy current (EC) crack sizes and resulting probability of detection (POD) estimates for the liner cylindrical sections, improving liner cylinder thickness measurements, demonstrating crack detection using a through-wall EC sensor (see photo), and development of an EC array probe to expedite liner crack inspection scan times. This follow-on work reduced uncertainty in the POD results and developed additional capabilities to optimize the system for high-production rate flight COPV inspections.

This work was performed by LaRC, JSC, WSTF, JPL, and MSFC.

Pilot Breathing Assessment *(In-Progress Update)*

United States Navy aircrew configuration with integrated PBA instrumentation.

In 2017, the Navy requested the NESC provide an independent review of their efforts to address an increased occurrence of physiological episodes across their F/A-18 fleet. The NESC initiated the Pilot Breathing Assessment (PBA) to better understand human physiology and breathing behaviors in high-performance aircraft during operation.

The PBA team designed novel instrumentation and used advanced analysis to examine pilot physiological state and interaction with aircraft life support systems. NASA test pilots flew instrumented NASA F/A-18 and F-15 aircraft through pre-specified flight profiles while wearing specialized equipment augmented with an advanced sensor system. This sensor system collected data during flight such as breathing characteristics, gas flow, air composition, and aircraft environment. These data streams were aligned and examined using advanced analysis techniques to identify pilot/aircraft interactions with potential for negative cognitive and physiological impact.

To date, the NESC team has successfully completed 105 PBA sorties. A "first round" of about ~50 scripted flights with a full complement of instrumentation was completed at the end of FY19. After analysis of the initial dataset, a second set of ~50 scripted flights were designed to fill specific data gaps. The team found that certain flight activities were more likely to disrupt pilot breathing, and so additional flight profiles were developed to more closely examine the pilot breathing performance and aircraft conditions. Extensive data reduction was required to process over 250 million data points, which were analyzed via data visualization tools, summary statistics, and mixed effects models. A detailed NESC engineering report is currently in preparation for peer-review and release in early FY21.

This work is being performed by LaRC, AFRC, ARC, GRC, GSFC, JPL, JSC, WSTF, and also the EPA, UF, USN, and USAF.

Priority 1

In-Progress Assessments

- CCP Crew-1 TPS Peer Review
- CCP Booster Return Loads Reuse Implications
- EMU Sublimator Corrosion
- Orion Frangible Joint Threshold and Margins Analysis
- Ti-NTO Compatibility Cross-Program Impact and Lessons Learned
- Review of CCP Additive Manufacturing Program
- CCP Propellant and Pressurization COPV Support
- Pilot Breathing Assessment
- Validation of ISS Li-Ion Main Battery's TR Mitigation Analysis and Design Features

In-Progress Support Activities

- CCP Launch Vehicle Orbital Tube Welding POD Study Samples
- CCP Corrosion Mitigation Strategy
- Fire Cartridge Failure Investigation, Manufacturing, and Hardware Verification
- Hardware Development for COVID Applications
- ISS Battery Charge Discharge Unit Investigation
- Materials Support to DC-8 Type A Mishap
- NESC Support of CCP Anomaly
- Rapid Slews for Lunar Reconnaissance Orbiter

Completed Support Activities

- CCP Software Review

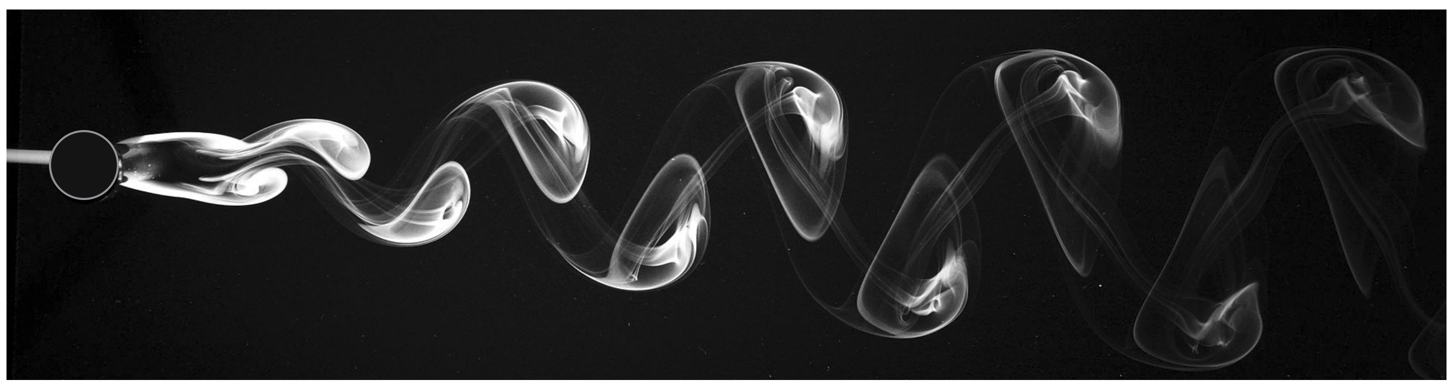
Priority 2 Completed Assessments

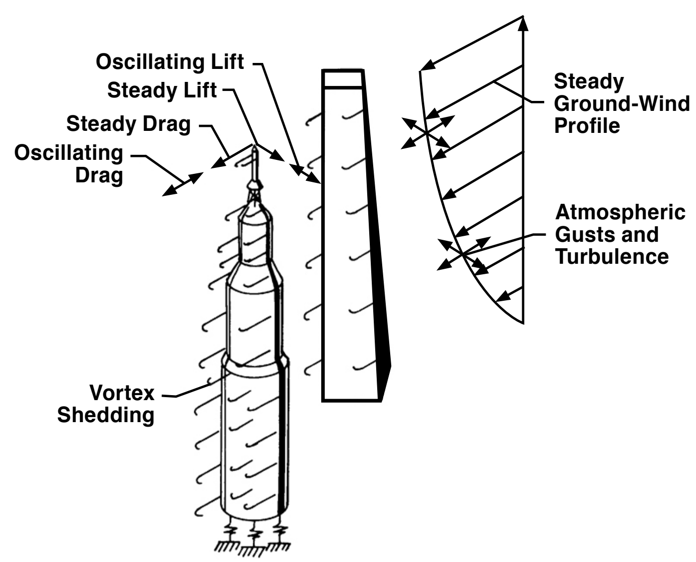
Projects in the Design Phase

Predicting Wind-Induced Oscillations on Launch Vehicles

Once situated on the launch pad, launch vehicles are exposed to ground winds and their corresponding loads. Of particular interest is a vehicle response to these loads called resonant wind-induced oscillation (WIO), which can damage vehicle structures or payloads and interfere with guidance or launch systems. Resonant WIO is a design driver for launch vehicles and is typically mitigated through the use of external dampers and strict launch criteria. To evaluate the methods for predicting WIO used by the commercial launch industry, an assessment team conducted a wind tunnel test campaign to assess key viscous flow properties and their effect on launch vehicle WIO. Testing on vehicle models demonstrated aerodynamic flow states surrounding the vehicle in ground winds are sensitive to Reynolds number and that aerodynamic loads change with structural deformation, i.e., aeroelastic coupling. The study also simulated the Earth's wind boundary layer for the first time in a large-scale facility at full-scale Reynolds number to investigate its effect on ground wind loads and WIO[1]. Agency design guidance emphasizes the importance of aeroelastic scaling in predicting WIO behavior. The team developed a crewed launch vehicle ground wind loads operational placard on the basis of these data.

This work was performed by LaRC.





LVs exposed to ground winds can oscillate and cause damage or affect systems.
Top: Example of vortex shedding off a cylinder.
Left: A model of the ARES I-X was tested for WIO.

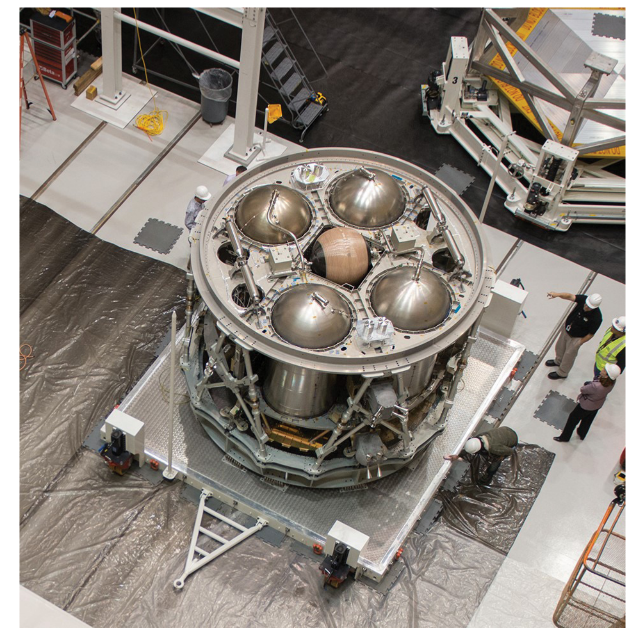
1. T. Ivanco; D. Keller; J. Pinkerton; et. al.: Development of an Atmospheric-Boundary-Layer Profile at the NASA Langley Transonic Dynamics Tunnel. 2018 AIAA SPACE and Astronautics Forum and Exposition.

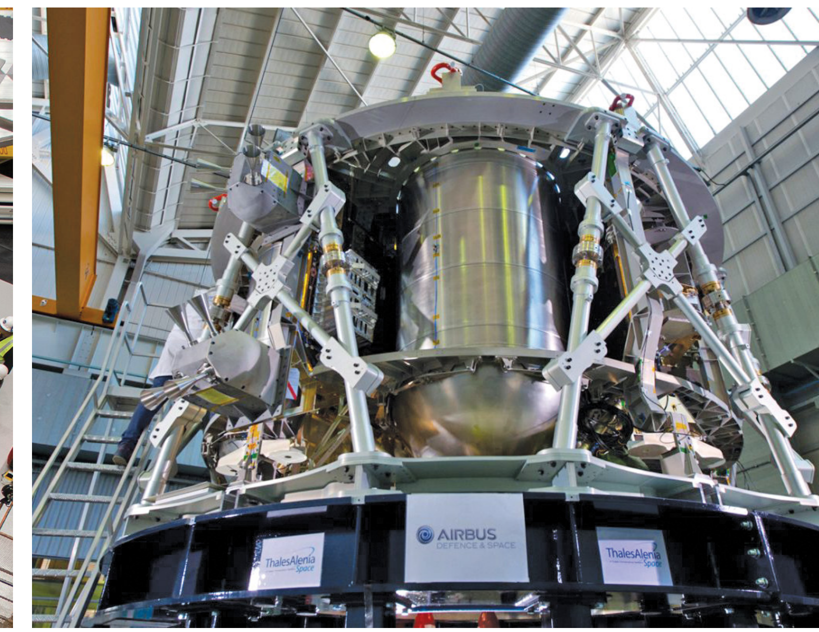
Sketch from NASA-TM-X-50548

Analysis of Propellant Tank Safe Life

Part of the safe-life demonstration of a propellant tank is understanding whether it is susceptible to environmentally assisted cracking, which is a process that promotes crack growth or higher crack growth rates than would occur without the presence of the environment. The NESC was engaged to help validate the safe life of a new propellant tank design. Sustained load tests were performed to determine if cracks in the tank weld would grow in the presence of monomethylhydrazine and mixed oxides of nitrogen propellants, common propellants used in spacecraft propulsion systems. For the tank under consideration, the NESC looked at the minimum detectable flaw size using the expected maximum design pressure. For the test, multiple pre-cracked material coupons were submerged in propellants and exposed to static loads that simulated anticipated flight conditions and elevated load conditions. The test coupons were monitored during the exposure test to measure crack growth. The NESC identified findings and observations in the areas of material characterization, tensile and fracture test results, fractographic inspection results, and propellant tank flaw analysis.

This work was performed by LaRC, WSTF, KSC, and JSC.





Propellant tanks within the Orion European Service Module are typical of tanks that are evaluated for safe service life.

Alternative O-Ring Materials for Hypergolic Propellant Systems

The NESC tested multiple O-ring materials for hypergolic fluid-compatibility in support of the government and commercial propulsion community.

NASA programs such as the Orion Multi-Purpose Crew Vehicle, the Commercial Crew Program, Mars 2020, the Europa Clipper, and the International Space Station use O-rings to seal high-pressure lines that contain liquid engine propellants and gases. When material obsolescence caused an O-ring supplier to stop producing a popular product, an NESC assessment team began testing potential replacement candidates, with a focus on material compatibility with hypergolic propellants.

The team chose six candidate materials for evaluation. The test metrics included mass changes, swelling, hardness, tensile strength, and compression set for exposure periods of 2 days and one month. Three materials successfully completed the short- and long-duration testing and were considered compatible replacements for O-rings used in hypergolic propellant applications. See NESC Technical Bulletin 20-04 page 39.

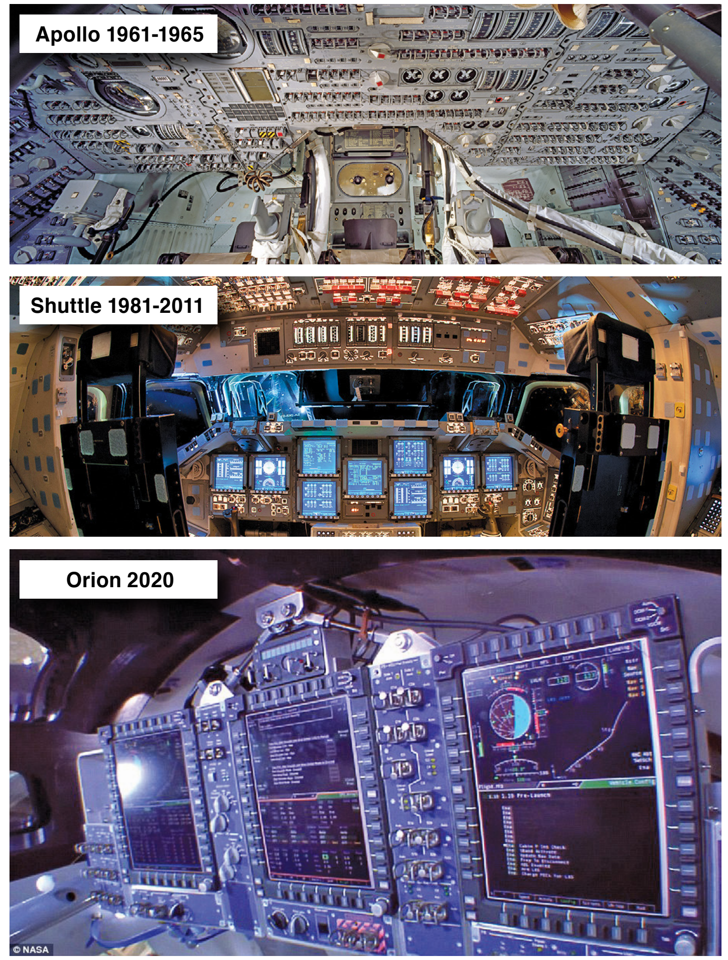
**This work was performed by MSFC, GRC, JSC, WSTF, KSC, and SSC.
TM-2020-5001493; TB-20-04**

Incorporating System Development Lessons Learned into Artemis

As software systems grow increasingly complex and provide more functionality for space systems, applying lessons learned from NASA's past spacecraft developments, commercial partners, and other flight systems will be critical to the success of the Artemis missions. Comprising three programs – the Orion Multi-Purpose Crew Vehicle, the Space Launch System, and the Exploration Ground Systems - the Artemis I mission will involve a complex integration and verification of hardware and software systems.

The NESC engaged an assessment team of systems engineering and software subject matter experts in a comprehensive review of a wide range of lessons learned potentially applicable to Artemis I and developed recommendations for the programs to help mitigate potential issues. The team focused on three key areas including testing improvements, systems engineering and integration, and software process compliance.

This work was performed by GSFC, JSC, LaRC, MSFC, and the NSC.



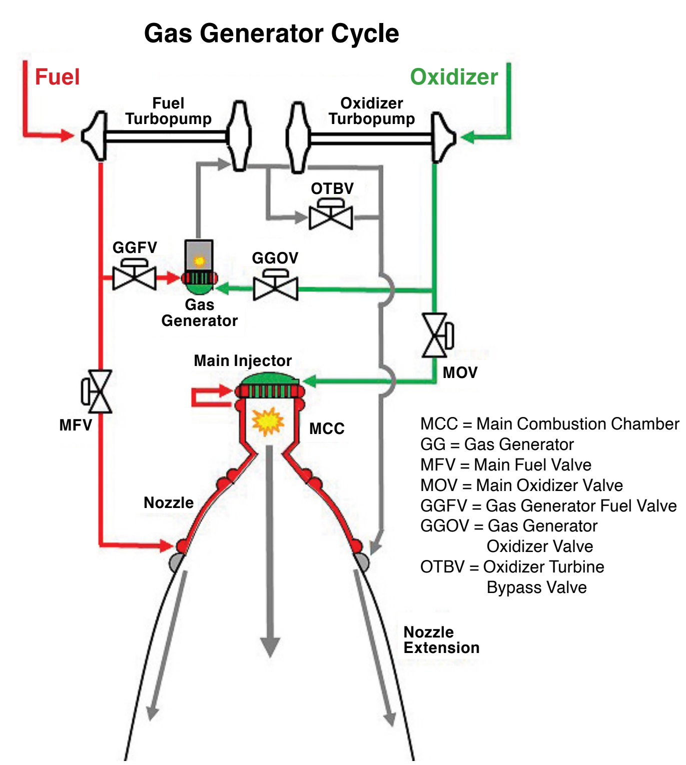
Human-rated flight hardware and software systems are becoming increasingly complex.

Assessing the Aerospace Valve Industrial Base

When NASA-wide propulsion control valve issues led to a perception of systemic quality and handling issues from an eroding supply chain, the NESC was asked to assess the aerospace valve industrial base as well as NASA's acquisition practices. To identify risks and potential mitigation steps that might help avoid future problems, programs and projects were surveyed across multiple NASA Centers; valve vendor data were mined for issues; and valve vendors were surveyed to obtain feedback on any supply issues with NASA's acquisition practices or valve design requirements.

Data and evaluations showed no erosion or decline in the industry and actually indicated some growth. The assessment found that valve-related issues may be attributed to multiple NASA programs requiring concurrent development, qualification, and manufacture of numerous challenging and unique valve designs.

This work was performed by MSFC, KSC, GRC, JSC, GSFC, and SSC. TM-2020-220577



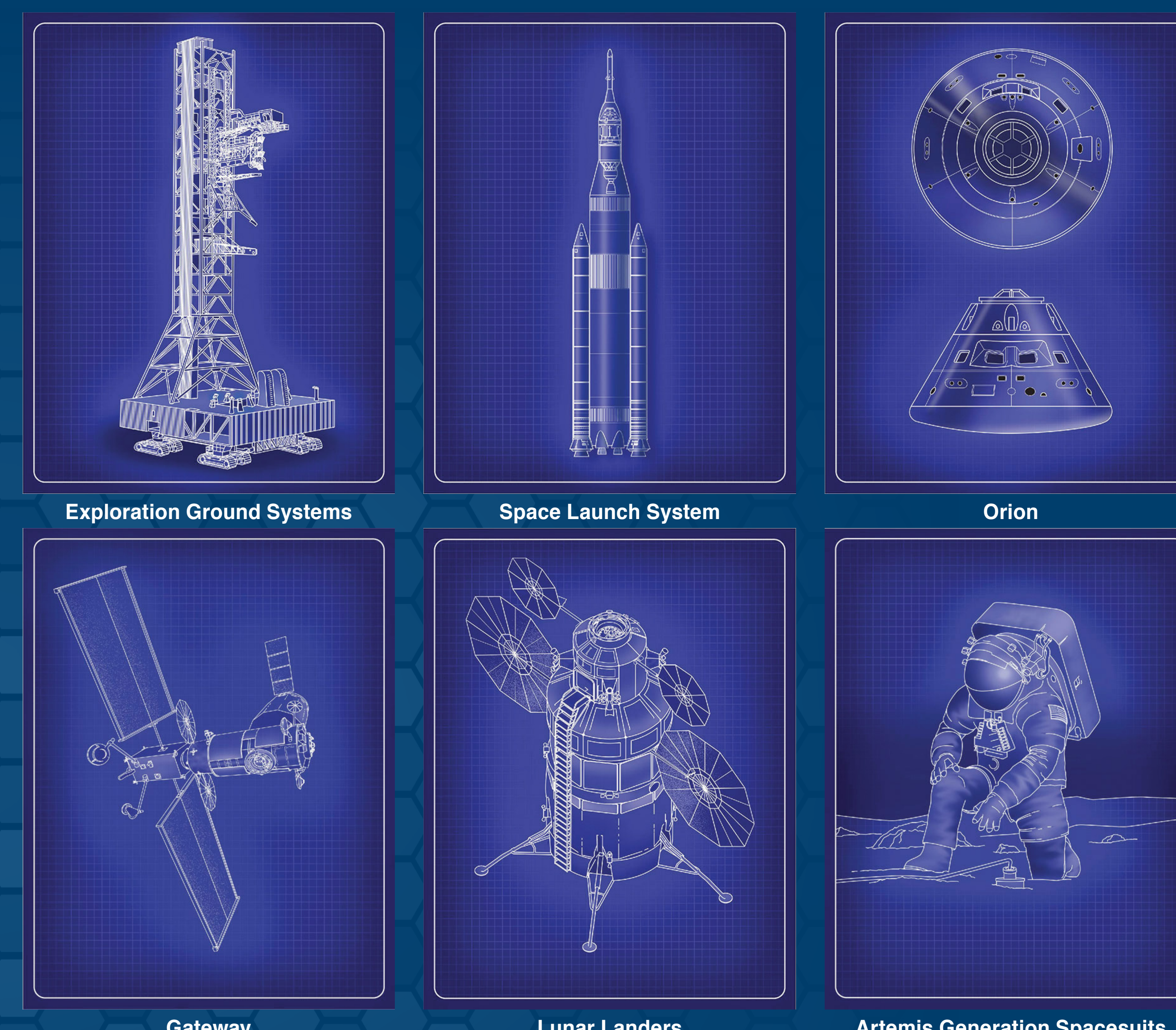
Propulsion systems rely on complex valves to control gas and liquid flows.

Guidance for Human Error Analysis

Mission safety and success rely on thousands of human tasks performed by operational personnel on the ground and in flight. The discipline of Human Factors leverages knowledge of human performance, which comprises both desired and undesired behaviors, to inform system design. This includes designing in capabilities to adapt to unexpected events as well as designing out "error traps" that provoke human error. Human error analysis (HEA) represents one approach for identifying error traps, error-producing conditions, and the means to mitigate them. Conducting an HEA is a human-rating requirement for space systems that enables a program to understand and manage hazards that could be caused by human error, understand the relative risks and uncertainties within the system design, and influence decisions throughout the system lifecycle.

To assist managers with HEA planning, execution, evaluation, and report preparation, the NESC developed a set of guidelines for meeting NASA's HEA requirements. The guide offers a systematic approach from assembling an HEA team and identifying functions and tasks to identifying potential catastrophic errors and developing a human error management strategy. See related article on page 35.

This work was performed by ARC and MSFC. TM-2020-5001486



NASA is working to achieve a human rating of the Artemis mission components.

SLS Mobile Launcher Model Review

NASA's Mobile Launcher (ML) will physically support the Space Launch System (SLS)/Orion Multi-Purpose Crew Vehicle and ground support systems during launch vehicle processing, rollout, launch, and post-launch securing operations. As the ML was readied for the SLS, the NESC was asked to review the dynamic finite element models of the ML to determine how well they matched design drawings and reflected the as-built configuration.

The NESC undertook 20 system-level modeling evaluations, which included an evaluation of the ML tower, ML base, and umbilicals, for consistency with design drawings, mass properties, and visual observations. Potential issues identified in the model reviews were then prioritized for a more in-depth review, which included trade studies and independent analyses performed to understand the potential areas of concern. As a result, findings, observations, and recommendations were provided to the Exploration Ground Systems Program and KSC Engineering.

This work was performed by LaRC, JSC, GRC, and ARC. TM-2019-220418

The SLS ML is shown on a crawler transporter.

Lift-off Modeling and Simulation of T-0 Umbilicals for SLS

A series of umbilical lines from the ML tower to the SLS will provide power, fuel, and communications until they are released at lift-off. The NESC undertook an effort to verify dynamic modeling and simulation of umbilical preload attachment and separation at lift-off. To determine the loads induced by the umbilicals on the vehicle at release, an integrated non-linear static and dynamic analysis was performed for the SLS, Exploration Ground Systems, and Orion Multi-Purpose Crew Vehicle Programs as an important step in evaluating the vehicles' structural integrity and ensuring crew safety.

The NESC developed a lift-off pad separation modeling and simulation capability inclusive of umbilical separation dynamics. This included a framework and forcing functions for assessing the SLS core stage umbilical separation, vehicle stabilizer system nonlinear struts, pad separation, extensible column re-contact, and aft strut cryogenic shrinkage at SLS lift-off. The fully nonlinear, flexible multibody simulation can accurately capture the loads from prelaunch stacking to umbilical and lift-off pad separation.

This work was performed by GRC, JSC, LaRC, KSC, and MSFC. TM-2020-5001550

Validating SLS Core Stage Pressurization Systems

In preparation for the launch of Artemis I, the NESC led an independent verification and validation of the SLS core stage pressurization systems to confirm they would meet operating requirements for worst-case cold environmental conditions.

As part of the NESC team, NASA's Launch Services Program (LSP) performed the modeling and simulation for this assessment using models and analysis techniques LSP developed for the Delta IV upper stage and anchored with flight data. The modeling effort utilized coupled thermal and fluid models that ran concurrently, exchanging requisite information between the various models at specified time increments during the prelaunch and ascent timelines. The integrated models were used to perform predictions for the SLS main propulsion system Green Run and ascent flight-operating conditions. The predictions for worst-case cold environmental conditions indicate that the propulsion system pressures remain within redline/abort limits throughout Green Run and ascent. The models were delivered to the SLS Program for continued development and operation.

This work was performed by MSFC, KSC, GRC, and SSC.

Illustration of SLS Block 1B crew configuration showing vehicle stabilizer system and umbilical connections between the SLS and the ML base and tower.

Effects of Natural Aging on Aluminum-Lithium Plate

Cryogenic propellant tank panels are commonly manufactured using thick-section aluminum-lithium (Al-Li) plate. With long lead times required to obtain the material, Al-Li plate is often procured in large quantities to support fabrication and multiple tank builds. Because the material may be stored for extended periods of time, the heat-treated Al-Li can, depending on the storage environment, undergo a natural aging process that affects tensile and fracture toughness properties.

To help determine the underlying effects of natural aging, an NESC team performed a detailed metallurgical and mechanical property characterization of Al-Li plate. The team performed tensile and fracture-toughness testing at ambient temperature to identify anomalous macroscopic or microscopic characteristics. Results indicated natural aging produced a measurable change in room temperature tensile and fracture properties. However, the subsequent final thermal treatment detected no mechanical property difference with "nominally" stored solution-treated material. Recommendations were given to use specific nondestructive evaluation and/or tensile testing for each material lot subjected to long-term storage prior to use to verify the results of this study.

This work was performed by MSFC.

The SLS core stage Al-Li liquid hydrogen propellant tank shown after welding at NASA's Michoud Assembly Facility.

Safeguarding Engine Test Stand Operations

SSC is NASA's largest rocket engine test facility, used by over 30 companies and agencies for engine testing. Following an increase in testing tempo and reported close calls that could have resulted in personnel injury at the SSC E-1 test stand complex, the NESC was asked to identify potential operational hazards from a human factors perspective and provide recommendations for mitigations. The E-1 test stand facility comprises three cells used to test engine components such as injectors or combustion chambers that require high-pressure and high flow rate industrial water, cryogenic, and non-cryogenic fluids.

During its assessment, the NESC team worked to gain insight into the effects of demanding test schedules, increased workload, and fatigue on personnel and operations. The team observed tests and reviewed documents and processes, including the SSC Close Call Reporting System and the NASA Mishap Information System databases. The NESC provided recommendations to the SSC Office of Safety and Mission Assurance for policy, procedure, and organizational modifications regarding planning and scheduling; workforce roles and responsibilities; training; and communication that could help mitigate the risks of personnel injury and hardware damage.

This work was performed by ARC, MSFC, KSC, JSC, and SSC.

The E Complex engine test stand at SSC.

Priority 2

In-Progress Assessments

- Independent Operational Modal Analysis of Dynamic Rollout Test Data
- Particle Ignition in a Peroxide Propulsion System
- CCP Fluid Systems Contamination
- LaRC Transonic Dynamic Tunnel Review
- CFD Assessment of AA-2 Axial Force Anomaly
- Lunar Meteoroid Ejecta Model Review
- ESD Integrated Hazard Review
- Effects of Helium Concentration on TEA-TEB Combustion in Oxygen
- Development of Fire Suppression System Requirements
- Examination of Time-Triggered Ethernet in Artemis Architecture
- Study for GSFC LISA Laser
- Biocide Impacts on Life Support and EVA Architectures
- EGS ICPS Umbilical Modeling Evaluation
- Cyclomatic Complexity Evaluation
- Tube Test Coupon for COPV Mechanics
- Anaerobic Hydrogen Detection Sensor
- Orion Crew Module Side Hatch Analysis
- Guidelines for an Avionics Radiation Hardness Assurance
- Hypervelocity Impact Testing of Kevlar KM2+
- Space Launch System High Reynolds Number Testing
- CCP Ascent Stability
- Qualification of Radiographic NDE Techniques
- CCP Post-Flight Reference Radiation Environments
- Review of Analysis to Support Midpoint Monitoring in Batteries
- Material Compatibility and EAC Data for Metals in Hypergolic Propellants
- CCP Autonomous Flight Termination System
- CCP Main Parachute NDE
- CCP Parachute Pack Ground Extraction Testing
- Spacecraft Safety Equipment Assessment
- Aerodynamic Buffet Flight Test
- Thermocouple Interference During High-Speed Earth Entry
- Lead H2 Pop During SLS RS-25 Start
- Evaluation of Occupant Protection Requirement Verification Approach by CCP Partners
- NESC Peer Review of ESD Integrated Vehicle Modal Test, Model Correlation, DFI, and Flight Loads Readiness
- Orion Titanium Hydrazine Tank Weld - Environmentally Assisted Cracking
- Infrared Laser Sensor Technology Readiness and Maturation
- Risk Reduction of Orion Government-Furnished ECLS
- Effects of Humidity on Dry Film Lubricant Storage & Performance
- Composite Pressure Vessel 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
- Launch Abort System Risk Mitigation
- Peer Review of the MPCV Aerodynamic/Aerothermal Database Models and Methods
- Helium Evolution from Helium-Saturated Hypergolic Propellants
- SLS Flight Computer
- Technical Standards Evaluation and Streamlining Approach
- Human Exploration and Operations Program Status Assessment
- Propulsion System Pintle Erosion Investigation
- OFT-1 Entry Risk Assessment
- Hydrazine Tank Investigation
- Oxygen Compatibility Assessment
- Capsule Water Landing Structural Design Reliability
- Cryogenic Fluid Management Feasibility Assessment for NTP
- Pyrotechnic Smart Initiator Redesign
- Mars 2020 Wheel/Flexure Stiffness and Strain Capacity
- Review of SLS SOW
- NASCAP Integrated Spacecraft Charging Analysis
- Service Module Pressure Control Assembly
- Active Mass Translator on Near-Earth Asteroid Scout
- EGS Crew Module Test Article Design Peer Review
- Pegasus ICON Mission
- ESD Dynamic System and Flight Test Analysis and Evaluation
- Orion CM/SM Separation Nut Test Fixture
- WFF Super Pressure Balloon Data Acquisition Design
- Orion CM Recovery During Underway Testing and Artemis I
- Mars 2020 Heatshield Structural Review
- Waterflow Pulse Test Support to Develop RL-10 Pogo Model Propulsion Terms
- SLS Booster Nozzle Throat Plug Debris
- Orion CM/SM Separation Bolt Life
- Acceleration Decoupling for Modal Test
- AA-2 Independent Review Team
- VAB Pile Cap Peer Review
- Technical Support for GOES-R Arcjet On-Orbit Anomaly
- Adiabatic Demagnetization Refrigeration on SOFIA Science Instruments
- NASA Support to Boeing OFT-1 Software Review

Completed Support Activities

- Evaluation of ABSL Moli-M Cell Li-Ion Batteries for L2 Missions
- CFD/DTA Analysis for a CCP Propulsion System
- European Solar Array Wing Deploy Model Review
- EGS Mobile Launcher 1 Weld
- CCP Thruster Design Modifications
- Review of Failure Analysis for Bellow Cracking Issue

In-Progress Support Activities

- CCP Sensor Anomaly Investigation
- NAFTU Software Engineering Review
- Flex Harness Technical Support
- Rotordynamic Analysis for Europa Clipper
- Mars 2020 Sample Tube Cracking
- Circuit Board Signal Integrity/Power Analysis and Training for CLPS Missions
- CCP Ascent Cover
- Ocean Color Instrument Engineering Test Unit Anomaly
- Space Charging of Ocean Color Instrument Rotating Mechanism
- Evaluation of CCP Fire Suppression
- Support for NASA P-3B Aircraft Anomaly
- CCP 1553 Dropped Commands
- Remote Analog Interface Unit
- Support to Blue Origin, New Glenn Launch Vehicle
- MPCV Welded Coupon Autofrettage Crack Growth Tests
- Evaluating Risk of an Alternative Pyro Lot Acceptance Test Plan
- SE&I Support to CCP DCRs
- Review of SLS FTS Battery Cell Out Test Procedure
- Orion, NDSB2, & Gateway Material Electrical Properties Support
- Orion Spacecraft Low-g Slosh Performance and Stability
- Orion Artemis I Spectrometer
- Power Electronics Technical Support for Electric Propulsion
- Hydrodynamics Support for the Orion CM Uprighting System
- CCP Parachute Flight/Ground Tests and Vendor Packing/Rigging
- Super Resolution Post-Processing of Air-to-Air Imagery of CCP High Altitude Parachute Test
- NOVICE Radiation Assessment
- SLS Design Certification Review
- Bond Verification Plan for Orion's Molded Avcoat Block Heatshield Design

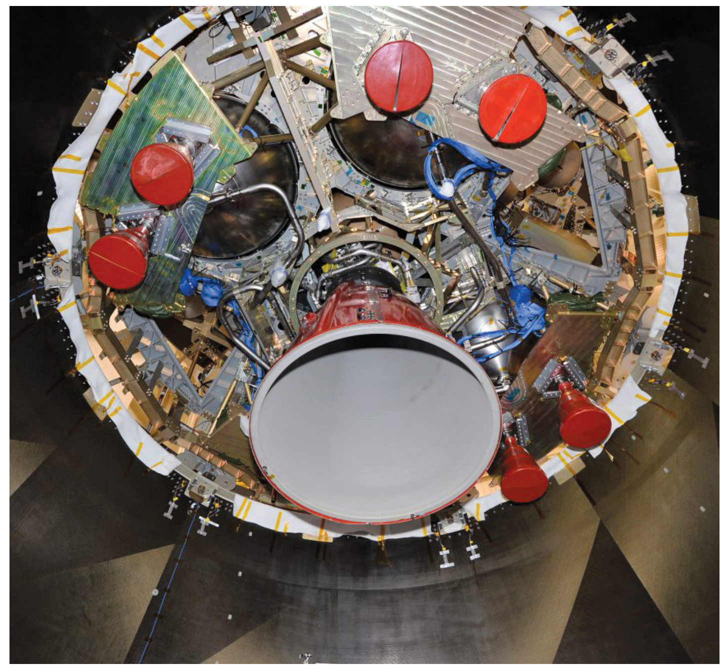
Priority 3 Completed Assessments

Known Problems not Being Addressed by any Project

Transient Combustion Modeling for Hypergolic Engines

Hypergolic engines provide maneuvering thrust on many spacecraft, and can experience transient combustion issues including start-up pressure oscillations and overshoots, ignition delays, and transient thrust excursions. During the Apollo Program, NASA performed significant testing and implemented hardware-specific mitigation approaches to address transient combustion issues. While those operational mitigations were generally successful, there was limited feedback into engine designs and little insight into foundational causes. An NESC assessment team performed fundamental propellant testing and developed 1-, 2-, and 3-dimensional models during a recent investigation into hypergolic engine transient combustion processes. The models described the interrelationships between operational parameters (e.g., flows, pressures, timing, etc.) and combustion chamber dynamic responses. The results will help designers and modelers understand relevant environments and inform test engineers of instrumentation best practices to help capture relevant behaviors. The user community will also benefit by preventing damage to hardware and designing safer and more efficient start-up sequences. See page 32 for additional detail.

This work was performed by LaRC, MSFC, KSC, JSC, and WSTF.



Orion's European Service Module uses multiple hypergolic engines.

Expedition 63 astronaut Chris Cassidy works to install Li-ion batteries on the ISS truss structure.

Lithium-Ion Battery Safety

Lithium-ion (Li-ion) batteries provide energy-dense power storage solutions that are lightweight and low volume and are extensively used for human spaceflight applications. On the ISS, Li-ion batteries store power from the solar array wings and power the ISS extravehicular mobility units and hand tools. However, Li-ion cells pose an inherent risk of thermal runaway (TR), a rapid release of stored electrochemical energy, which can be triggered by physical or electrochemical abuse or an electrical short. Within a battery, TR in a single cell can rapidly propagate to adjacent cells resulting in a potentially catastrophic event.

The NESC is focused on designing safe, high-performance Li-ion batteries. This requires a thorough understanding of the thermal energy that is liberated during TR. Additionally, the NESC has been involved in basic research by measuring the fractional energy yield and effluent/composition ejected from a cell in TR. Insights gained from this work have improved thermal modeling of Li-ion cells and batteries. Techniques to measure TR energy yield developed by the NESC will benefit Li-ion cell and battery design in commercial applications.

This work is being performed by JSC, GRC, KSC, and MSFC.

Space Weather Architecture

Since the final human Moon landing in 1972, all human space exploration has taken place in low-inclination low Earth orbit, where the Earth's magnetosphere provides significant protection from harmful space radiation. But for journeys beyond low Earth orbit to destinations in cislunar space and Mars, new monitoring infrastructure and operational procedures will be required to protect astronauts from space radiation hazards.

To help reduce these radiation risks for crewed and robotic systems operating in the inner heliosphere in orbits about Earth, cislunar space, and Mars, the NESC reviewed prior and current NASA, NOAA, and DoD work on space weather monitoring and forecast architectures to understand gaps in knowledge and status of existing space environment monitoring infrastructure. They also assessed operational response time for space weather monitoring, reviewed the status of relevant space weather forecasting tools, and assessed solar energetic particle threshold levels for exploration missions. The data gathered were used to develop options for a robust, cost-effective space weather situational awareness architecture to reduce radiation risks for human and robotic deep space exploration.

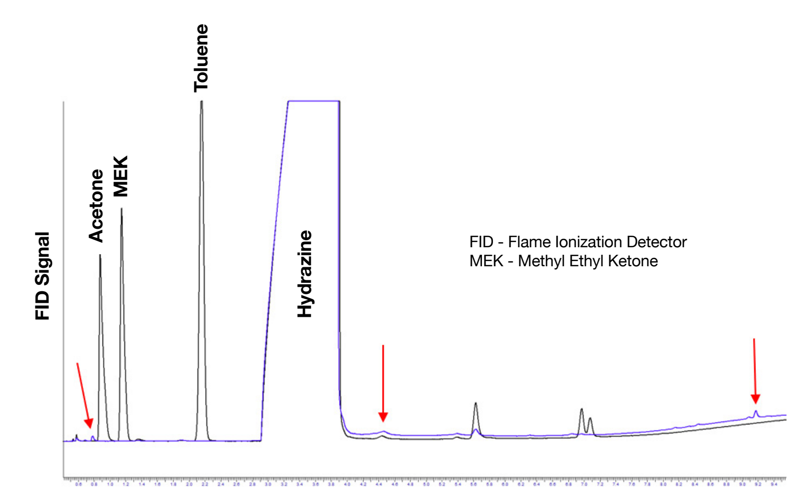
This work was performed by MSFC, JSC, GSFC, JPL, LaRC, NOAA, and the U.S. Air Force. NASA/TM-2020-5000837

Sustained exploration of the Moon and Mars requires a space weather monitoring capability to warn crews of approaching hazards from solar energetic charged particles.

The Consequences of New Hydrazine Production Process

Hydrazine dominates the class of hypergolic liquid propellants used for rocket propulsion and is widely used in auxiliary power units and thrusters for satellites and spacecraft. New methods to produce ketazine-derived high-purity hydrazine (HPH) have shown the presence of extraneous, unknown organic byproducts from the synthesis processes. To understand if these byproducts could affect the long-term storage of HPH or propulsion performance, the NESC led a full organic and elemental analysis of hydrazine samples as well as a round-robin style test protocol with numerous government and contractor laboratories. The team identified and quantified organic compounds and developed procedural guidelines for future analyses that will benefit the propulsion community as it responds to the adoption of this HPH commodity. Recommendations will be made to U.S. Air Force owners of MIL-PRF-26536G, *Performance Specification - Propellant, Hydrazine* for possible incorporation into a future revision. See NESC Technical Bulletin 20-08, page 41.

This work was performed by KSC, MSFC, JSC, WSTF, JPL, and GSFC. TB-20-08



Testing of HPH samples at KSC yielded extraneous, unidentified peaks in the carbonaceous assay when analyzing HPH made from a newer ketazine method.

Characterizing Damage Tolerance Life in COPVs

Linear elastic fracture mechanics (LEFM) methods have traditionally been used to characterize the damage tolerance life of elastically responding components, but may have limitations when predicting fatigue-crack growth-rate behavior in the thin metal liners of COPVs. The NESC initiated an assessment to develop data to define these limitations by performing fatigue and fracture testing and LEFM analyses, and developing a finite element model to compare crack behaviors. The results included an analysis approach to identify where LEFM small-scale and constrained plasticity assumptions are violated, and found that measured crack growth behavior gradually diverges from LEFM predictions as the crack depth approaches the liner thickness. They also demonstrated a test-based methodology for validating damage tolerance life requirements by performing material evaluation, autofrettage crack growth tests, and damage tolerance life tests. These tests and analyses provided evidence to support best practices to comply with COPV standards for damage tolerance life.

This work was performed by KSC, GRC, LaRC, JSC WSTF, JPL, and MSFC.
NASA/TM-2020-5006765

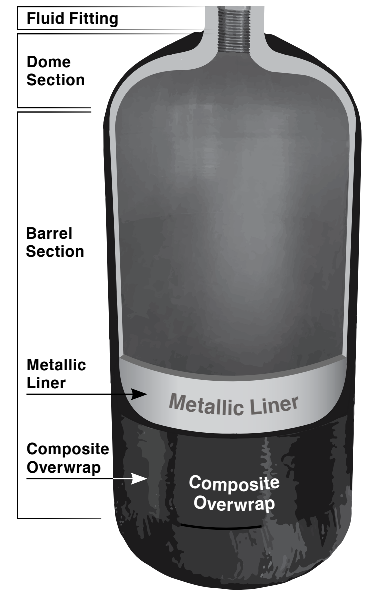


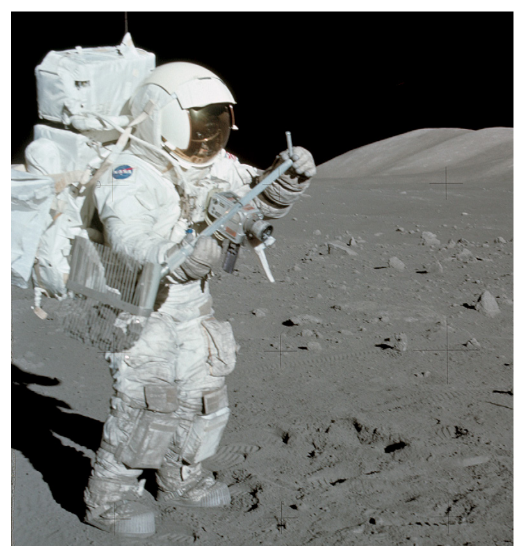
Illustration of COPV major components.

Understanding Lunar Dust

Lunar dust is an Agency and industry concern affecting most mission subsystems. Precursor landers on the Moon will need to ascertain dust characteristics that will influence hardware design and provide toxicology data to safeguard crew health.

To aid in that effort, the NESC hosted the 2nd Lunar Dust Workshop in early February 2020 focusing on the impact of lunar dust on human exploration. The workshop addressed concerns about the physical nature of the dust, its impact on human health, and its impact on lunar surface systems and operations. The goal was to provide insight for lunar mission designers and engineers and for mission planners deciding on payload selections for future lunar missions.

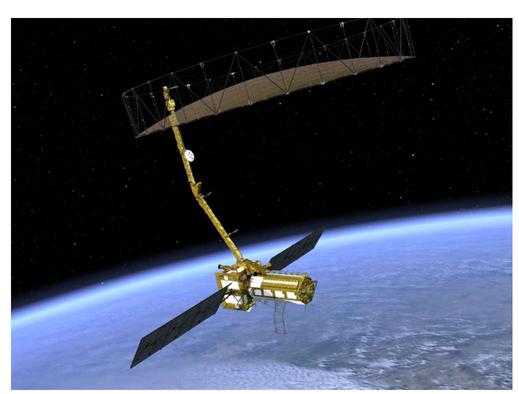
This work was performed by JSC, JPL, LaRC, and ARC.



Abrasive lunar dust caused issues with EVA suit joints.

Qualifying an Updated Flight Computer

The RAD750 radiation-hardened single-board computer has been the standard flight computer for many NASA and DoD projects and instruments. Because of part obsolescence and the need for increased performance and capabilities, an updated design was needed that would meet the conditions and environments for the majority of NASA space missions. The NESC teamed with other NASA directorates to oversee the qualification of the new version of the RAD750 as well as review the analyses associated with the updated design. This joint effort prevented multiple programs from having to develop and qualify revised boards for their systems. The updated RAD750 successfully completed acceptance and qualification testing, and can be used not only for future applications, but as a backward-compatible component to existing hardware.



Planned missions like the NASA-ISRO Synthetic Aperture Radar satellite use radiation-hardened single-board computers.

Preparing for Composite SBKF Testing (In-Progress Update)

The Shell Buckling Knockdown Factor (SBKF) assessment was chartered to develop and experimentally validate new analysis-based buckling knockdown factors for stability-critical metallic and composite launch vehicle structures. The project has provided new knockdown factors for metallic structures to the SLS core stage, which resulted in documented mass, cost, and schedule savings, and a new update to NASA SP-8007 *Buckling of Thin-Walled Circular Cylinders* is currently being finalized. The current focus of the SBKF team is developing buckling analysis approaches for sandwich composite cylinders that can be used to develop new buckling design factors. To support this effort, a series of large-scale 8-ft-diameter test articles are being tested to validate these analyses.

The fourth and final such large-scale test article was fabricated in fall 2019 and is being prepared for testing in November 2020. In order to ensure that the SBKF research is state of the art, a number of external collaborations have also been established with domestic and international partners in government, academia, and industry. There is an active collaboration between the SBKF team and the Delft University of Technology in the Netherlands. This collaboration is an effort to establish rigorous scaling laws for the buckling response of sandwich composite shells and to investigate the buckling response of single-piece composite cone-cylinder shells.

Removal of 8-ft-diameter sandwich composite test article from the tool after fabrication and before preparation for test at MSFC.

Priority 3

In-Progress Assessments

- Unconservatism of LEFM Analysis Post-Autofrettage
- Medical Ceramic Oxygen Generator (M-COG)
- Honeywell MIMU Operational Life Investigation
- COTS Guidance for all Mission Risk Classification
- 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 & Qualification
- Wireless EDL Instrumentation Validation
- Microthrusters for Low-Jitter Space Observatory Precision Attitude Control
- Guidelines for Battery TR on Robotic Missions
- Auroral Charging Threat Assessment
- Creation of Agency Standards for Additive Manufacturing
- Safe, High Power Li-ion Battery Module Design
- Southern Hemisphere Meteoroid Environment Measurements
- MMOD Pressure Vessel Failure Criteria
- Shell Buckling Knockdown Factor Proposal

Completed Support Activities

- Restore-L RPO and Kodiak Systems
- Lunar Lander Standing Acceleration Limits Standards Development
- DART Spacecraft SmartNav Independent Review Team

In-Progress Support Activities

- Arecibo Failure Support
- GRC High Voltage Fault/Transient Anomalies
- Human Factors Support for OSAM-1
- Update Human Systems Integration Practitioner's Guide
- Technical Readiness Assessment of Lidar Instruments for ACCP SET
- Advanced Weapons Elevator CVN-78
- DARPA Experimental Space Plane
- Revision of NASA-HDBK-4002A
- Lunar Lander Mentor Team
- PAMELA Radiation Data Recovery
- 6 Degree-of-Freedom Trajectory Simulation with Integrated CFD Aerodynamics
- Completion of NASA-HNBK-5010A

Priority 4 Completed Assessments

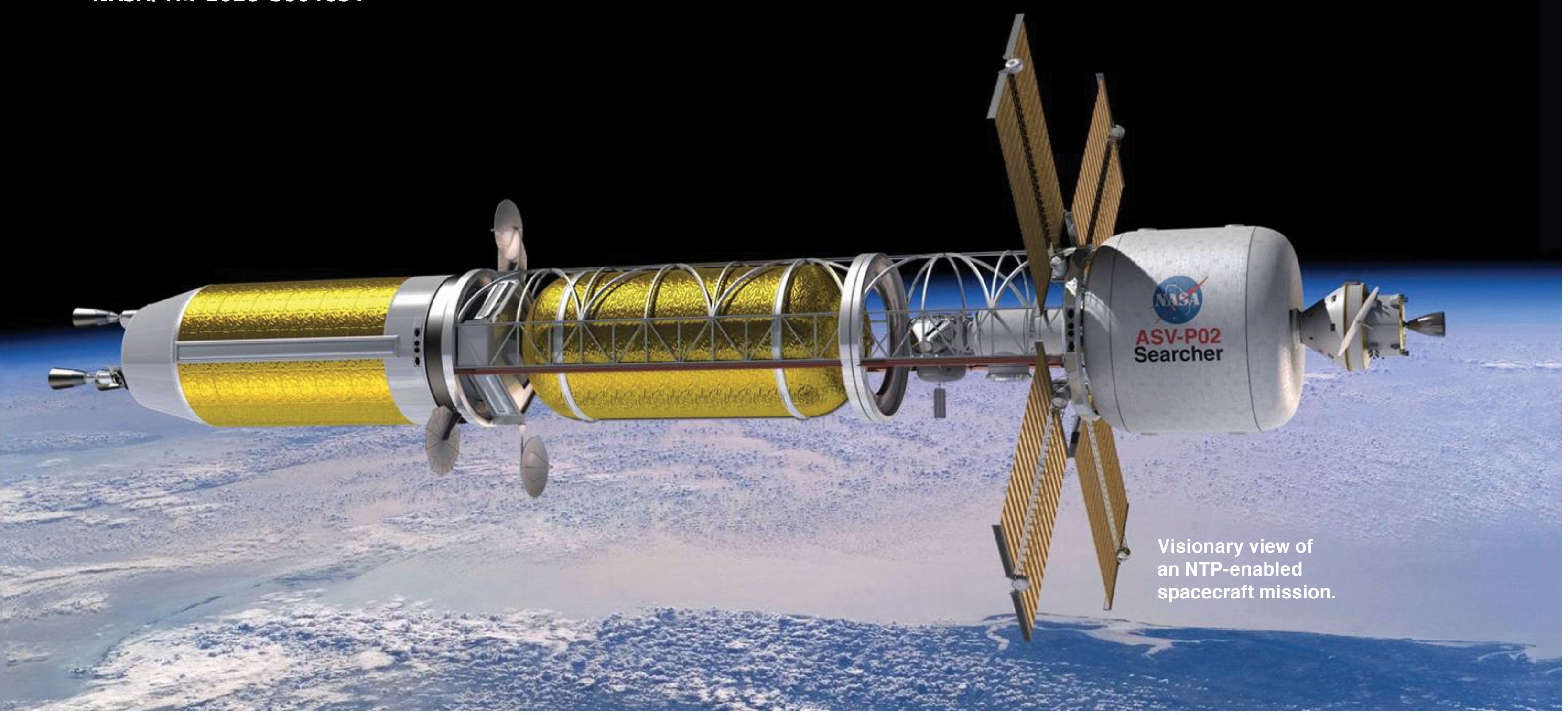
Work to Avoid Potential Future Problems

Evaluating Nuclear Propulsion Technologies for Future Mars Missions

Both nuclear electric propulsion/chemical propulsion (NEP/Chem) and nuclear thermal propulsion (NTP) architectures are being considered both internal and external to NASA for missions to Mars during the 2030s. To help inform current architecture development efforts, the NESC recently assessed a range of components and systems to determine their technical maturity and potential to reach flight qualification by 2035.

The team evaluated 26 systems and 72 technologies including NTP and NEP reactors and fuels, NEP auxiliary systems, and cross-cutting technologies. The system/component maturity was assessed using Technology Readiness Levels (TRL) and the Advancement Degree of Difficulty (AD2). The latter is a predictive description of what is required to move a system or component from one TRL to another. Lower AD2 values imply less risk moving to higher TRLs. The team found the majority of critical technologies evaluated are at a relatively high AD2 for reaching flight qualification, but could be matured to support a 2035 crewed mission to Mars, given a dedicated and well-funded program.

This work was performed by MSFC, GRC, JPL, GRC, KSC, and JSC.
NASA/TM-2020-5001631



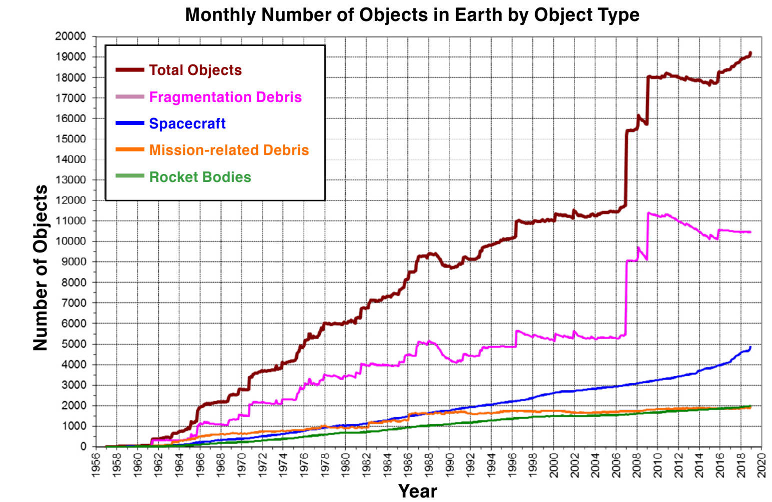
Visionary view of an NTP-enabled spacecraft mission.

Priority 5 Completed Assessments

Work to Improve a System

Guidelines for Spacecraft Passivation

Impacts from orbital debris can damage or destroy space vehicles. To limit the growth of the orbital debris population across widely used orbits, NASA requires space vehicles such as satellites and launch vehicle stages undergo a decommissioning. Called spacecraft passivation, the process removes stored energy from a space vehicle that has reached the end of its mission—but will remain in orbit—to help reduce the risk of high-energy releases like explosions or fragmentations that would produce orbital debris. An NESC team conducted an assessment to develop guidelines for spacecraft designers and operators to ensure they are meeting NASA passivation requirements. The team reviewed literature; evaluated pressurized systems to recommend guidelines for acceptable depressurization targets; provided a process to determine the number of meteoroid/orbital debris particles a spacecraft may encounter in its passivated state; and demonstrated the potential risk associated with pressure increases due to residual propellant decomposition.

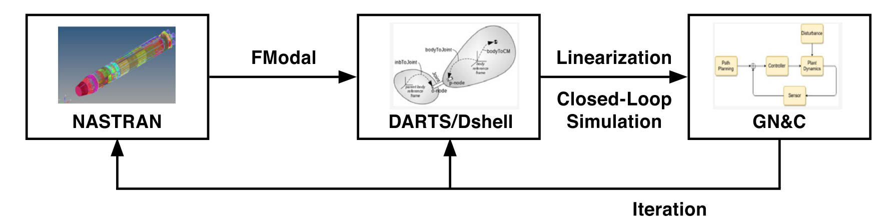


Fragmentation debris is the majority of orbital debris.

This work was performed by LaRC, JSC, GSFC, GRC, KSC, and JPL. NASA/TM-2020-5001631

Bridging the Gaps Between Multibody Dynamics and GNC

Flexible multibody dynamics modeling of launch vehicles and satellites is often critical for the design and analysis of guidance, navigation, and control (GNC) systems and for evaluating structural loads. While the GNC and structures disciplines share a need for high-fidelity structural models to predict dynamic behavior, fragmented modeling approaches have historically persisted because the needs of the disciplines differ. The NESC developed a toolchain to improve the process of generating and integrating structural dynamics data for use in multibody aerospace system models. The work addressed common issues by developing a finite element model (FEM) to GNC modeling pipeline using a general multibody dynamics framework. The work resulted in a tool that streamlines the processing between structural analysis models and GNC models. Test cases were developed to emphasize dynamic coupling between bodies and the results compared against models developed by MSFC Engineering. The tool was further demonstrated using a FEM developed for the SLS core stage and was separately used to develop GNC flexible body models for an NESC assessment to reduce jitter in science missions requiring challenging pointing stability requirements.



A FEM-to-GNC modeling pipeline using a general multibody dynamic framework.

This work was performed by KSC, JPL, MSFC, GSFC, and JSC.

Priority 4

In-Progress Assessments

- Shock Prediction Advancement: Transient Finite Energy Predictor
- FPMU Data Processing Algorithm Development and Analysis
- BON Galactic Cosmic Ray Model Improvements
- Updating RefProp with Nitrogen Tetroxide Properties
- Wire and Wire Bundle Ampacity Testing and Analysis
- Solderless Interconnects and Interposers
- EEE parts Copper Wire Bonds for Space Programs

Completed Support Activities

- State of In-Space Propellant Tanker/Transfer Technology

In-Progress Support Activities

- Ethical Use of Artificial Intelligence Policy Development
- AFRL/STMD Advanced Radiation-Hardened Memory

Priority 5

In-Progress Assessments

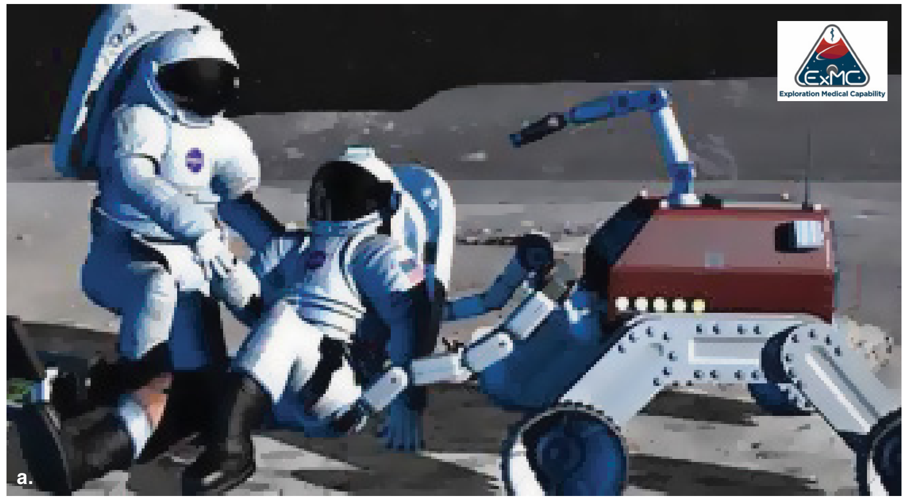
- Flight Mechanics Analysis Tools Interoperability and Component Sharing
- Improvements to the Flight Analysis and Simulation Tool

Completed Support Activities

- Determining the Composition and Depth of the Lakes on Titan
- Agile Software Development Methodology Use Summary

In-Progress Support Activities

- U.S. Army: Reentry Aeroballistics Trajectory & Thermal Protection
- DARPA TRADES Study



Innovation that Impacts All NASA Missions: Improving How We Engineer Our Systems

John F. Kennedy set the tone for NASA's culture in 1961 during his famous speech on going to the Moon, "We choose to go to the Moon not because it's easy, but because it's hard; because that goal will serve to organize and measure the best of our energies and skills, because that challenge is one that we are willing to accept, one we are unwilling to postpone…"

That culture has never faded, even across NASA's diverse spectrum of missions. The continuous challenge to do what is hard or near impossible includes the requirement for innovation. Innovation is the importance of what we do, but also how we do it. With a goal of improving the way NASA's workforce engineers its systems, the Systems Engineering (SE) Technical Discipline Team (TDT) has partnered with numerous facets of the NASA workforce to better enable innovation in how we work. Over the past year, three diverse teams made progress toward that goal by looking at the way we levy technical standards, improving understanding and integrated risk (cost, schedule, and technical), reducing project risk by better management of mass growth, and moving SE into the model based digital domain. A brief summary of each team's efforts follows.

Kerry McGuire
(ExMC)

ExMC: Systems Analysis and Integration Using MBSE

Via its Model-Based Systems Engineering (MBSE) Infusion And Modernization Initiative (MIAMI), the NESC SE TDT partnered with the Human Research Program's Exploration Medical Capability (ExMC) Element (https://www.nasa.gov/hrp/elements/exmc) at JSC. ExMC has adopted SE principles and tools (MBSE and the Systems Modeling Language) to develop an initial architecture and requirements for a future exploration medical system. MIAMI is assisting the ExMC work by providing an MBSE modeler who is matrixed to ExMC, one NASA MBSE Community of Practice (CoP) meeting per month dedicated to responding to ExMC's needs, and any available/needed Agency MBSE infrastructure. In return, MIAMI is receiving modeling lessons learned, feedback to the MIAMI Leadership Team on available MBSE resources, and data needed to communicate MBSE successes and challenges to their SE TDT peers.The partnership has been mutually beneficial to ExMC, the SE TDT, and the greater NASA MBSE community. With MIAMI support, ExMC architected their system model, developed a model management plan, better defined their MBSE hiring and training needs, provided guidance to junior modelers, and developed ideas to push the boundaries of model usage.

As a return benefit, the MBSE community received a sample model architecture, an updated model management plan template, and valuable discussions at the MBSE CoP, where the ExMC presented ideas that had not been considered before. Ideas included the characteristics of good system modelers, how to manage model configuration, and using models with non-modeling tools. Notes from all these lively and well-attended CoP discussions are on the NASA Engineering Network MBSE website (https://nen.nasa.gov/web/mbse/). Beyond this, ExMC's input on what will be necessary to grow NASA's MBSE community and capability (e.g., modeler skillsets) continues to inform and ground in reality MIAMI's recommendations to NASA's Digital Transformation initiative. *For more information, contact Kerry McGuire, kerry.m.mcguire@nasa.gov.*

a). MBSE is being applied to help architect the ExMC, which is pushing the boundary of space medical systems to care for future astronauts. b). A proposed Mars sample return mission development project would benefit from using the NASA-endorsed ANSI/AIAA standard: *Mass Properties Control for Space Systems.* c). New approaches to streamlining design and constructions standards will benefit projects like the Gateway Power and Propulsion and Habitation and Logistics Outpost.

Robert Shishko
(JPL SE)

NASA/JPL: Enterprise Approach to Mass Properties Control

In August 2019, a team of NESC and NASA subject matter experts (SME) issued a report regarding mass growth. It included recommendations to initiate the development and sustainment of an expanded mass growth database as an Agency resource and reforms in how programs and projects estimate, manage, and report mass properties based on the NASA-endorsed ANSI/AIAA S-120A-2015 [2019] standard, *Mass Properties Control for Space Systems*. The intent is to reap the benefits of a more common approach across NASA in managing and controlling mass growth and of using a common terminology among NASA Centers and its contractors. Historical mass growth data, consolidated in a single place, will help programs and projects in establishing Mass Growth Allowance (MGA) factors and mass margins above MGA that can reduce the risk of mass issues and potential cost overruns. To date, the NESC recommendations have resulted in major changes in mass management and control requirements and recommended best practices at JPL and other NASA Centers. Beyond Center-level actions, the NESC has engaged with the Office of the Chief Financial Officer to promote the use of the ANSI/AIAA standard's terminology and calculations in future data collections for NPR 7120.5-mandated *Cost Analysis Data Requirements* documents. *For more information, contact Robert Shishko, robert.shishko@jpl.nasa.gov.*

Jenny Devolites
(HALO SE)

HALO: Modernized Application of Design & Construction Standards

The NASA Technical Standards Process Improvement pilot activity initiated by the Habitation and Logistics Outpost (HALO) Project seeks to improve the way that NASA levies and manages technical standards by 1) moving from document-centric to data-centric (databases) management of the requirements; 2) incorporating important attributes into the database so that applicability, tailoring, and information management is streamlined; and 3) providing technical recommendations on acceptable approaches for compliance evidence. The effort is a fleet-leader on how to streamline the standards deployment, assessment, and long-term verification process, while also improving the allocation of resources based on mission risk.

NASA Technical Fellows participated in this review and provided important input and support for the assessment of Design and Construction (D&C) standards for the HALO project. The approach "shredded" the requirements documents into a database of individual requirements with fields to populate describing the requirement type and compliance approach. Overall, the pilot activity is an important first step in properly assessing and flowing D&C standards to NASA's contractors and partners. NESC systems engineering and integration SMEs reviewed the HALO pilot deployment activity for managing and implementing design and construction standards. The SMEs identified advantages and disadvantages of the pilot activity and offered suggestions for improving the standards streamlining effort in the future. *For more information, contact Jennifer Devolites, jennifer.devolites@nasa.gov.*

Lift-off Modeling & Simulation of T-0 Umbilicals Using a Flexible Multibody Dynamic Model Framework

The NESC has developed a fully nonlinear lift-off pad separation capability inclusive of umbilical separation dynamics for the Space Launch System (SLS) and the Exploration Ground Systems programs. This flexible multibody capability allows for characterization of umbilical separation at lift-off (i.e., T-0) and to perform relative clearance analyses when vehicle rise time is a critical parameter[1]. For the subject SLS lift-off transient coupled loads analysis (CLA), the separating interfaces, include Vehicle Support Posts to booster aft skirts, Vehicle Stabilizer System (VSS) to core stage (CS), and the CS umbilicals (Figure 1). This work provides a fully nonlinear, flexible multibody simulation for accurately capturing the loads from prelaunch stacking to umbilical and pad separation at lift-off. The prelaunch stacking and cryogenic shrinkage simulations lock-in the preloads and provide the initial conditions to the lift-off pad separation. It is the sudden transient release of these preloads, often referred to as the lift-off "twang," that can result in high vehicle load indicator dynamic response. For the event of umbilical secondary disconnect, the multibody simulations solve for the umbilical force time-histories at the vehicle interfaces. These nonlinear interface forces are transient with significant peak amplitudes and quick decay rates. This combination can result in a pre-pad-separation twang in vehicle load indicators near umbilical separation locations. These phenomena manifest as a high frequency "buzz" in some load indicators to significantly altered response time-histories in others.

For vehicle-pad separation, simulations utilize an enhanced version of the Henkel-Mar (HM) pad separation nonlinear algorithm. The enhancement involves an iteration loop that discerns which separating interface takes precedence in the event when two or more interfaces separate at the same time. This results in a more realistic release of strain energy, resulting dynamics, and separation twang. A contact/recontact nonlinear algorithm tracks potential re-contact between all separating interfaces, e.g., booster aft skirt lateral rebound due to "squat" loads and extensible-post separation/recontact with the mobile launcher. The VSS model is a nonlinear substructure including the radial and tangential hydraulic struts with parameters defined from test data. A Newton-Raphson algorithm is utilized to solve for the VSS nonlinear behavior. The separation simulation of the VSS from the CS uses a timed-release algorithm. The Tail Service Mast Umbilical (TSMU) (liquid oxygen and liquid hydrogen), CS Intertank Umbilical (CSITU), and CS Forward Skirt Umbilical (CSFSU) secondary disconnects were included in the lift-off nonlinear simulations. Umbilical secondary disconnect scenarios for the two TSMUs, CSITU, and CSFSU utilize the HM algorithm inclusive of contact/recontact. This flexible multibody framework provides for exceptionally fast nonlinear simulation times and flexibility in adding components and nonlinearities without having to reformulate the entire system. *For more information, contact Joel Sills, joel.w.sills@nasa.gov.*

The SLS lift-off CLA is a nonlinear transient dynamic event. For the lift-off CLA to be valid, it must include the major system nonlinearities and their impact on dynamic response. This innovative technique includes Deformed Geometry Synthesis (DGS) for the replications of all physical stacking steps, cryogenic shrinkage, and associated geometric nonlinearities (e.g., aft strut rotations) for accurate preloads. The DGS algorithm locks in preloads due to geometry (e.g., stacking and cryogenic shrinkage) misalignments at component interfaces. This provides the preload contribution to the lift-off pad separation twang (i.e., includes the release of strain energy due to gravity effects). The nonlinear simulations utilize a flexible multibody framework with key benefits including the ability for the solver algorithms to handle nonlinearities at the substructure level without affecting the overall system computational performance. As such, the nonlinear lift-off transient CLA capability solves at fast computation speeds that are congruent with sensitivity and other risk reduction studies.

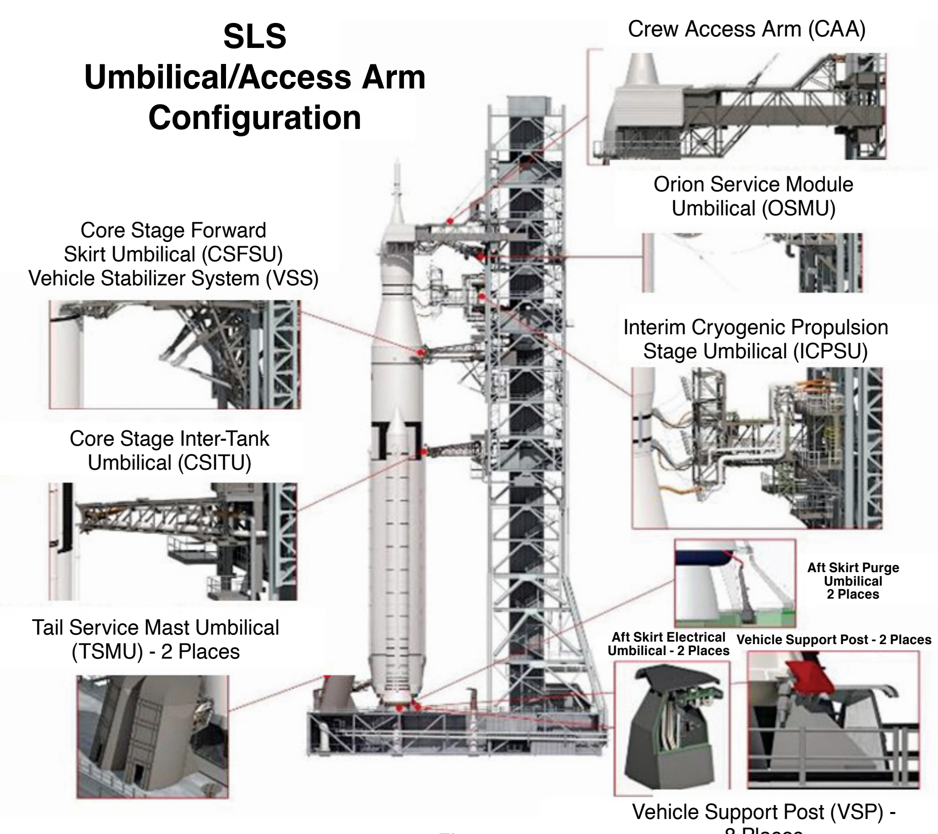


Figure 1
Mobile launcher layout showing umbilicals.

1. Anshicks, R. D. (1970), Interactions with Launch Stand and Umbilicals, NASA-SP-0861, LaRC.

Strain-Hardness Correlation Testing Technique

A new material analysis technique was developed at the MSFC Materials & Processes Lab to efficiently generate correlation curves between indentation hardness measurements and localized material strain.

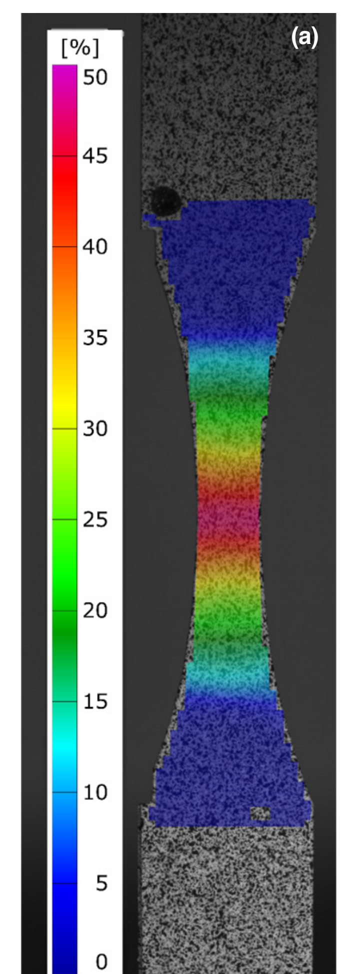
The technique employs digital image correlation (DIC) to map local plastic strain development in a tensile test specimen under stress. The test specimen includes a constant radius gage section designed to establish a plastic strain gradient along the longitudinal axis of the test specimen. The hourglass-shaped test specimens are then loaded to a desired stress level using standard tensile testing procedures while monitoring the specimen surface with DIC.

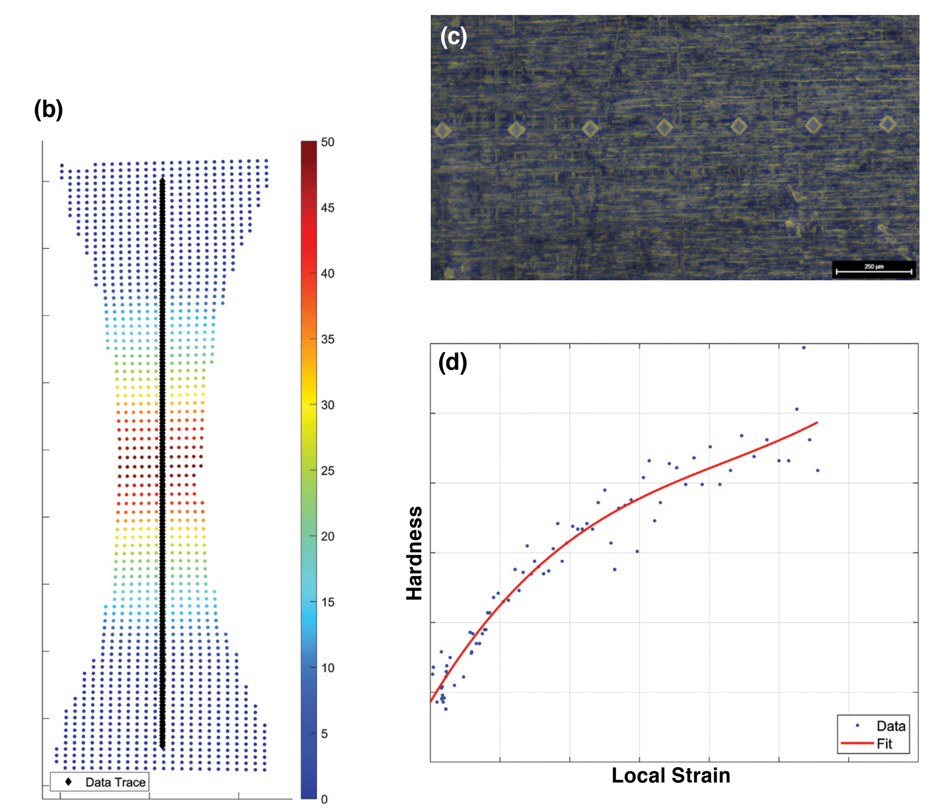
Post-test, the specimens are longitudinally sectioned, and a trace of micro-hardness indentation measurements are obtained along the cross-section. With careful attention to specimen orientation and relationships between spatial reference features on the test specimen, a corresponding local strain value can be determined for each microhardness measurement from the DIC data obtained during the initial test. When performed using thin sheet materials, the through-thickness strain variations are minimal, which allows for direct correlation of the DIC information with microhardness measurements.

Traditional methods for correlating hardness and material strain involve testing many specimens, one for each plastic strain value of interest. By taking advantage of DIC techniques and automated hardness measurement, the developed technique requires only one test specimen for the generation of the entire correlation curve, from no plastic strain up to material failure. The method is particularly suited to evaluating thin sheet materials, but could be extended to thicker sections with appropriate adaptations.

The resulting strain-hardness correlation curve is a tool to inform other material evaluations by providing a calibration between hardness and the plastic strain developed in the material. The technique is particularly suited to evaluations where specimen geometry or material availability preclude full-size mechanical test specimens; for example, a hardness correlation curve can be produced to aid in the evaluation of a complex additively manufactured part by using a bespoke test specimen produced alongside the part. Other example applications would include investigations on the effect of bending operations on sheet metal, metallurgical failure analyses of components, or surveys of plastic strain effects due to thermal processing.

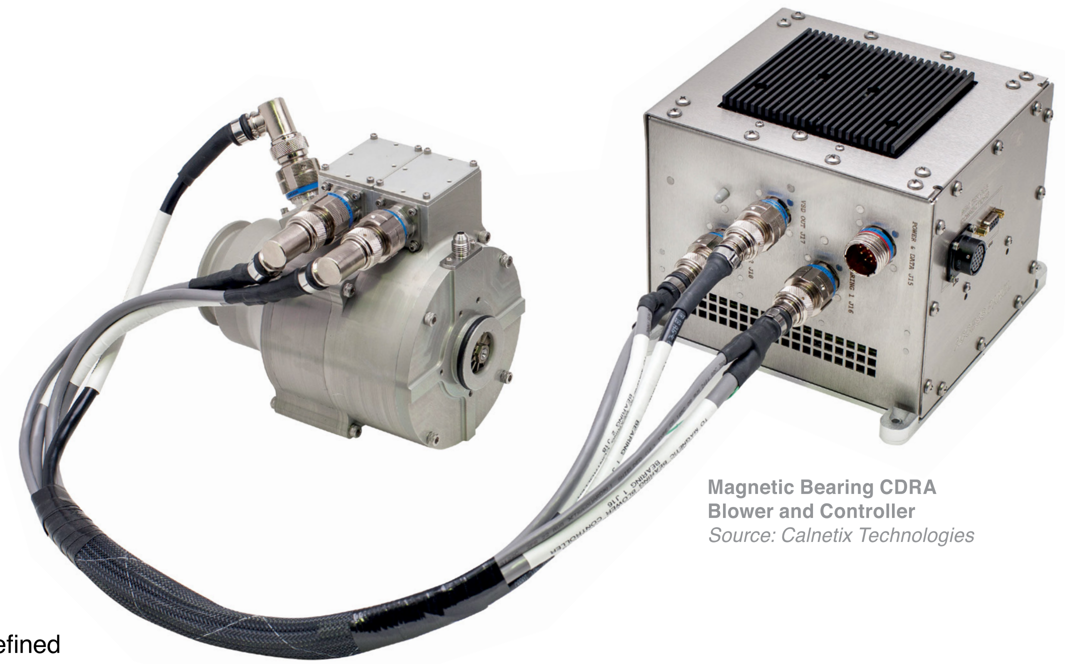
For more information, contact William Tilson, william.g.tilson@nasa.gov or Douglas Wells, douglas.n.wells@nasa.gov.





(a) Overlay of DIC data on test specimen.
(b) Spatial relationship between exported DIC data and hardness trace.
(c) Representative hardness indentations.
(d) Strain-to-hardness correlation curve.

Magnetically Levitated Space Mechanisms



Magnetic Bearing CDRA Blower and Controller
Source: Calnetix Technologies

Space mechanisms can be loosely defined as any mechanical component or assembly that moves and operates in a space environment. As such, space mechanisms include such mechanical systems as deployable solar arrays, linear actuators, rotary actuators, motors, and gear systems. One of the basic components of many space mechanisms are bearings, and because bearings inherently experience wear over time, rotating space mechanisms have a finite life expectancy. In addition, some space mechanisms have suffered from premature wear, which can jeopardize the success of a mission. For these reasons, there is always a search for longer-life bearing solutions for space mechanisms.

Rolling element bearings have a long space mechanism heritage and are often the first choice in mechanism design. However, for some applications that demand extremely long life or operation where contamination from lubricants (oil and grease) are a concern, magnetic bearings are a potential solution. Magnetic bearings are a relatively recent development that is making significant inroads in large terrestrial machine applications like pipeline pumps and compressors. A few magnetic bearing reaction wheels have been flown, but the technology has not yet gained wide-spread adoption in space, primarily due to concerns regarding cost, mass and reliability. However, in response to various rolling element bearing failures in space mechanisms, the NESC Mechanical Systems Technical Discipline Team has supported the concept of developing magnetic bearing technology for space mechanisms beginning in 2012.

The NESC sponsored an in-depth study of the state of the art in magnetic and other bearing technologies to identify the key pros and cons of each technology. A near-term potential application considered was the ammonia cooling pump on the International Space Station (ISS), which had suffered failure due to wear of its carbon bushings. The NESC study identified the areas where an investment in magnetic bearing technology would be needed to address shortcomings for space mechanisms and concluded that there are no significant technical hurdles that could not be overcome. The review of bearing technologies was eventually published as a NASA TM[1].

The NESC-sponsored study inspired a recent demonstration application of magnetic bearings, which is expected to set precedent for future space applications of the technology. A magnetic bearing air blower has been designed, built, tested, and in August 2020 was delivered to NASA MSFC for use in the next generation Carbon Dioxide Removal Assembly (CDRA) aboard the ISS. The current CDRA blower utilizes foil air bearings. Magnetic bearings offer improved resistance to debris in the air stream and the ability to endure vacuum operation can occur during operational anomalies. To accomplish this ISS-funded demonstration project, in 2017, NASA issued a Request For Information seeking design concepts for a CDRA blower. Magnetic levitation was submitted by industry as a potential design that could meet all of the system requirements. A procurement phase for the magnetic bearing blowers was initiated in early 2018. The magnetic bearing blower[2] is now undergoing system-level ground testing and is scheduled to be used as the heart of the 4-Bed Molecular Sieve CDRA system. Successful launch and operation on orbit stands to open the door to many future applications of magnetic bearing space mechanisms in future NASA missions. This work was performed at GRC.

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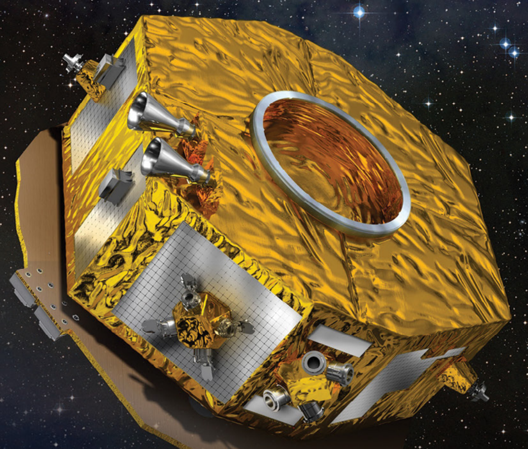
Cornelius J. Dennehy
NASA Technical Fellow for GNC

Microthrusters as a Potential Solution for Accomplishing Pointing Stability for Large Space Telescopes



NASA ST7/ESA LISA Pathfinder

NASA is planning missions that will operate high-performance optical payloads with highly vibration-sensitive scientific instruments for science observations. Stringent pointing stability requirements to mitigate jitter and microvibration are key for such large space telescope missions of the future. Managing jitter is essential to obtain distortion-free images of planetary bodies on exo-planet coronagraph missions. Traditionally these space observatories have relied upon reaction wheels to provide the attitude-control torques needed for stabilization and pointing. For example, the Hubble Space Telescope (HST) uses four reaction wheels as part of its pointing control system. However, the reaction wheels themselves are typically the largest pointing disturbance source on the spacecraft, primarily due to static and dynamic mass imbalances in the flywheel as well as wheel-bearing mechanical noise. Therefore satisfying stringent jitter requirements for missions, in this class requires methods to limit or isolate vibrations generated by the wheels. On most high-performance observatory missions GNC engineers typically invest significant time and resources to conduct special reaction wheel disturbance characterization tests, exquisite wheel balancing, and the design and development of wheel-disturbance mechanical isolation devices.

Busek cluster of four colloid microthrusters as flown on the LISA Pathfinder Mission. *Source: ESA/Airbus*

A recent NESC assessment investigated the feasibility of using microthrusters as an alternative or supplement to reaction wheels for providing attitude control during periods of scientific data collection requiring precision pointing. Microthrusters, or micronewton thrusters, are thrusters capable of producing forces in the micronewton range. Microthrusters have been developed by NASA as part of a drag-free control system for the Laser Interferometer Space Antenna (LISA) mission. Microthrusters come in different forms, using different types of propellant. The NESC assessment focused on cold-gas microthrusters that use gaseous nitrogen and on colloidal microthrusters, a type of electrospray thruster that applies a high electric potential difference to charged liquid at the end of a hollow needle in such a way that a stream of tiny, charged droplets is emitted generating thrust. Both cold-gas and colloidal microthrusters were flown on the NASA ST7/ESA LISA Pathfinder technology demonstration mission.

The assessment team recognized that the need for the observatory to perform large angle slew maneuvers would exceed the control authority of microthrusters, necessitating the use of either wheels or traditional reaction control system (RCS) thrusters (using hydrazine or bipropellants) for large slews. The need for different control actuators for large slews and fine-pointing leads to different mission operational scenarios studied by the team. One scenario used reaction wheels for performing large slews, which are then spun down to zero speed during science observations, with microthrusters used as the sole actuator for fine pointing. In this scenario, any need to mechanically isolate the reaction wheels is eliminated because the wheels are shut down during fine pointing. A second scenario employed RCS thrusters for large slews, with microthrusters used as the sole actuator for fine pointing. Both the cold gas and colloid microthrusters with their nanonewton resolution provide an appropriate level of attitude control torque to maintain the observatory's fine pointing without introducing undesirable jitter. The assessment results indicated the microthrusters could provide an order of magnitude performance improvement relative to HST. The general conclusion is that microthrusters have potential for reducing the cost and technical risks of achieving demanding pointing stability performance on observatory-class missions. *For more information, contact Cornelius J. Dennehy,* cornelius.j.dennehy@nasa.gov or Aron Wolf, aron.a.wolf@jpl.nasa.gov.

Transient Combustion Modeling for Hypergolic Engines

Dr. Daniel J. Dorney
NASA Technical Fellow for Propulsion

One goal of the recent NESC assessment, *Transient Combustion Modeling for Hypergolic Engines*, was to identify and characterize the early reactions that occur between monomethylhydrazine (MMH) fuel and dinitrogen tetroxide (NTO) oxidizer in the liquid and gas phases to improve modeling for liquid-fueled space propulsion system hypergolic propellant engines. Drs. Tim Pourpoint and Hilkka Kenttämaa of Purdue University were asked to perform experiments to support the effort.

Identification of Reaction Products

Identifying the first products formed upon interactions of NTO and MMH requires an analytical technique capable of quickly and unambiguously providing elemental composition and structural information for the products. A combination of low- and high-resolution tandem mass spectrometry was chosen for this task. This technique requires the products to be converted into gas-phase ions before analysis.

The initial products formed upon liquid- and gas-phase hypergolic reactions may react immediately with other liquids or gases that form in the mixture. Because the reactions cannot be halted to collect the first species generated, evaporation and ionization (if necessary) must occur at the moment the products form to ensure that the correct species are being analyzed. Based on this condition, the team selected laser desorption/ionization (LDI) as the most promising technique due to its speed. The current state of laser technology enables laser pulse lengths on the order of nanoseconds, much shorter than the expected time scale of the reactions of interest.

LDI has been successfully used by researchers with a 355 nm laser to evaporate and ionize solid aromatic compounds[1], proteins[2,3], and polymers[4]. Since MMH and NTO are relatively small molecules, have different structures compared to the types of samples discussed in the literature, and have largely unknown early reaction products, the energy of the photons and the laser power (density of photons) required for LDI of their products were unknown.

Purdue Test Facility

To conduct the investigation of the liquid phase and early gas phase reactions of MMH with NTO, the Purdue team designed an apparatus that brought approximately 3 µl drops of MMH and NTO into contact with each other in a highly repeatable manner, synchronized with the LDI technique, and under controlled conditions. The small liquid volumes made the experiment easier to control and improved safety. Figure 1 shows the final drop-on-drop experimental apparatus installed in a mobile fume hood. The NTO drop was placed into the bottom tube as opposed to MMH due to its low surface tension. The MMH drop was then moved down to touch the NTO drop by using an actuator with a maximum actuation speed of 14 inch/second and spatial resolution of 1 µm. This high actuator speed was chosen to minimize interactions between NTO and MMH vapors before the drops contacted one another.

MMH/NTO Drop-on-Drop Testing

Prior to each experiment, the laser was allowed to warm up while the laser beam was blocked from entering the test area by a beam shutter. With the laser ready, the MMH drop was brought down and into contact with the NTO drop. Simultaneously, the data acquisition system sent a signal to the mass spectrometer to begin data acquisition. Shortly after triggering the mass spectrometer, the system sent a signal to open the beam shutter and allow a single laser pulse to pass next to the reaction just as the mass spectrometer began detecting ions. Figure 2 shows a still photo of the laser pulse hitting the area between the touching droplets and the mass spectrometer inlet during a test sequence. Evidence of the laser pulse is clearly visible because of the ionized gases created as the laser beam passes through the area. The orange coloration was caused by the laser filter used to protect the camera. Figure 3 shows a high-resolution mass spectrum measured for the MMH/NTO liquid reaction products showing the measured elemental compositions of the ions and proposed structures for some of the ions. Additional results demonstrated that the liquid-phase reactions of MMH and NTO readily produce large amounts of ions in the absence of any ionization method (i.e., LDI), which can be detected by the mass spectrometer. Aside from the ionic compounds produced, the neutral intermediates cannot be detected without LDI, which will be part of future experimentation.

Interestingly, while many positively charged ions were observed, only a few negatively charged ions, the most abundant corresponding to nitrate, were detected. These conclusions are in agreement with the nature of the highly energetic hypergolic reactions, as ions are much more reactive than neutral molecules in the gas phase. The results of the experiments conducted by the NESC assessment team will augment modeling capabilities with the objective of improving combustion instability predictions for existing and future hypergolic propellant engines. *For more information, contact Dr. Daniel J. Dorney, daniel.j.dorney@nasa.gov.*

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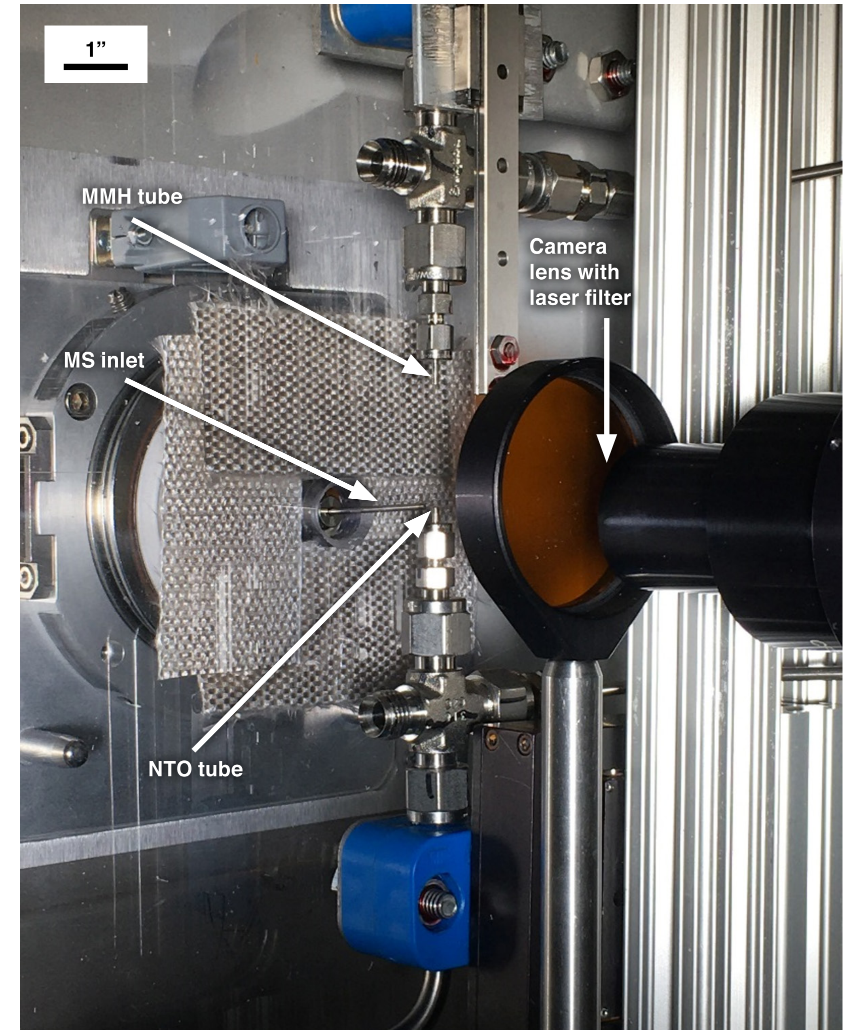
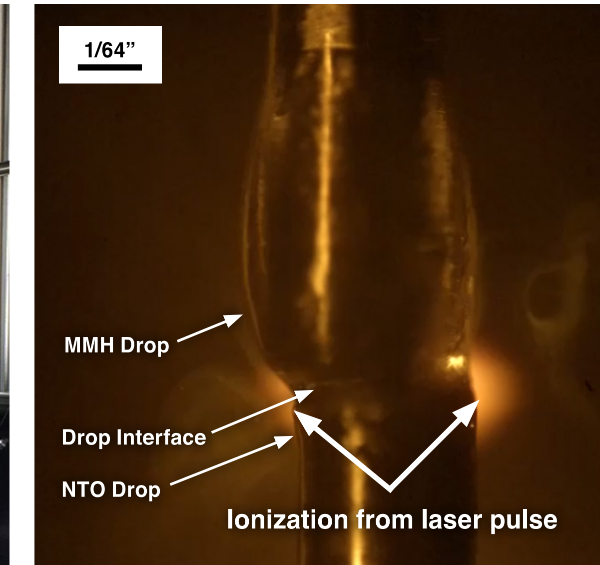
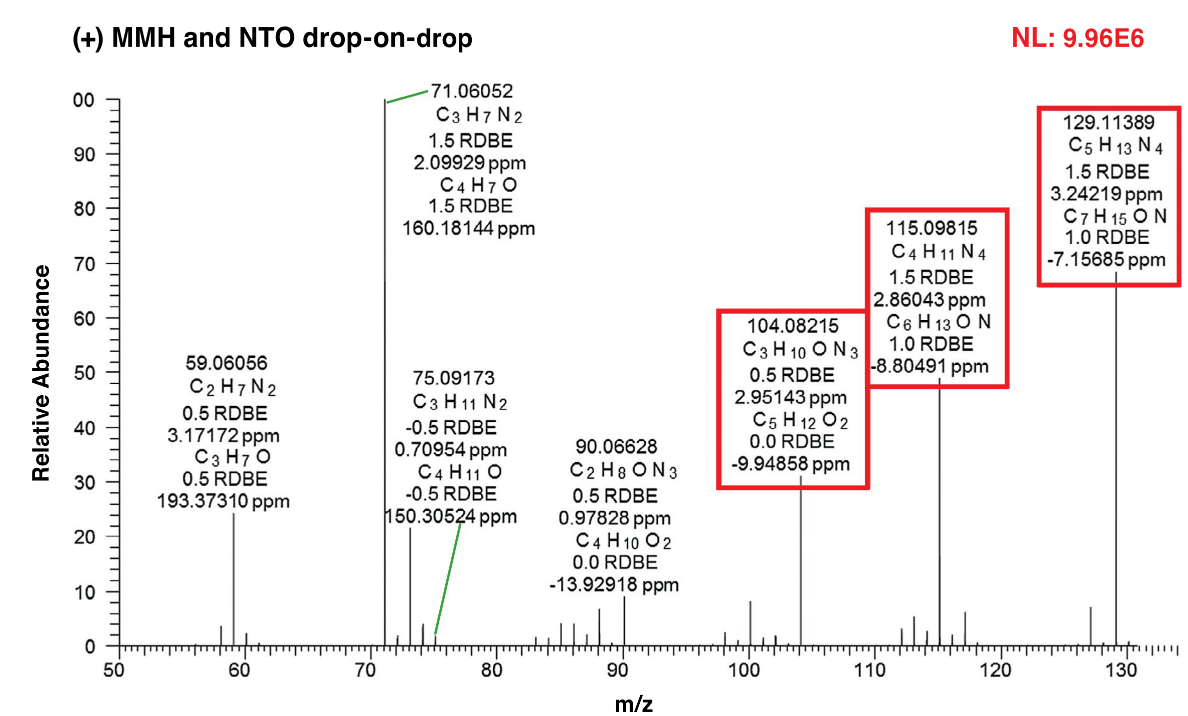




Left: FIGURE 1
MMH/NTO drop-on-drop experimental configuration.

Above: FIGURE 2
Laser pulse hitting the MMH/NTO droplets.

Below: FIGURE 3
Example high-resolution mass spectrum collected during MMH/NTO drop-on-drop test. Ions boxed in red were subjected to Collision-Activated Dissociation in tandem mass spectrometry experiments to obtain structural information.



Jon B. Holladay
NASA Technical Fellow
for Systems Engineering

Systems Engineers Bring an Integrated Perspective to NASA Missions

Engineers from every technical discipline provide the critical subsystems necessary for NASA's spaceflight missions. But ensuring these integrated subsystems will operate seamlessly at lift-off and successfully transport their payloads to their destinations requires the input of another technical discipline–systems engineering.

"The systems engineer is the jack-of-all-trades," said Mr. Jon Holladay, NASA Technical Fellow for Systems Engineering (SE). He leads the 50-member SE Technical Discipline Team (TDT), which has found itself in high demand as NASA's timeline for executing multiple, complex missions reaches an apex this decade. "To me, this is a revolutionary time at NASA," Holladay said, ticking off a long list of anticipated near-term launches including the James Webb Space Telescope, Artemis I, the Habitation and Logistics Outpost, and Human Lander System.

"The ability to effectively integrate how we do what we do, in perhaps one of the most critical and complex arenas, is what systems engineering brings to the table," he said. Increasing complexity and requirements for more autonomous operations and seamless data flow come with each new mission, all of which are maturing at speeds much faster than the decades-long development of earlier NASA programs like Apollo, Space Shuttle, and International Space Station (ISS). "We have to do more, move faster, and make decisions more quickly, and that requires understanding the integrated perspective of what those decisions mean."

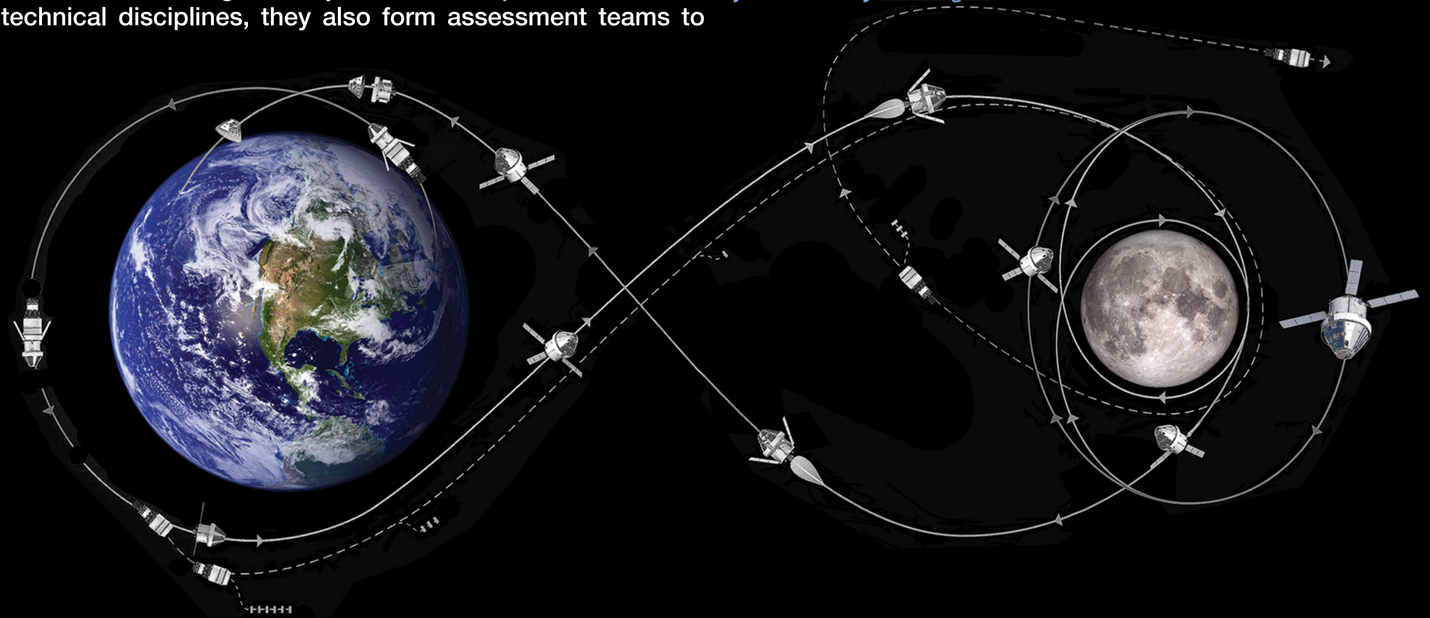
Mr. Holladay, his TDT Deputy Mr. Robert Beil, and TDT members have worked to establish the SE discipline as a vital Agency resource and communicate the importance of balancing technical issues with integration. The TDT's statistics, data mining, systems analysis, and SE subject matter experts serve on standing review boards, mishap investigation teams, integrated hazard reviews, and technical standards evaluations. Pulling in subject matter experts from other technical disciplines, they also form assessment teams to help programs find the best strategies for integration and uncover the errors that, in complex systems, often trace back to where interfaces occur.

In 2020, the SE TDT led or participated in a range of activities that reveal the increasing importance of the integration aspect of systems engineering to NASA missions. They recently led a comprehensive review of SE, software, and systems integration lessons learned, the results from which are being leveraged for Artemis I and commercial flights to ISS. They are currently working with the thermal, power, and avionics disciplines on extravehicular activity power systems for ISS and lunar systems, opening the door to cross-program integration opportunities by exploring a common system architecture that could be used across multiple missions. And the TDT statistical team helped analyze whether a test program for a critical piece of propulsion hardware was robust enough to ensure reliability, which is growing in importance as NASA integrates with commercial partners striving for increased production rates and quick mission turn arounds.

The TDT also helped identify critical failure modes of ventilators for COVID-19 patients and consultation on verification and test methodology for non-NASA commercial vehicles.

In the coming decade, the SE TDT will continue integrating the pieces of the increasingly complex systems required to accomplish NASA's future missions, leveraging what they learn from each assessment, conducting outreach through workshops and their community of practice, and taking advantage of digital platforms like model-based systems engineering.

"Often, if you are embedded in one project or program, you don't always see that big picture," Mr. Holladay said, noting the challenge for the SE TDT will be to bring those lessons learned and the big picture, integration perspective to every NASA mission. *For more information, contact Jon B. Holladay, jon.holladay@nasa.gov.*



Dr. Cynthia H. Null
NASA Technical Fellow
for Human Factors

Defining Human Error Analysis for Human Rating of Crewed Spacecraft

NASA's Human-Rating Requirements for Space Systems (NPR 8705.2C) calls for Program Managers to conduct a human error analysis (HEA) during system development. The analysis should cover all mission phases, including ground processing, launch preparation, flight, and recovery/disposal operations. The purpose is to identify human errors that could lead to catastrophic outcomes and apply this information to identify areas for design changes. The requirement makes it clear that HEA is a qualitative analysis that complements probabilistic hazard assessments. The requirement for HEA applies to systems developed by NASA, but depending upon agreements, HEA may also be applied to other crewed space systems.

For as long as the NASA HEA requirement has been in force, there has been uncertainty about exactly what is a human error analysis, and how should one be done. In 2018, after the NESC received a request for guidance on this issue, Dr. John O'Hara (Brookhaven National Lab) and Dr. Alan Hobbs (San Jose State University) were tasked with answering these questions. The resulting position paper *Guidance for Human Error Analysis* was approved by the NESC Review Board in November 2019 and is available as NASA/TM-2020-5001486.

Their resulting position paper presents methods that can be used to meet the intent of NPR 8705.2C, but does not rule out the use of alternative approaches. The document covers the essential elements of human error analysis including establishing the HEA team; screening-in tasks for analysis; identifying potential catastrophic errors for each analyzed task; error management strategies; and documenting the analysis.

Error analysis is about identifying and mitigating problems at a system level, and not about finding fault with individuals. In many cases, errors occur in the context of error-producing conditions in hardware, software, or procedures. If we can influence the design to eliminate these conditions, we can reduce the likelihood of human error, while retaining the positive contribution that humans make to system operations.

The position paper distinguishes error-producing conditions (EPC) from error traps. An EPC is a general condition (such as time pressure or fatigue) that can increase the likelihood of error across a range of tasks. An error trap is a particular set of circumstances that can provoke a specific error, e.g., adjacent items of hardware with compatible connectors that enable a cross-connection error. Many EPCs can never be eliminated entirely. However, in most cases, error traps can be designed out of the system. The elimination of error traps is one of the most valuable outcomes of HEA. *For more information, contact Dr. Cynthia H. Null, cynthia.h.null@nasa.gov or Dr. Alan Hobbs, alan.hobbs@nasa.gov.*

General HEA Principles

The goal of HEA is to enhance system reliability and safety.	**HEA enhances system reliability and safety by identifying where significant human errors could occur, the conditions that could provoke these errors (including error traps), and means to mitigate them.**
HEA is an iterative process.	**Analysis of potential human errors should occur throughout all phases of the design process.**
HEA is directed at the entire system, not people alone.	**HEA identifies problems with the total system, including hardware, software, equipment, facilities, processes, and procedures. HEA is not about finding fault with people or attributing blame.**
HEA cannot be applied in detail to every task.	**Mission success relies on thousands of human tasks performed by operational personnel on the ground and in flight. It is impossible to analyze all of them. Screening is necessary to identify those which, if performed incorrectly, would pose the greatest risk to mission success and safety.**
HEA must consider tasks in context.	**Tasks are not performed in isolation, but occur in the context of a workflow. Potential interactions between tasks must be considered.**
HEA must consider work as actually performed.	**HEA must consider the full range of possible human interactions with systems, including interactions not envisioned by designers or covered by formal procedures.**
HEA should be integrated with other analyses.	**HEA should use information from other sources such as hazard and task analyses and provide input to other products such as risk analyses.**
HEA benefits from independent perspectives.	**HEA should provide a perspective that is independent from the design team.**
HEA should be performed by a multidisciplinary team.	**It is best performed by a team that includes personnel trained in HEA, as well as subject matter experts (SMEs) and design engineers familiar with the systems being evaluated.**
HEA requires input from operational personnel.	**The analysis should include input from personnel who perform the tasks in question. Even when a task is new, or associated with a new system design, input from personnel who have performed similar tasks can provide valuable insights.**
HEA requires imagination.	**HEA requires careful thought and imagination to identify vulnerabilities where human performance could pose a threat to the mission. It should not be a "box checking" exercise.**
There is no single correct approach to HEA.	**HEA can use a variety of methods, including evaluations by SMEs, the application of engineering judgment, task analysis, and formal analyses such as human reliability analysis.**

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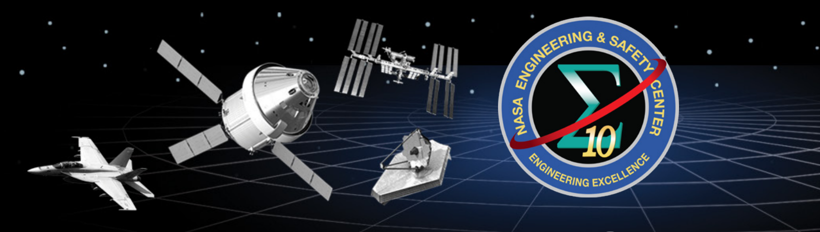
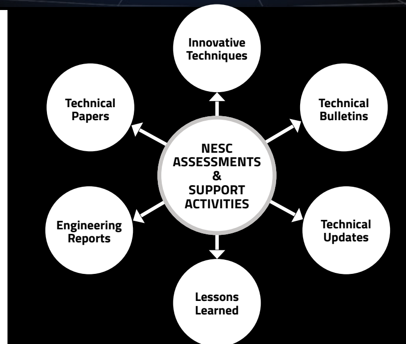


NASA Engineering & Safety Center

NESC Knowledge Products:

Capturing and Preserving Critical Knowledge for the Future

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



NESC Knowledge Products

Engineering Reports

The detailed engineering and analyses generated from each assessment are captured in comprehensive engineering reports and converted to NASA Technical Memorandums (TM) for permanent archive and access. For information on NESC reports, visit ntrs.nasa.gov and ntrsreg.nasa.gov.

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NESC Academy
NASA Engineering and Safety Center

NESC Academy

The NESC Academy presents live and on-demand content from researchers, engineers, and field experts in 20 technical disciplines. The Academy hosts over 790 videos and webcasts containing interviews, tutorials, lectures, and lessons learned in an engaging format that features side-by-side video and slides, powerful search capabilities, downloadable lesson materials, and more. These lessons, many of which are publicly available, can be viewed at nescacademy.nasa.gov, with content exclusive to NASA employees available upon sign-in.

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An Agency-level lessons learned database called the Lessons Learned Information System (LLIS) is used to capture important and broadly applicable lessons learned. NESC and Agency lessons learned can be found at llis.nasa.gov and nen.nasa.gov.

Innovative Techniques

Solutions developed from NESC assessments and highlighted annually in the Technical Update and at nasa.gov/offices/nesc/innovativetechniques.html

Technical Papers

Written by members of the NESC and NESC Technical Discipline Teams to capture and convey new knowledge learned on NESC assessments. A list of NESC technical papers and conference proceedings is available at nasa.gov/nesc/technicalpapers.

Discipline Focus Articles

Discipline Focus articles highlight important information, gleaned from NESC assessments, which may benefit a wider audience. A list of overarching NESC featured articles is available at nasa.gov/nesc/features.

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A forum for the NASA community to gain critical knowledge to aid professional development and support the NASA mission.

Beginning in 2007, the NESC Academy was formed to capture and disseminate knowledge from NASA discipline experts to the engineering community. The NESC Academy enables effective knowledge capture and transfer, ensuring technical information remains viable and accessible. It provides a forum for the NASA community to gain critical knowledge to aid professional development and support the NASA mission. Researchers, engineers, and field experts in 20 technical disciplines present live and on-demand content relevant to the design, development, test, and operation of NASA programs and projects. The Academy hosts more than 790+ videos and webcasts containing interviews, tutorials, lectures, and lessons learned. Viewers learn from subject matter experts in an engaging format that uses a self-paced structure based on a state-of-the-art video player for education that includes side-by-side video and slides, powerful search capabilities, downloadable course materials, and more. The platform enables dual video streams for content across desktop and mobile devices.

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Flight Mechanics	Standard Check-Cases for Six-Degree-of-Freedom Flight Vehicle Simulations
GNC	Robust Stability: From Disk Margins to Neural Network Analysis
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Loads & Dynamics	Shock & Vibration: 01.Natural Frequencies, Part 1
Materials	Shape Memory Alloys - Not Your Ordinary Metal
Mechanical Systems	Overview of Fastener Requirements in the New NASA-STD-5020
NDE	Materials Durability (Reliability of NDE) Part 1 of 3
Passive Thermal	Short Course on Lithium-ion Batteries: Fundamental Concepts, Heating Mechanisms, and Simulation Techniques
Propulsion	Generalized Fluid System Simulation Program Training Course 01: Course Introduction
Sensors & Instrumentation	Lidar for NASA Applications
Software	Introduction to Software Engineering 13: Configuration Management
Space Environments	(MOWG) NASA Robotic CARA Probability of Collision
Structures	Structural Analysis Part 1
Systems Engineering	Model-Centric Engineering, Part 1: Intro to Model-Based Systems Engineering

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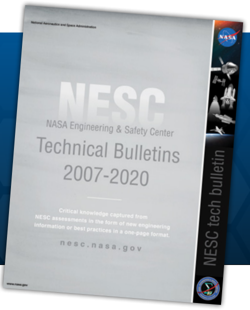
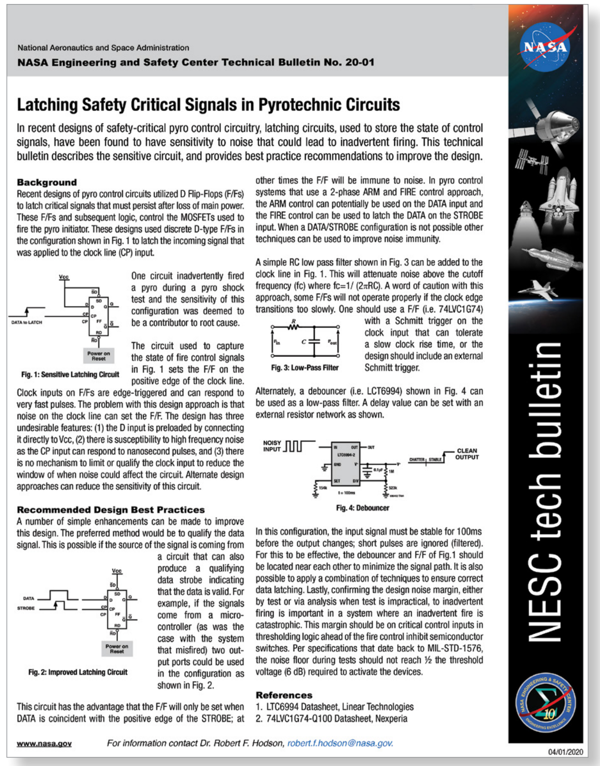



National Aeronautics and Space Administration
NASA Engineering and Safety Center Technical Bulletin No. 20-01

Latching Safety Critical Signals in Pyrotechnic Circuits

NESC tech bulletin

Technical Bulletin No. 20-01

Latching Safety Critical Signals in Pyrotechnic Circuits

When a shock test of safety-critical pyrotechnic circuits resulted in an inadvertent firing, it revealed a sensitivity to electrical noise in the latching circuits, which store the state-of-control signals in pyrotechnic control circuitry. This technical bulletin, developed by Dr. Robert Hodson, NASA Technical Fellow for Avionics, recommends enhancements to recent designs of these circuits that would reduce this sensitivity and the susceptibility of the circuit to unintentional firing. These best practices offer simple improvements such as qualifying data signals and adding filters to the design of these critical circuits that are vital to the safe operation of spacecraft.

A companion lesson learned, LL 27003, is available at llis.nasa.gov.


National Aeronautics and Space Administration
NASA Engineering and Safety Center Technical Bulletin No. 20-03

Navigation Filter Design Best Practices

NESC tech bulletin

Technical Bulletin No. 20-03

Navigation Filter Design Best Practices

This Technical Bulletin introduces a new handbook that aggregates NASA's extensive knowledge base on navigation estimation systems and filters, which are used extensively throughout the Agency on both crewed and uncrewed missions. Targeted to mission designers, the handbook provides a comprehensive reference to NASA's best practices for navigation filter designs, which have safely and reliably supported missions since the Gemini/Apollo era. The handbook's development was, in part, an outgrowth of an NESC assessment of best practices for rendezvous navigation filter design, led by the NASA Technical Fellow for Guidance, Navigation, and Control, Mr. Neil Dennehy.


National Aeronautics and Space Administration
NASA Engineering and Safety Center Technical Bulletin No. 20-02

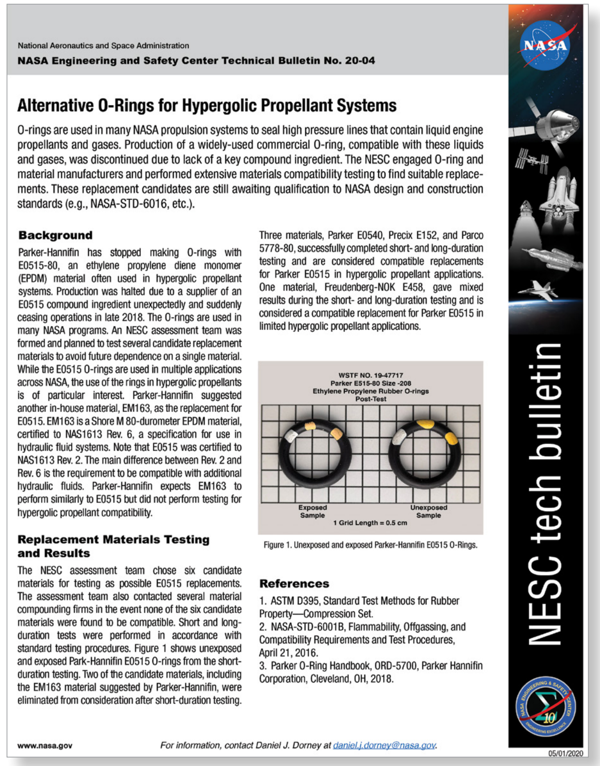
Effective and Environmentally Compliant Cleaner - Solstice® Performance Fluid

NESC tech bulletin

Technical Bulletin No. 20-02

Effective and Environmentally Compliant Cleaner - Solstice Performance Fluid

Historically, NASA has used Hydrochlorofluorocarbon-225 (HCFC-225 or AK-225) solvent to clean and verify propulsion systems that use liquid and gaseous oxygen, but when the EPA implemented restrictions regarding its use, NASA began efforts to find an acceptable replacement. This Technical Bulletin highlights the cleaning capabilities and compatibility of alternative fluids, Honeywell's Solstice® Performance Fluid (PF), PF-high purity (HP), and PF-HP spray, that may be used in a variety of cleaning applications. The bulletin is provided by Mr. Steven Gentz, NESC Chief Engineer at Marshall Space Flight Center, who through NESC assessments, supported the Agency's initiative to identify and test alternatives to AK-225.


National Aeronautics and Space Administration
NASA Engineering and Safety Center Technical Bulletin No. 20-04

Alternative O-Rings for Hypergolic Propellant Systems

NESC tech bulletin

Technical Bulletin No. 20-04

Alternative O-Rings for Hypergolic Propellant Systems

Parker-Hannifin has stopped production of O-rings using the material E0515. NASA programs such as the Multi-Purpose Crew Vehicle, the Commercial Crew Program, Mars 2020, the Europa Clipper, and the International Space Station have used O-rings made of this material to seal high pressure lines that contain liquid engine propellants and gases. As NASA reserves of the E0515 O-rings will soon be depleted, Dr. Daniel Dorney, NASA Technical Fellow for Propulsion, led an NESC assessment team that tested potential replacement candidates. This Technical Bulletin provides the results of that testing as well as recommendations for replacement O-rings that are compatible with hypergolic propellant applications.

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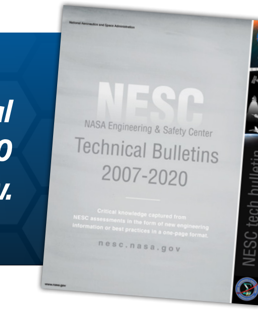
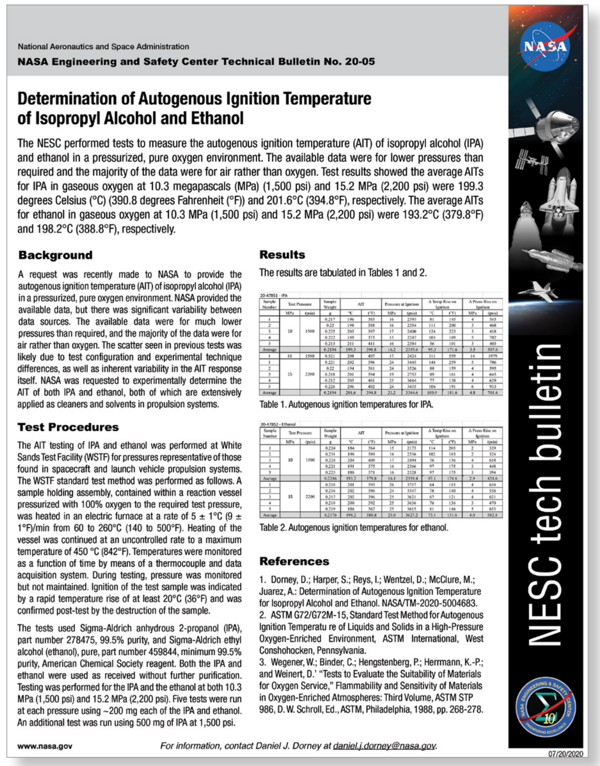
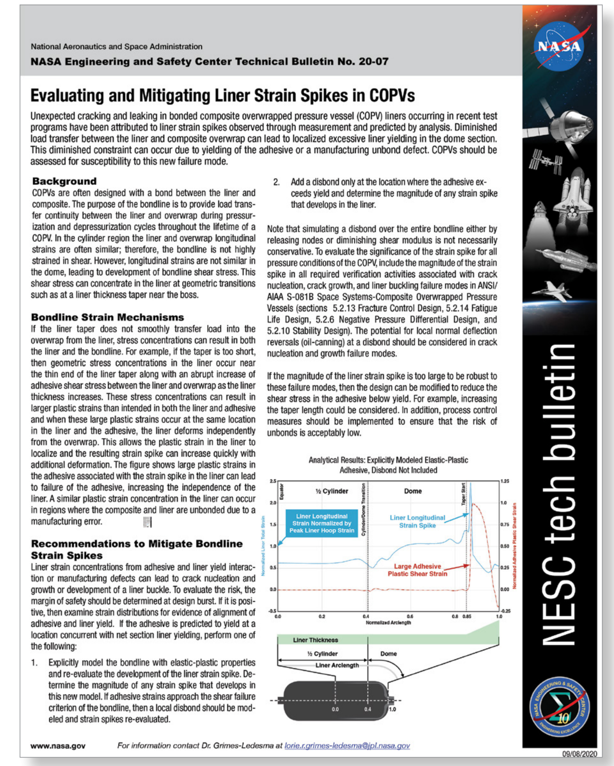




Technical Bulletin No. 20-05

Determination of Autogenous Ignition Temperature of Isopropyl Alcohol and Ethanol

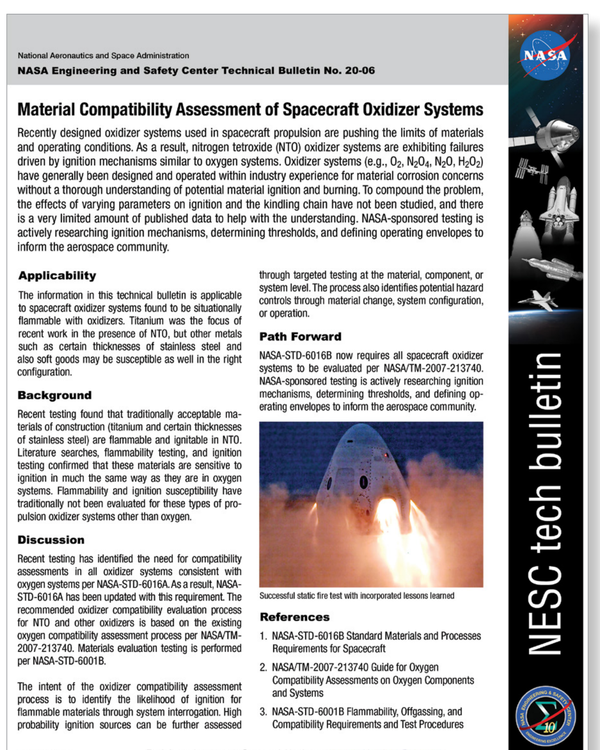
Following a liquid rocket engine shutdown investigation, NASA was requested to provide any available data on the autoignition temperature (AIT) of isopropyl alcohol (IPA) in a pressurized, gaseous oxygen environment. IPA is commonly used as a solvent or cleaner in launch vehicle and spacecraft propulsion systems. When the data were found to be focused primarily on air and for much lower pressures than needed, the NASA Technical Fellow for Propulsion, Dr. Daniel Dorney, led an NESC assessment to determine the AIT of IPA, as well as ethanol, in the required conditions. The new data were provided to interested programs and projects across NASA and industry. This Technical Bulletin summarizes those findings.



Technical Bulletin No. 20-07

Evaluating and Mitigating Liner Strain Spikes in COPVs

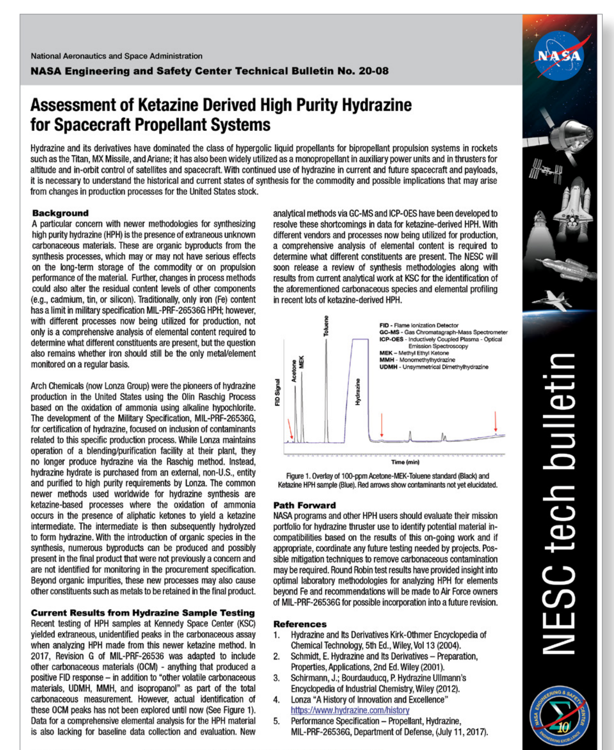
Based on NESC analysis of cracks and leaks that occurred in flight Composite Overwrapped Pressure Vessels (COPV), a failure mode due to liner strain spikes was observed through measurement and predicted by analysis. The failure mode may be present in COPVs used on NASA programs and by the aerospace industry. This technical bulletin was developed to alert manufacturers and the user community to this failure mode and contains approaches to evaluate COPVs for susceptibility to this failure mode.



Technical Bulletin No. 20-06

Material Compatibility Assessment of Spacecraft Oxidizer Systems

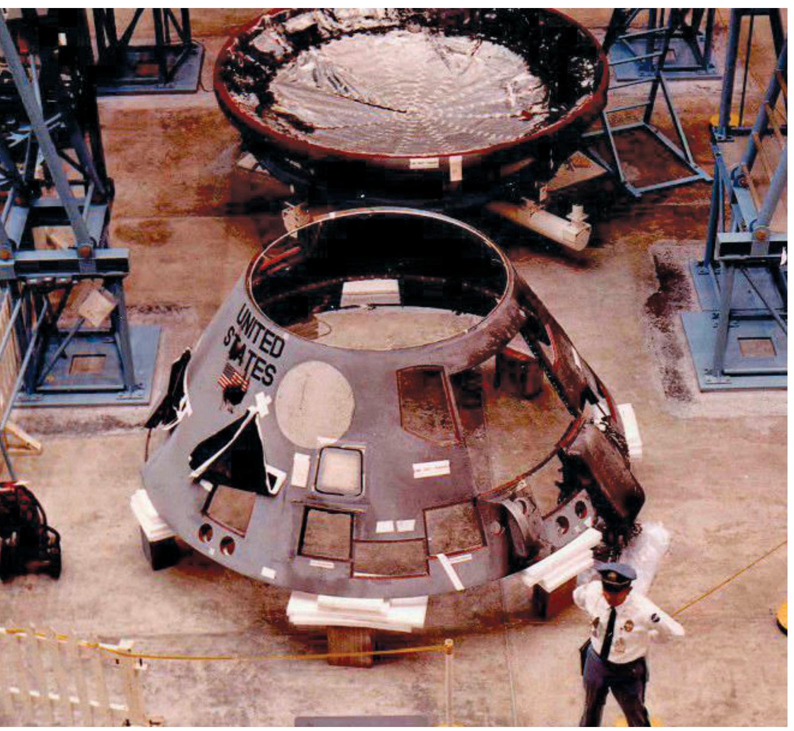
After recognition that an ignition vulnerability existed between certain materials and oxidizers used in spacecraft propulsion, the NESC researched ignition mechanisms to better understand the potential risk to NASA and industry. An assessment focused on the flammability/ignition behavior of titanium and oxidizers such as nitrogen tetroxide, but revealed that other metals may also be susceptible. While the oxidizer compatibility assessment process is ongoing, this technical bulletin discusses the immediate steps NASA is taking to mitigate this risk until these ignition mechanisms are fully understood and thresholds and operating envelopes can be determined.



Technical Bulletin No. 20-08

Assessment of Ketazine-Derived High Purity Hydrazine for Spacecraft Propellant Systems

Hydrazine and its derivatives have dominated the class of hypergolic liquid propellants for bipropellant propulsion systems and is used as a monopropellant in auxiliary power units and thrusters. With continued use of hydrazine in current and future spacecraft and payloads, it is necessary to understand the historical and current states of synthesis for the commodity and possible purity implications that may arise from changes in production processes for the United States stock. This technical bulletin describes these issues in detail.



Learning from Past Mistakes to Safeguard Spaceflight's Future

"No one wants to learn by mistakes, but we cannot learn enough from successes to go beyond the state of the art."

- Henry Petroski, *To Engineer is Human*

An unprecedented number of human spaceflight systems are entering their crewed test flight and early operational phases, including systems developed by NASA and its contractors, commercial crew partners, and at least two commercial suborbital space tourism operators. But the start of every human spaceflight program since the 1967 Apollo 1 fire has been marred by major mishaps and significant close calls. Recently, the NESC and NASA Safety Center (NSC) completed an in-depth study of these historical mishaps, which has provided a rich dataset to help advance the state of the art in system safety and, as a result, raise the bar for flight and ground crew safety.

A Study of Early Program Mishaps

Looking at mishaps that occurred during testing and early operations, the NESC/NSC team chose eight for their study, including mishaps from the Apollo, Soyuz, Skylab, Space Shuttle, and Constellation (Ares 1-X test flight) Programs as well as commercial suborbital systems. Prior studies by NASA and others have cataloged close calls and mishaps by flight phase (ref. *Significant Incidents and Close Calls in Human Spaceflight*, JSC Safety and Mission Assurance https://spaceflight.nasa.gov/outreach/SignificantIncidents/index.html). The NESC/NSC study further advanced our understanding of systemic safety issues that affected multiple programs.

The study's goal was to identify recurring organizational causes that, if addressed within the broader context of support systems and processes, would have a maximum impact on reducing the frequency and/or severity of incidents, especially those in integrated test flight and early operational phases. While seldom identified as root causes, these recurring causes may be overlooked or inadequately addressed by actions resulting from a single investigation board's findings and recommendations.

Top: The Artemis missions will depend on innovative but complex systems and technologies. Systems safety will be of utmost importance.

Middle: Parts of the Apollo 1 command module after the fire.

Bottom: During the launch of STS-1, a low estimate of the pressure spike generated by the reflection of the solid rocket booster initial overpressure wave resulted in nearly catastrophic damage to the orbiter.

Most Common Recurring Causes

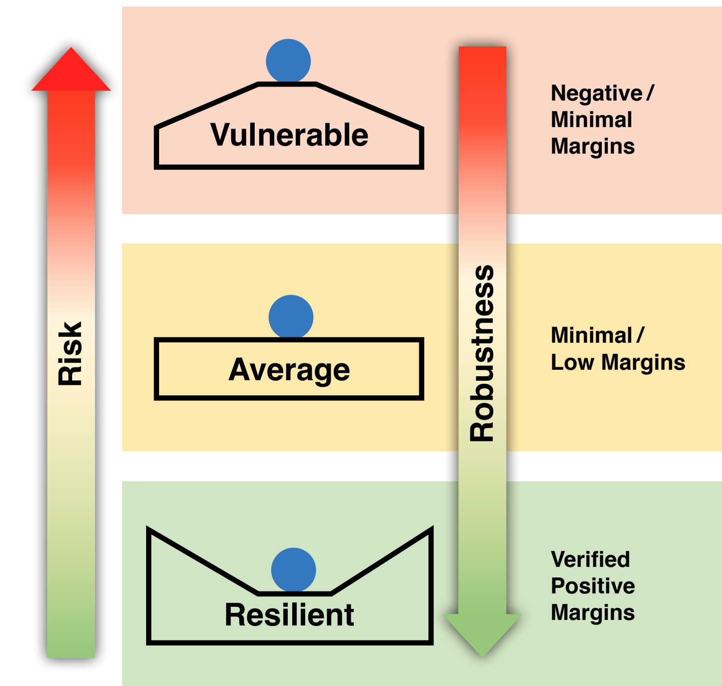
The study team identified 180 causes across the 8 mishaps, with an average of 22.5 causes per incident. From those causes, the team was able to classify 25 recurring-cause types. Number one on the list, *Inadequate technical controls or technical risk management practices*, had the highest number of occurrences, 16, and contributed to every mishap in the study. Examples of insufficient analysis of technical or safety issues or inadequate readiness reviews were seen across the mishaps, such as Skylab's meteoroid shield (MS), which was damaged during launch. New to Skylab were the shield material and auxiliary tunnel stowage method, which was subject to the supersonic freestream during ascent. Despite rigorous technical reviews and experienced leadership, the effects of aerodynamic load and aeroelastic interactions between the shield and its external pressure environment during launch were not seen until flight.

Similarly, there were 12 occurrences of *incomplete procedures* in 7 of the incidents, as seen during SpaceShipOne ground operations. While testing a steel tank carrying approximately 10,000 pounds of nitrous oxide (N2O), the tank exploded, killing three ground crew members and injuring three others. Material safety documents from N2O suppliers cautioned against pressure shock, but the work instructions contained no warnings about those dangers or steps to reduce the risk of a serious mishap. Scaled Composites workers could stand behind a chain link fence near the tank during testing because there was no designated hazard control area.

Contributing to six of the incidents were *system design and development issues*. One example included the inaugural launch of the Space Shuttle on April 12, 1981. A significantly low estimate of the pressure spike generated by the reflection of the solid rocket booster (SRB) ignition overpressure (IOP) wave resulted in nearly catastrophic damage to the orbiter. The SRB IOP was anticipated, but prelaunch modeling used Tomahawk missile motor data to validate the models, and the SRBs had much higher ignition pressures. The Tomahawk ignition test was accepted as a sufficient simulation as engineers did not fully appreciate the effect of the differences between the SRB and Tomahawk ignition characteristics.

Inadequate inspection or secondary verification requirements was a cause of main and reserve parachute failure on Soyuz 1, which ended in the death of the single cosmonaut on board. The parachute container had been damaged during a thermal protection system baking process, however, there was no requirement to inspect the parachute container for contamination or damage.

The Apollo-1 pad fire on January 27, 1967, was preceded by a similar event: an electrical fire of an Apollo command module during an environmental control system test in a vacuum chamber. This was an example of *inadequate organizational learning systems*. The test was conducted under a lower atmospheric pressure (i.e., 5 psi to simulate cabin pressure in space versus 16.7 psi for the LC-34 test), but in a 100% oxygen environment. However, the test incident report was classified and inaccessible to personnel without clearance. *(continues...)*



Identifying and Addressing Underlying/Systemic Safety Issues Improves Robustness

Top Nine Recurring Cause Types

1. Inadequate technical controls or technical risk management practices
2. Incomplete procedures
3. System design and development issues
4. Inadequate inspection or secondary verification requirements
5. Inadequate organizational learning systems
6. Inadequate schedule controls
7. Inadequate task analysis and design processes
8. Organizational design issues
9. Organizational safety culture issues

During launch of Skylab 1, there was a complete loss of the micrometeoroid shield from around the lab and damage to a solar array. Repairs made during the Skylab 2 mission included installing a sunshade for thermal control and releasing the damaged solar array.

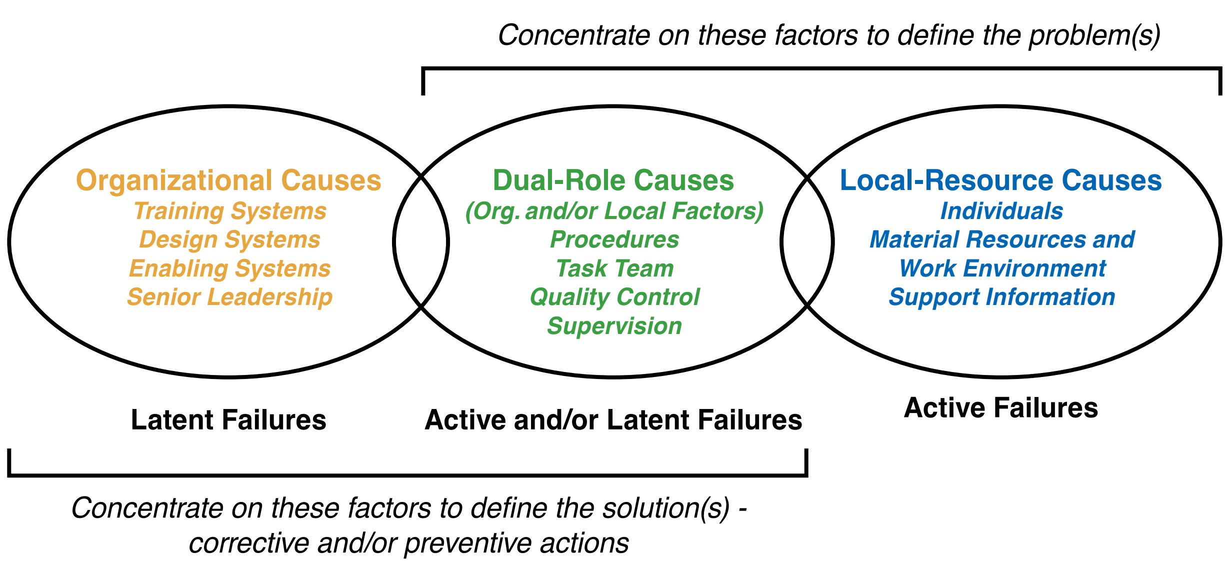
Applying Past Lessons to Future Missions

To make organizational systems more robust and resilient to mishaps, systemic safety issues should be addressed, especially as spacecraft and launch vehicles operate closer to their design limits. This requires a broad systems perspective looking across different types of mishaps and close calls, with actions that focus on being proactive and preventive complementing those actions that are more reactive and corrective in nature. The NESC itself was established in 2003 as a direct result of the Columbia tragedy, created as a solution to an underlying, or systemic, safety issue affecting crewed, non-crewed, and science missions.

Through a Human Spaceflight Knowledge Sharing Forum and series of panel discussions and presentations, the study team's primary recommendation to human spaceflight program personnel was to internalize these study results, consider their personal degree of safety accountability, and determine whether additional mishap risk reduction actions are warranted. Before crewed flights begin, personnel should step back from their busy schedules and ask questions like "What else can be done within my area of responsibility to ensure crew safety?" "What are we doing now that needs to be improved?" "What could be stopped and replaced with a better approach?" "What is working in other subsystems than can be extended to my subsystem?" Hopefully, the results from this study provide data and examples to seed those discussions.

The shared purpose of the NESC and NSC is helping NASA programs achieve safety goals through engineering and technical excellence. For those in the human spaceflight community, excellence is often perceived as being synonymous with perfection. Surgeon and author Atul Gawande wrote, "No matter what measures are taken, doctors will sometimes falter, and it isn't reasonable to ask that we achieve perfection. What is reasonable is to ask that we never cease to aim for it." The flight, ground, and organizational systems, processes, and decision making will sometimes falter, and tragedies will occur. Although it is true that the only way to maintain a perfect human spaceflight safety record is to never fly, human spaceflight organizations can never cease aiming for perfection…and excellence.

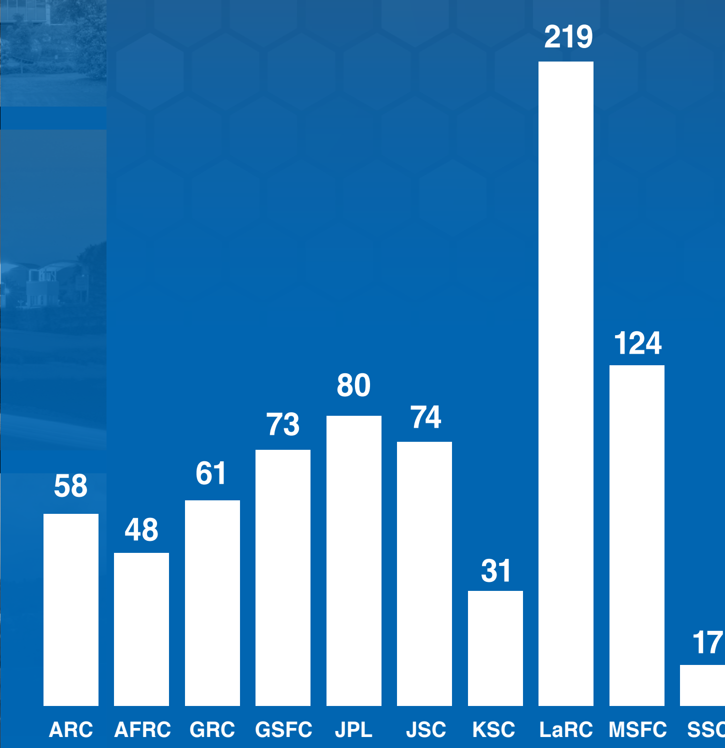
In 2019, the study was expanded to include recent mishaps, and a final report was published (NASA/TM 2020-220573). The results were also featured in the NESC Academy and an NSC Safety Webinar series. For more information, contact Dr. Timothy Barth, tim.barth@nasa.gov or Steve Lilley, steve.k.lilley@nasa.gov.



In the taxonomy used in the study, systemic safety issues have organizational and/or dual-role causes.

NESC at the Centers

Drawing Upon Resources from the Entire Agency to Ensure Mission Success



NASA Employees Supporting NESC Work in FY20

From top left: Stennis Space Center, Armstrong Flight Research Center, Langley Research Center, Ames Research Center, Marshall Space Flight Center, Glenn Research Center, Kennedy Space Center, Jet Propulsion Laboratory, Goddard Space Flight Center, and Johnson Space Center.

Ames Research Center

The Ames Research Center (ARC) supports a diverse suite of capabilities for the NESC including advanced computing, aerodynamics testing, intelligent systems, aerothermal/entry, descent, and landing (EDL) modeling, thermal protection materials, and human factors research. ARC is represented on 15 NESC Technical Discipline Teams (TDT). The Technical Fellow for Human Factors is also resident at ARC. ARC has a long history of EDL research and development. ARC's Dr. Michael Wright has long been a key part of EDL development and now serves as deputy lead of NASA's EDL systems capability team, helping guide the future direction of this critical area of spaceflight for the Agency. Experts in entry systems, under Dr. Michael Barnhardt, provided key support to the Orion program investigating the thermocouple anomaly observed on EFT-1, combining interactions of aerothermal ablation with aerodynamics and trajectory analyses, to develop understanding of complex thermal-fluid flow phenomena.


Dr. Michael Wright

Working Across Disciplines to Advance EDL Capability

Dr. Michael Wright has served as the Agency's EDL deputy capability lead as well as a member of the Aerosciences TDT, both of which have allowed him broad reach into multiple NASA projects. His work in entry systems modeling has focused on improving the fidelity of modeling and simulation for all of NASA's EDL missions, including Mars 2020, which launched in July. Because EDL influences many disciplines, including Aerosciences, thermal, structures, materials, and flight dynamics, Dr. Wright works with many of the NASA Technical Fellows. "It serves as an extremely useful and fruitful collaboration," he said, giving everyone more insight into the depth and breadth of a problem. He also works with the Aerosciences TDT, helping to propose solutions to the discipline's technical challenges. When he was the project manager of Entry Systems Modeling, he led the development of computational abilities for high-fidelity parachute fluid dynamics. In his TDT role, he has continued that effort as the topic lead for two early-stage innovation grants for parachute modeling. "We need to understand the strange dynamic behavior of parachutes, as most of our missions require them. We're right on the cusp of substantially contributing to a better understanding of that challenge."


Dr. Michael Barnhardt

Advancing the Aerosciences Discipline

To help the NESC better understand the Orion Exploration Flight Test (EFT)-1 thermocouple anomaly, Dr. Michael Barnhardt brought expertise from the Space Technology Mission Directorate's Entry Systems Modeling Project (ESM) to aid in the investigation. As ESM manager, he knew the project might help the NESC determine the cause of thermocouple interference by providing cutting-edge analysis of the interaction between ablation products and the surrounding plasma field. ESM has also partnered with the NESC to advance technology in parachute modeling and free-flight computational fluid dynamics (CFD). "Free-flight CFD allows a simulated capsule to fly realistic trajectories. If we can understand drivers of entry vehicle flight dynamics, we can better predict how they will fly without being completely reliant on expensive ground tests. Thinking longer-term, free-flight CFD capability has potential to impact how we develop guidance and control for entry vehicles." Dr. Barnhardt also brings his aerothermodynamics and thermal protection system background to the Aerosciences Technical Discipline Team, which allows him to interface with discipline experts from across the Agency. "We are frequently asked to work at the intersection of multiple disciplines, and being a part of the TDT has greatly benefited my work."

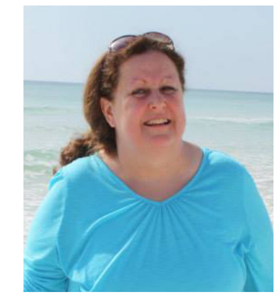
58 ARC Employees Supported NESC Work in FY20

KENNETH R. HAMM, JR.
NESC Chief Engineer

Armstrong Flight Research Center

The Armstrong Flight Research Center (AFRC) provided technical expertise to the NESC for numerous activities in 2020. For the past two years, AFRC committed its entire fighter aircraft fleet and a large contingent of staff to gather critically important breathing data from pilots flying these high performance jets. AFRC has been instrumental in the NESC's flight test campaign to gather missing information for the U.S. military regarding pilot breathing to help shed light on the human-machine interaction during high-performance flight. Over the assessment duration, AFRC flew approximately 131 sorties utilizing five pilots, six fighter aircraft, and two aircrew equipment configurations for the *Pilot Breathing Assessment* (PBA). AFRC also completed a study to assist prospective NASA science partners to improve cryostat designs for the Stratospheric Observatory for Infrared Astronomy (SOFIA) program.


Jessica Malara


Priscilla Taylor-Percival


Bonnadeene Trimble


Jonathan Brown

Tracking Every Step of an Assessment

Ms. Jessica Malara is a risk manager, assessing the risks an AFRC project might encounter that could impact time, resources, and costs. To manage eight projects, Ms. Malara's workday requires strict attention to detail and a strong eye for forecasting problems long before they can arise. It was this skill set the NESC needed in a scheduler for its PBA. "I collect data from the PBA Team on every task needed to run a successful program." That includes tracking each of those tasks as well as every key milestone, deliverable, and commitment date and ensuring the PBA team is on track to meet them. "I enjoy working with a diverse group of people with different backgrounds and watching their efforts come together to fly the PBA mission. With PBA, I think the work is important, and I'm learning more than just my job, I'm learning about everyone's role in PBA. I like that I can provide assessments to the team so they can proactively plan resources and schedule to mitigate potentially impactful outcomes."

Supporting F/A-18 and F-15 Pilots in Flight

To better understand pilot breathing behaviors during the PBA, NASA test pilots equipped with specialized sensors flew NASA F/A-18 and F-15 aircraft through pre-specified flight profiles. During flight, Ms. Priscilla "Sim" Taylor-Percival and Ms. Bonnadeene Trimble assisted the pilots in accurately marking the starts and ends of flight maneuvers to be compared later to breathing data. Providing countdowns, taking notes, and publishing flight data for researchers was challenging work. "I've been at NASA for 35 years, but the *Pilot Breathing Assessment* has been the most exciting," said Ms. Taylor-Percival, who has scribed for other NASA aircraft. "I have a lot of experience working with the pilots' office and the researchers." She mentored Ms. Trimble, who was new to scribing. "It was a whole new experience and really opened my eyes to more of the very cool things NASA does. Sim and I are a great team. She's pushed me forward and given me more confidence in myself and what I can do."

Taking a Holistic Approach to Systems Engineering

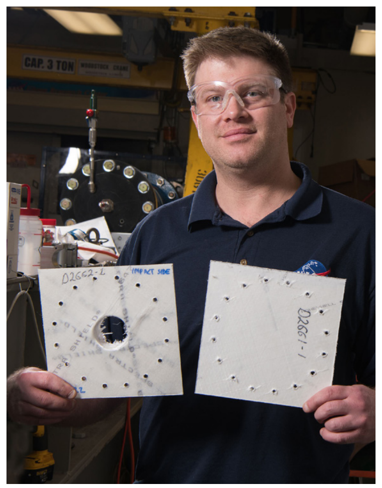
As the Systems Engineering and Integration Lead for SOFIA, Mr. Jonathan Brown oversees the configuration management for the project and also serves as the flight systems integration lead and software manager. With a robust systems engineering (SE) focus, the project has moved into its operations and sustainment phase, successfully managing its science workload even as staffing requirements diminish. Mr. Brown also brings his SE background to NASA's Systems Engineering Working Group Planning Team, where he helps coordinate its yearly workshop. "We're interested in making SE that much better and more efficient for NASA. As we all struggle to do more without additional resources, we look at every opportunity to use model-based systems engineering and collaborative tools that will make SE processes more efficient. That is what the workshop is all about," he said. "We network with other SE subject matter experts at every Center and work to find a common understanding regarding risk leadership and tool sets the Agency can embrace."

48 AFRC Employees Supported NESC Work in FY20

DR. W. LANCE RICHARDS
NESC Chief Engineer

Glenn Research Center

The Glenn Research Center (GRC) provided a broad spectrum of technical expertise to 19 NESC technical assessments/activities and 19 NESC Technical Discipline Teams (TDT). These activities supported all NASA mission directorates as well as several cross-cutting discipline efforts. GRC provided significant contributions this year through the use of specialized 3-D scanning/modeling tools and high-speed photogrammetry to capture the dynamics of parachute extraction for the Commercial Crew Program (CCP). GRC also provided an acting Technical Fellow for Software and the evaluation of software complexity using the cyclomatic complexity metric to help determine the appropriate level of testing for key human spaceflight applications. The NASA Technical Fellows for Cryogenics and Loads & Dynamics, as well as deputies for the Propulsion; Electrical Power; Software; Systems Engineering; and Nuclear Power & Propulsion TDTs, are resident at GRC.



Charles Ruggeri

Parachute Ground Extraction Testing

Mr. Charles Ruggeri began his tenure at GRC more than 10 years ago as an intern from nearby University of Akron. Today, the aerospace engineer spends much of his time in the Center's impact dynamics lab capturing data with high-speed photogrammetry. The NESC recently called on his expertise to configure a suite of more than 14 high-speed cameras to capture a parachute pack ground extraction test. He was a member of the NESC assessment team that designed a unique ground test configuration to aid CCP in comparing computational model results to actual physical measurements. The data would validate the model and inform future missions. The team used the Langley Impact Dynamics Load Facility, rigging a large mass to swing down from the gantry crane and extract the parachute at flight-like speeds. "The NESC team came up with test parameters and how the data would be fed into the models. There was a lot of planning involved. In the end, the test worked even better than expected," he said. "Everyone on the assessment team had the same goal, and when everyone has the same goal, it is infectious. The test was a big success and a very proud moment for me."

Laura Maynard-Nelson

Evaluating Cyclomatic Complexity

Ms. Laura Maynard-Nelson's childhood love of space likely led to her more than 30-year career at GRC. "It came from growing up with a father who was fascinated by it and my brother, who also worked at NASA for a while." Her time at NASA has been focused on software, and she has watched software systems grow in complexity, along with the tests required to verify them for spaceflight. The former chief of GRC's Flight Software Branch and now co-deputy for the NASA Technical Fellow for Software brought her expertise to an NESC assessment to evaluate the software metric, Cyclomatic Complexity. The metric evaluates every function within a software system to assign a complexity level. "This will help us determine the appropriate levels of testing we need for our safety-critical software." Even a small software system can involve up to 50 separate functions, each of which require multiple test cases for verification, she said. "It's been an eye-opener for all of us." She has enjoyed the unique opportunities the assessment has provided her. "It is exciting and lets me feel actively engaged and doing something for the discipline and the Agency."

61 GRC Employees Supported NESC Work in FY20

ROBERT S. JANKOVSKY
NESC Chief Engineer

Goddard Space Flight Center

The Goddard Space Flight Center (GSFC) supported a wide range of NESC activities, including 35 assessments with 60 engineers, technicians, and scientists participating. Key assessments included *Guidelines for an Avionics Radiation Hardness Assurance, Recommendations on Use of Commercial-off-the-Shelf Guidance for all Mission Risk Classification, Aerodynamic Buffet Flight Test, ISS Battery Charge Discharge Unit Flight Anomaly Investigation, Reference Architecture for ISS and Exploration Extravehicular Activity Power System, Risk Evaluation of ABSL Moli-M Cell Lithium-Ion Batteries for L2 Missions, Independent Assessment Study for the GSFC Laser Interferometer Space Antenna Laser, Space Charging of the Ocean Color Instrument Rotating Mechanism, and State of Hydrazine Synthesis and its Potential Impact on Spaceflight Applications*. In addition, the NASA Technical Fellows for Systems Engineering; Mechanical Systems; and Guidance, Navigation, & Control; and the NESC Chief Scientist reside at GSFC.

Dr. Diego Janches

Monitoring Meteoroids in the Southern Sky

A metric ton of meteors, most the size of a grain of sand, enter Earth's atmosphere daily, and are a threat to satellites, spacecraft, astronauts, and the International Space Station (ISS). "They are very small, but very fast and can cause serious damage," said Dr. Diego Janches, a research astrophysicist in the GSFC Heliophysics Science Division. Until recently, most observations were focused over the northern hemisphere. "There are many characteristics of the southern meteor environment we didn't know because we were half blind to the sky," he said. Recently he teamed with the NESC in a multiyear effort to upgrade the Southern Argentina Agile Meteor Radar meteoroid monitoring facility to collect data for NASA's Meteoroid Environment Office. Following the upgrades, Dr. Janches's team began capturing measurements in late September 2019, and the following March they were able to detect the precise location and pattern of an unexpected meteor outburst in the southern hemisphere (*The Astrophysical Journal*, May 2020). "In going to the Moon and Mars, this will be an important source of data and offer a better understanding and more thorough monitoring of the meteoroid environment."

Jill Stanton

Providing a Broad Perspective on Materials & Processes

As a member of the Materials Technical Discipline Team, Ms. Jelila Stanton has provided expertise for an NESC assessment and helped revise Agency standards and guidelines. "I enjoy having the opportunity to collaborate with experts around NASA because I learn so much from the process," she said. As head of GSFC Materials Engineering, she and her team of 30 engineers and technicians regularly assist the NESC with Composite Overwrapped Pressure Vessels inspection, insight into astronaut safety risks, and analyses into a variety of materials issues and anomalies. "We all work on a wide array of hardware and instruments for flight missions in planetary and earth science, astrophysics, ISS payloads, and astronaut tools. We learn from each project and have many lessons learned and historical findings we can draw from for new materials applications." Across more than 20 laboratories, they work technical issues from trade studies in the proposal phase to on-orbit anomaly investigations. And she routinely shares the unique expertise of the branch. "With so many labs and capabilities, I find we help resolve issues through consulting, testing, or analysis in areas that some projects didn't even realize we cover."

73 GSFC Employees Supported NESC Work in FY20

FERNANDO A. PELLERANO
NESC Chief Engineer

Jet Propulsion Laboratory

Throughout the year, the Jet Propulsion Laboratory (JPL) provided technical expertise to over 35 NESC assessments and each of the 20 Technical Discipline Teams (TDT). Efforts supported both the Science and Human Exploration and Operations Mission Directorates, along with the Department of Defense. Tasks included the design and flight test of an in-mask CO_2 water vapor sensor for the *Pilot Breathing Assessment*, flexible body dynamics modeling, low-jitter space observatory attitude-control analysis, materials analysis related to a DC-8 mishap, and development of methods for reliable management of mass properties. In addition, JPL provided support to a number of NASA's Commercial Crew Program activities. The NESC COPV working group lead and TDT deputies for Space Environments and Guidance, Navigation, & Control also reside at JPL.

Dr. Bryan McEnerney

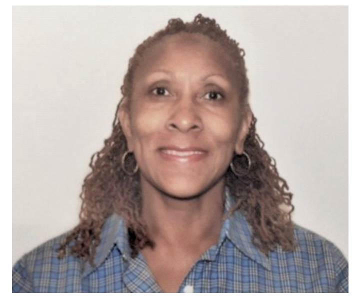
Charting the Course for Additive Manufacturing

Leading the Materials and Processes group at JPL, Dr. Bryan McEnerney was part of a team of additive manufacturing (AM) experts that helped the NESC develop Agency standards for this 3D-printing technology, which has applications for both crewed and non-crewed spaceflight hardware. He was also part of the NESC review of a commercial partner's AM program. "More and more companies are adopting this technology and want to put it on high value spaceflight missions. It's tremendously exciting because these standards are a first of their kind, comprehensive documents that explain what is needed to qualify material for AM and ensure best-in-practice approaches." The assessments also allowed Dr. McEnerney to foster his Agency knowledge base. "I can confidently say that I know good people I can call at any NASA Center. It is all too easy to wear a small Center hat rather than the large NASA hat, but these activities bring in people from all the Centers, which benefits everyone."

Dr. Ratnakumar Bugga

Developing and Evaluating Battery Technologies

A battery scientist at JPL, Dr. Ratnakumar Bugga develops advanced energy storage technologies for NASA/JPL planetary missions in custom chemistries and configurations. He assisted the NESC in the review of a lithium-ion (Li-ion) battery charge-management scheme that monitors half-string voltages in a battery made up of a series-parallel network of cells for extravehicular activities. He was also called on to assess the risk of swapping lithium-ion batteries of different chemistries for the James Webb Space Telescope mission. Dr. Bugga has enjoyed the challenges of evaluating commercial Li-ion cells with high energy/power densities and validating and adapting them for future aerospace applications. "Often, we encounter unique battery-related problems, and it is exciting to be able to solve these system-level issues." His aim is to "provide safe, reliable, and robust battery solutions with low mass and volume and infuse them into NASA missions, with the goals of enabling increased science payload and enhanced mission lifetimes."



Lorraine Johnson

Managing the Fiscal Health of NESC Assessments

As a Resource Analyst, Ms. Lorraine Johnson oversees the financial aspects of NESC work performed at JPL by tracking all assigned assessment tasks and TDT work. She forecasts budgets and monitors funding and spending to ensure the more than 60 active projects at JPL are financially healthy and meeting their monetary goals. Ms. Johnson's work with the NESC has allowed her to meet her counterparts across the NASA Centers and given her broad insight into the business side of NASA and NESC projects. "We all work together to make sure we don't have overrun issues and stay on top of funding requirements. It might not be as exciting to talk about the finance aspect of the work, but there is a lot of effort and diligence required to do the job right. It's also very important that your work is trustworthy and performed accurately." At JPL for 21 years, Ms. Johnson said, "I've been in business management for a long time, and I really enjoy the work."

80 JPL Employees Supported NESC Work in FY20

KIMBERLY A. SIMPSON
NESC Chief Engineer

Johnson Space Center

The Johnson Space Center (JSC) and the White Sands Test Facility (WSTF) provided engineering analysis, design, and test expertise for the continuous operation of the International Space Station, development of the Orion Multi-Purpose Crew Vehicle and Space Launch System for the upcoming Artemis missions, consultation for Commercial Crew Program vehicles, and the lunar Gateway vehicle. JSC personnel provided expertise and leadership to numerous assessments within the Agency relating to SLS loads and dynamics; Orion heatshield molded Avcoat block bond verification; frangible joint designs; composite overwrapped pressure vessels (COPV); and pilot breathing in high performance aircraft. The NASA Technical Fellows resident at JSC joined with other Agency discipline leaders to strengthen technical community connections through joint sponsorship and participation in activities such as the Structures, Loads, and Mechanical Systems Young Professionals Forum; the Thermal and Fluids Analysis Workshop; and Capability Leadership Teams to help define the future of NASA technical disciplines.

Dr. Donna Dempsey

Understanding the Human Role in NASA Missions and Systems

As a Discipline Deputy for Human Factors, Dr. Donna Dempsey supports a variety of human factors work across the Agency. The discipline reaches into many areas of aeronautics and spaceflight, including human performance; mission planning; design of habitats, vehicles, workstations, workspaces, equipment, and tasks; human-computer and human-robotic interaction; and training. Dr. Dempsey said human factors remains a challenge as NASA focuses on returning to space. Specializing in space flight training, she assists in managing human factors assessments and is leading the development of a tradespace analysis method to better balance the number of crew against mission design parameters. "There are trade-offs in determining crew size given the mission objectives and the capabilities of the vehicle," she said. The analysis will determine important tradespace factors for NASA's future long-duration missions to Mars.

Dr. Daniel Wentzel

Capturing Test Data at High Speeds in the WSTF Test Lab

At the WSTF Hypervelocity Test Lab, Dr. Daniel Wentzel leads a team employing two-stage light-gas guns to fire projectiles at speeds up to 24,000 feet per second. These guns test critical space flight components' abilities to withstand impacts from meteoroid and orbital debris (M/OD). He has supported NESC assessments by subjecting COPV materials to simulated M/OD and overseeing carbon fiber strand testing for a stress rupture study. He also uses the lab's high-speed video and photon Doppler velocimetry to capture detonation data on pyrotechnic devices; design experiments and analyze data for an ascent cover separation mechanism model; and create a thermal model to predict current-carrying capacity. As a member of the Mechanical Systems Technical Discipline Team, Dr. Wentzel takes a multidisciplinary approach to problem solving, "structuring teams around problems to leverage the best of different disciplines. Nobody is as smart as all of us."

Jason Wolinsky

Developing and Testing a New Reefing Line Cutter

Mr. Jason Wolinsky is the test director for the Energy Systems Test Area in the JSC Propulsion and Power Division Test Lab. He is working to develop, test, and qualify a new government-furnished reefing line cutter, a pyrotechnic device that allows a staged opening of main and drogue parachutes on NASA spacecraft. Typically, Mr. Wolinsky develops the plans and procedures to test and qualify already-established hardware, but the reefing line cutters offer him the new challenge of developing and testing hardware from the ground up. This includes determining the environments the cutters will encounter during flight, abort, and deployment to ensure they can survive those conditions. To help develop those environments, the NESC has provided additional expertise from various Centers to assist in the effort. "It is a great approach to find people who do similar or different testing that is relevant to what we do. The NESC can pull the right people together in the same room to tackle those problems."

74 JSC Employees Supported NESC Work in FY20

T. SCOTT WEST
NESC Chief Engineer

Kennedy Space Center

The Kennedy Space Center (KSC) provided technical expertise to 21 NESC activities and Technical Discipline Teams in 2020. KSC personnel were engaged in numerous NESC assessments including Commercial Crew Program (CCP) crew module ascent cover modeling; Space Launch System propellant pressurization modeling; heatshield thermal instrumentation evaluation; and NASA additive manufacturing standard development. Likewise, the NESC provided technical support for KSC programs including CCP composite overwrapped pressure vessel analysis; CCP fire suppression analysis; Exploration Ground Systems Crew Module Test Article design evaluation; and Mobile Launcher and Crawler structural crack evaluation. The NASA Technical Fellows for Electrical Power and Materials reside at KSC and rely on KSC expertise in many of their activities. The NESC also invested in KSC's laboratories to evaluate Virgin Orbit electro-static discharge testing, and hydrazine synthesis and contamination analysis for the Agency.

Dr. Janelle Coutts

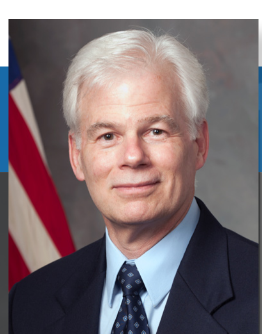
Assessing Hydrazine Purity

When a new hydrazine manufacturing process led to the presence of unknown contaminants, Dr. Janelle Coutts helped identify the contaminants to determine if they posed any risks to thruster systems that use the commodity for various NASA programs. "It is a big concern for the propellant community because depending on what these contaminants are, they could plate out in a thruster system and cause clogging or poison the catalysts beds the fuel comes in contact with." As the technical lead for an NESC assessment, Dr. Coutts used her background in organic chemistry to develop analytical methodologies to identify and quantify the unknown contaminants. Next, the Agency-wide assessment team will determine if there are any potential risks to propulsion-system performance, the results of which are critical for not only NASA missions, but also government and industry. Dr. Coutts appreciates the NESC's multi-Center approach to solving technical problems. "I am an analytical chemist, but I do not specialize in how catalyst beds are affected, so the NESC has helped us get contacts across the Agency to help us get those answers. It's been a great experience." Dr. Coutts contributed to NESC Technical Bulletin 20-08, page 41.

Dr. Robert Youngquist

Investigating Thermocouple Anomalies

Physicist Dr. Robert Youngquist has been working with the NESC's Thermocouple Interference During High-Speed Earth Entry Team to investigate thermocouple anomalies seen by the Space Shuttle orbiter and Orion Exploration Flight Test (EFT)-1 during reentries. The thermocouples embedded in the heatshields to measure reentry temperatures showed non-physical signal variations near peak heating that were correlated with vehicle maneuvers. To help understand the root cause of this phenomenon, Dr. Youngquist directed tests on Shuttle tiles and EFT-1 heatshield thermocouples to demonstrate how electromagnetic fields could interact with the thermocouple wire and yield signal variations. "We would propose theories, test them, review the data, and then try again." The team is nearing the end of the more than 2-year assessment to understand the source of these anomalies and provide the program feedback to ensure thermocouples operate properly during re-entry. "It's been a long effort with a very diverse team," he said. As the originator of KSC's Optical Instrumentation Laboratory (now called the KSC Applied Physics Laboratory), Dr. Youngquist brings more than 30 years of experience to the team. His experience also aided the NESC in the demonstration of an ultrasonic level gauge for the Orion Multi-Purpose Crew Vehicle to determine fuel levels in the service module's hypergolic tanks.



31 KSC Employees Supported NESC Work in FY20

STEPHEN A. MINUTE
NESC Chief Engineer

Langley Research Center

The NESC relies on Langley's expertise for design evaluation, ground model validation tests, trajectory analysis, material testing for future launch vehicles, and other critical assessments. Over 100 technical experts participated on Technical Discipline Teams across the Agency. Langley delivered a highly instrumented payload for an aerodynamic buffeting flight test and completed computational fluid dynamics modeling to determine what caused NASA's research P3 aircraft to experience cracking in the ailerons during flight. Langley's facilities were used to conduct multiple wind tunnel tests, characterize defects in propulsion system bellows through nondestructive evaluation (NDE), and develop a proving ground for a parachute extraction test to validate computational models prior to crewed flight. The NASA Technical Fellows for Aerosciences, Avionics, Flight Mechanics, and NDE are resident at LaRC.

Dr. Richard Boitnott

Lisa Jones

Dr. Matthew Chamberlain

Unique Parachute Extraction Test Required Skill and Creativity

Designing a ground test that would simulate main parachutes being extracted from a spacecraft parachute bay was a unique challenge for Dr. Richard Boitnott. "This was different from other testing I've done," said the 40-year NASA veteran test engineer, who conducts crash and water impact testing for NASA and commercial spacecraft and aircraft. His unique test design involved a pendulum swing of a large mass outfitted with a tail hook that would swing down, lock onto the parachute harness, and extract it from its container. Energy modulators used in the parachute extraction chain limited loads to prevent lines from snapping, and a large sand dune brought the mass to a halt after its high-speed swing from LaRC's 240-foot tall gantry. "It was like a lab experiment out of a physics course. Everything worked beautifully, and the data we measured agreed with the software model's prediction," he said. "Every project the NESC brings draws in people from all the Centers, and it gave the gantry a new possibility for similar tests."

As the facility manager for the test, Ms. Lisa Jones said the extraction test was "very much a team effort. There was a lot of brainstorming and working through multiple ideas. Complexity-wise, this test was right up there with some of more complex work we've done." When early component-level tests needed the swing mass to move at even higher speeds, they added 0.75-inch thick bungie cords to reach higher velocities. "But the bungie has issues. If you pull it back and let sit too long, it softens. So, we had to work quickly and efficiently and figure out how to get what we needed from an environment that was changing all the time." Ms. Jones has been performing impact testing at NASA for 34 years, including small aircraft, Orion test articles, helicopters, and even a stock car. "It's a great thing to do for a living, but it can be intense," she said. "This test was not without its challenges, but it was a lot of fun."

Technical Lead Dr. Matthew Chamberlain managed the overall execution of the extraction test. "The goal was to develop data to help validate the customer's computer model, so the team studied the model, then designed a test to check it. This was a completely new type of test. The geometry was complicated, as well as getting enough speed to simulate the parachute being pulled out of the bay." The test required coordinating the efforts of a distributed set of engineers, technicians, machine shops, and photogrammetric measurement experts to generate the data needed to validate model predictions. "There were a lot of moving parts required to get it done," he said. As part of the Structural Dynamics Branch, Dr. Chamberlain typically works on small spacecraft structures, but said "executing a program of this scale exposed me to many new aspects of project management, budgeting, and workforce planning. The test and the results generated really impressed everyone, but the best part is that it was dreamed up by people right here at Langley. That to me is really cool."

219 LaRC Employees Supported NESC Work in FY20

MARY ELIZABETH WUSK
NESC Chief Engineer

Marshall Space Flight Center

The Marshall Space Flight Center (MSFC) provided engineer, scientist, and technician subject matter expert support to over 38 NESC activities. These activities involved 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 insulations, 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; and the Technical Discipline Team (TDT) Deputies for Propulsion; Nuclear Power & Propulsion; Materials; Space Environments; Loads & Dynamics; Nondestructive Evaluation; Cryogenics; Flight Mechanics; and Software are resident at MSFC.

Dr. Emily Willis

Space Environments for the Artemis Program

Dr. Emily Willis is a member of the Natural Environments Branch and a key element of the NESC Space Environments TDT for four years. Her primary responsibilities include space environment specification and spacecraft charging analysis. She supports a variety of programs including the Space Launch System, Commercial Crew, Gateway, and the Human Landing System. She has coordinated support from members of the Space Environments TDT in numerous activities related to developing and evaluating new space environment specifications for NASA's human spaceflight programs. The NESC recently provided support for a multi-Center, multi-discipline team, which she established for the development of a new plasma environment specification for Artemis missions. The team used THEMIS-ARTEMIS data to define the lunar plasma environment, which is now being used in the design of the Gateway and Human Landing System. Her emphasis on collaborative engagement of the NESC Space Environment discipline in the ongoing, fast-paced work of the Artemis Program allows for effective independent review and community buy-in as the mission designs mature.

Charles Pierce

A Journey in the Advancements of Propulsion Technology

Mr. Pierce joined NASA in 1987 at KSC where he specialized in the servicing of the Space Shuttle Program orbiter with hypergolic propellants for the orbital maneuvering system and reaction control subsystems. In 1996, he transferred to MSFC, where he has led or supported the development of multiple hypergolic and cryogenic engines and propulsion systems including the Fastrac/Propulsion Test Article, Next Generation Reusable Launch Vehicle, U.S. Propulsion Module, and Crew Exploration Vehicle. From 2007 to 2019, he served as the Deputy Chief, then Chief, of the Spacecraft Propulsion Systems Branch. He became a Deputy NASA Technical Fellow for Propulsion in 2019 and has led the NESC Assessments for Transient Combustion Modeling of Hypergolic Systems (see page 32), and the Nitrogen Tetroxide Properties Development for the National Institute for Standards and Technology Reference Fluid Thermodynamics and Transport Properties database. His time supporting the NESC has opened his eyes to the crosscutting capabilities that the NESC provides to the Agency, and to the pockets of propulsion expertise that reside throughout our country.

124 MSFC Employees Supported NESC Work in FY20

STEVEN J. GENTZ
NESC Chief Engineer

Stennis Space Center

Expert technical support was provided to the NESC by Stennis Space Center (SSC), including subject matter expertise in hardware testing, facility capabilities, risk assessment, test operations, modeling, and space exploration. Despite SSC's small number of employees, two new experts were added to NESC Technical Discipline Teams (TDT). Particularly noteworthy is the valuable contribution of three SSC subject matter experts on the Artemis I integrated hazards assessment. SSC also supplied experts and early-career engineers for assessments of *Parker O-Ring Material Obsolescence*, *Aerospace Valve Industrial Base and Acquisition Practices*, *Filtration for Propellant and Pressurization Systems*, and *Space Launch System (SLS) Booster Nozzle Throat Plug Debris*. Additional activities included a failure investigation for the Commercial Crew Program, plus modeling support on *Sierra Nevada Hydrogen Peroxide Propellant System* and *SLS Hydrogen and Oxygen Pressurization Systems*. In collaboration with the NASA Propulsion Technical Fellow, the SSC Engineering Director volunteered to host engineers from other Centers for hands-on training to help the Agency enhance the proficiency of the NASA workforce.

Robert Williams

A Unique Perspective on Structures

During its review of the Exploration Systems Development Integrated Hazards, the NESC brought in Mr. Robert Williams to address any potential structural issues during ground systems testing. His expertise comes from 11 years at SSC, where his focus is on structures – from design and analysis to loads and dynamics issues seen during ground testing of rocket engines at the Center's test stands. While it is the engines that are tested, the test structures supporting the engines are also subject to stress and fatigue, he said. "We upgrade and change our facilities for every test program, but it is difficult to do a dynamic analysis of an entire test facility. So when we find resonant frequency issues or components behaving in ways we weren't expecting, we do analysis and work on solutions to mitigate or avoid them." Working with these structures, some of which date back to the 1960s, often involves studying old designs without much insight into the rationale behind changes made many years ago. "It can be like interpreting a foreign language," he said. "But that is the unique perspective I bring."

Richard Wear

Networking Within the Thermal Discipline

For 10 years, Mr. Richard Wear has attended the annual Thermal Fluids Analysis Workshop (TFAWS) sponsored by the NESC. "It is a great conference for beginning engineers because it offers training, short courses by field experts, and a chance to network within the thermal community." This year, he led a steering committee for the virtually held TFAWS. Virtual workshops limited hands-on activities, but still allowed him insight into thermal discipline activities across the Agency. As the resident subject matter expert in thermal fluids at his Center, he models piping and valve systems and answers questions on the thermal dynamics and heat transfer involved in propellant systems. That experience made him a valuable consultant on a recent NESC assessment on hydrogen and oxygen pressurization systems for the SLS. Mr. Wear also represents SSC on both the Passive Thermal, and Environmental Control & Life Support TDTs. "If I have a problem come up, I know who I can call at every Center to ask for help. The TDTs are good collaboration tools."

17 SSC Employees Supported NESC Work in FY20

MICHAEL D. SMILES
NESC Chief Engineer

NESC Leadership

OFFICE OF THE DIRECTOR


Timmy R. Wilson
NESC
Director


Michael T. Kirsch
NESC Deputy
Director


Michael P. Blythe
NESC Deputy Director
for Safety (Acting)


Jill L. Prince
NESC Integration
Office Manager


Dr. Azita Valinia
NESC Chief
Scientist


Patrick A. Martin
NASA HQ Senior SMA
Integration Manager


Barry E. Wilmore
NESC Chief
Astronaut

NESC PRINCIPAL ENGINEERS


Clinton H.
Cragg
LaRC


Dr. Michael G.
Gilbert
LaRC


Donald S.
Parker
KSC


Michael D.
Squire
LaRC

NESC CHIEF ENGINEERS


Steven J.
Gentz
MSFC


Kenneth R.
Hamm Jr.
ARC


Robert S.
Jankovsky
GRC


Stephen A.
Minute
KSC


Fernando A.
Pellerano
GSFC


Dr. W. Lance
Richards
AFRC


Kimberly A.
Simpson
JPL


Michael D.
Smiles
SSC


T. Scott
West
JSC

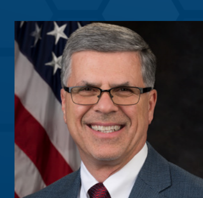

Mary Elizabeth
Wusk
LaRC

NASA TECHNICAL FELLOWS


Dr. Morgan B. Abney
Environmental Control
& Life Support


Cornelius J.
Dennehy
GNC

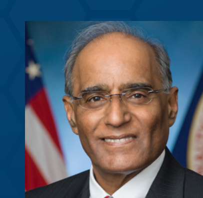

Dr. Michael J.
Dube
Mechanical Systems


Dr. Daniel J.
Dorney
Propulsion


Dr. Robert F.
Hodson
Avionics


Jon B.
Holladay
Systems Engineering

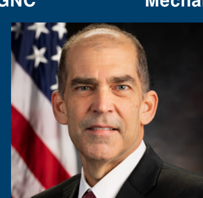

Dr. Christopher J.
Iannello
Electrical Power

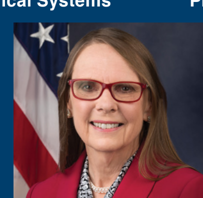

Kauser S.
Imtiaz
Structures


Dr. Dexter
Johnson
Loads & Dynamics

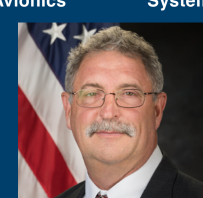

Michael L.
Meyer
Cryogenics


Dr. Joseph I.
Minow
Space Environments


Daniel G.
Murri
Flight Mechanics


Dr. Cynthia H.
Null
Human Factors

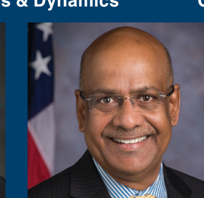

Dr. Lorraine E.
Prokop
Software


Dr. William H.
Prosser
Nondestructive Evaluation


Steven L.
Rickman
Passive Thermal


Richard W.
Russell
Materials


Dr. David M.
Schuster
Aerosciences


Dr. Upendra N.
Singh
Sensors & Instrumentation

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
NESC Chief Engineer
MSFC (2005)

Derrick J. Cheston
NESC Chief Engineer
GRC (2003-07)

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

Dr. Nancy Currie-Gregg
NESC Principal Engineer
(2011-17)

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

Dennis B. Dillman
NESC Chief Engineer
NASA HQ (2005-08)

Freddie Douglas, III
NESC Chief Engineer
SSC (2007-08)

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

Dawn C. Emerson
NESC Chief Engineer
GRC (2011-14)

Walter C. Engelund
NESC Chief Engineer
LaRC (2009-13)

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

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

Dr. Michael S. Freeman
NESC Chief Engineer
ARC (2003-04)

T. Randy Galloway
NESC Chief Engineer
SSC (2003-04)

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

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

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

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

Michael Hagopian
NESC Chief Engineer
GSFC 2003-07

David A. Hamilton
NESC Chief Engineer
JSC (2003-07)

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

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

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

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

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

George L. Jackson
NESC Chief Engineer
GSFC (2015-18)

Danny D. Johnston
NESC Chief Engineer
MSFC (2003-04)

Michael W. Kehoe
NESC Chief Engineer
Dryden Flight Research
Center (2003-05)

R. Lloyd Keith
NESC Chief Engineer
JPL (2007-16)

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

Dr. Dean A. Kontinos
NESC Chief Engineer
ARC (2006-07)

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

Nans Kunz
NESC Chief Engineer
ARC (2009-15)

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

Matthew R. Landano
NESC Chief Engineer
JPL (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
NESC Chief Engineer
GRC (2009-10)

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

Brian K. Muirhead
NESC Chief Engineer
JPL (2005-07)

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

Stan C. Newberry
MTSO Manager
(2003-04)

Dr. Tina L. Panontin
NESC Chief Engineer
ARC (2008-09)

Joseph W. Pellicciotti
NASA Technical Fellow
Mechanical Systems
(2008-13) and NESC
Chief Engineer GSFC
(2013-15)

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

Dr. Shamim A. Rahman
NESC Chief Engineer
SSC (2005-06)

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

Paul W. Roberts
NESC Chief Engineer
LaRC (2016-19)

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

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

Henry Rotter
NASA Technical Fellow
for Environmental Control
& Life Support (2004-19)

Dr. Charles F. Schafer
NESC Chief Engineer
MSFC (2006-10)

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

Bryan K. Smith
NESC Chief Engineer
GRC 2008-10

Dr. James F. Stewart
NESC Chief Engineer
AFRC (2005-14)

Daniel J. Tenney
MTSO Manager
(2009-13)

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

Timothy G. Trenkle
NESC Chief Engineer
GSFC (2009-13)

Clayton P. Turner
NESC Chief Engineer
LaRC (2008-09)

Daniel Winterhalter
NESC Chief Scientist
(2005-20)

NESC Honor Awards

Honoring Those Who Have Made Outstanding Contributions in 2020

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

NESC DIRECTOR'S AWARD:

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

David E. Williams - In recognition of his courage, strength, and persistence highlighting the technical risks associated with Commercial Crew Program fire suppression safety systems

NESC LEADERSHIP AWARD:

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

Bohdan Bejmuk - In recognition of continued exceptional technical leadership to the NASA Engineering and Safety Center in proactively reducing risk of NASA's new Human Spaceflight Programs

Matthew K. Chamberlain - In recognition of exemplary leadership in support of the NASA Engineering and Safety Center's Main Parachute Extraction Ground Test for the Commercial Crew Program

Julie Halverson - In recognition of outstanding leadership toward successful implementation of new maneuvers that enable previously unattainable science collection for the Lunar Reconnaissance Orbiter

Thomas G. Ivanco - In recognition of outstanding technical leadership in the assessment of Ground Wind Loads and Wind Induced Oscillation for Commercial Crew Program launch vehicles

Sarah E. Luna - In recognition of outstanding technical leadership in the development of the Agency's Additive Manufacturing Standards for crewed spaceflight hardware

Mark B. McClure - In recognition of outstanding technical leadership in the testing of propellants and combustible fluids

Stephen F. Peralta - In recognition of outstanding technical leadership resulting in an improved understanding of titanium/nitrogen tetroxide ignition vulnerability

Michael Watson - In recognition of outstanding technical leadership in support of numerous NASA Engineering and Safety Center assessments and the advancement of NASA's systems engineering and integration capability

Brian M. West - In recognition of outstanding technical leadership in the development of the Agency's Additive Manufacturing Standards for crewed spaceflight hardware

Sara R. Wilson - In recognition of outstanding technical leadership in guiding a dynamic team toward statistical engineering methods, demonstrating cost and schedule savings while achieving the key engineering goals

NESC ENGINEERING EXCELLENCE AWARD:

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

James C. Akers - In recognition of engineering excellence and innovative implementation of experimental and operational modal analysis techniques in evaluating the Artemis Mobile Launcher

William W. Benson - In recognition of engineering excellence for the alternate ascent flight control design development in support of the NASA Engineering and Safety Center's Commercial Crew Program Ascent Stability Assessment Team

Mark Balzer - In recognition of engineering excellence as the key troubleshooter on the USS Gerald R. Ford's (CVN-78) Advanced Weapon Elevator for the United States Navy

Robert Hall - In recognition of engineering excellence in providing the historical perspective and physics-based analysis to establish a standard for evaluation of launch vehicle ascent stability for commercial crew missions

David L. Iverson - In recognition of engineering excellence to the NASA Engineering and Safety Center's Pilot Breathing Assessment Team in the field of engineering data analysis support

Mark Karpenko - In recognition of engineering excellence and innovative implementation of new maneuvers that enable previously unattainable science collection for the Lunar Reconnaissance Orbiter

Donald F. Keller - In recognition of engineering excellence in developing aeroelastically scaled models and subsequent wind tunnel testing for Ground Wind Loads and Wind Induced Oscillation of Commercial Crew Program launch vehicles

Cyrus J. Kosztowny - In recognition of engineering excellence shown in real-time test-analysis correlation and outstanding post-test contributions in support of the NASA Engineering and Safety Center Shell Buckling Knockdown Factor project

Patrick L. Leser - In recognition of engineering excellence in the development of the Composite Overwrapped Pressure Vessel linear elastic fracture mechanics analysis failure criterion

Jennifer L. Pinkerton - In recognition of engineering excellence in the development, testing, and evaluation of an atmospheric boundary layer capability for NASA Langley's Transonic Dynamics Tunnel

Adam Przekop - In recognition of engineering excellence demonstrated as lead test-article designer for large-scale composite testing in support of the NASA Engineering and Safety Center Shell Buckling Knockdown Factor project

Kyongchan C. Song - In recognition of engineering excellence shown by planning instrumentation, developing the test plans, providing pretest predictions, and performing post-test analysis in support of the NASA Engineering and Safety Center Shell Buckling Knockdown Factor project

Floyd Spencer - In recognition of engineering excellence in the development and implementation of innovative probability of detection methodologies enabling the successful qualification of nondestructive inspection methods for the Artemis I Orion heatshield

Warren Ussery - In recognition of engineering excellence in the development, qualification, and implementation of innovative nondestructive evaluation methods to inspect the critical heatshield bond line for the Artemis I Orion spacecraft

NESC ADMINISTRATIVE EXCELLENCE AWARD:

Honors individual accomplishments that contributed substantially to support NESC mission.

Jonay A. Campbell - In recognition of outstanding technical editor support in the creation of the Agency's Additive Manufacturing Standards for crewed spaceflight hardware

Jessica Malara - In recognition of outstanding support of the NASA Engineering and Safety Center's Pilot Breathing Assessment Team in developing and tracking key project tasks, milestones, and deliverables for the final report

Priscilla Taylor-Percival - In recognition of outstanding support of the NASA Engineering and Safety Center's Pilot Breathing Assessment Team in flight data processing and data team coordination at NASA Armstrong Flight Research Center

Bonnadeene Trimble - In recognition of outstanding support of the NASA Engineering and Safety Center's Pilot Breathing Assessment Team in flight data product tracking and coordination at NASA Armstrong Flight Research Center

NESC GROUP ACHIEVEMENT AWARD:

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

Human Exploration and Operations, Orbital Flight Test Joint Independent Review Team and Artemis Verification Risk Reduction Support Team - In recognition of exceptional contribution to the Human Exploration and Operations Mission Directorate in risk reduction and systems engineering improvements to the Artemis 2024 schedule

Parker-Hannifin Corporation Ethylene Propylene Rubber E0515 O-Ring Material Obsolescence - In recognition of outstanding dedication and engineering excellence in the evaluation of replacement material for propulsion system O-Rings

Nuclear Electric Propulsion and Nuclear Thermal Propulsion Technology Maturity Assessment Team - In recognition of outstanding dedication and engineering excellence in the evaluation of Nuclear Electric Propulsion and Nuclear Thermal Propulsion systems and technologies

Transient Combustion Modeling for Hypergolic Engines Assessment Team - In recognition of a unique and insightful combination of modeling, testing and analysis to determine the sources of zots and pressure spikes in hypergolic engines

Commercial Crew Program Bellows Manufacturing Anomalies Investigation Assessment Team - In recognition of exemplary contributions to the Bellows Manufacturing Anomalies Investigation in support of the Commercial Crew Program Demonstration Mission-2 Launch

Large-Format Fractional Thermal Runaway Calorimeter Development Assessment Team - In recognition of outstanding contributions in the development of the Large-Format Fractional Thermal Runaway Calorimeter and its use to quantify thermal runaway energy for lithium-ion cells in excess of 100 ampere-hour capacity

Commercial Crew Program Launch Vehicle Ground Wind Loads Assessment Team - In recognition of outstanding technical achievement in the evaluation of the Ground Wind Loads and Wind Induced Oscillation for Commercial Crew Program launch vehicles

Publications | Based on NESC Activities

Technical Papers, Conference Proceedings, and Technical Presentations

Aerosciences

1. Schuster, D.: State of the NASA Aerosciences Discipline. AIAA Sci Tech 2020, January 6-10, 2020, Orlando, FL.
2. Schuster, D.: CFD Vision 2030 Integration Committee - Spaceflight Grand Challenge, AIAA SciTech 2020, January 6-10, 2020, Orlando, FL.
3. Mitchell, D.; Klyde, D; Pitoniak, S.; Schulze, P.; Manriquez, J.; Hoffler, K.; Jackson, E.: NASA Flying Qualities Research Contributions to MIL-STD-1797C, NASA/CR-2020-5002350.
4. Schuster, D.: CFD 2030 Grand Challenge: CFD-in-the-Loop Monte Carlo Flight Simulation for Space Vehicle Design. AIAA SciTech, Nashville, TN.

Avionics

1. Slenski, G.: COP Flight Connector and Wiring. Virtual 2020 NEPP Electronics Technology Workshop, June 15-17, 2020, Greenbelt, MD.

Cryogenics

1. Meyer, M.: In-Space Cryogenic Propellant Storage and Transfer Systems for Crewed Exploration: A Boiling (Prevention) Challenge. NASA SLPSRA Fluid Physics Workshop, October 16-17, 2019, Cleveland, OH.
2. Meyer, M.: The NASA Cryogenics Tech. Discipline Team and an Update of the Long-Life Space Cryocooler Flight Operating Experience Survey
3. Meyer, M.: Cryogenic Fluid Management Technology Maturity Assessment: Liquid Hydrogen Systems for NTP Liquid Methane/ Liquid Oxygen for In Space Chemical Propulsion Stage. Virtual Space Nuclear Propulsion Technologies Meeting 2.

Environmental Control & Life Support

1. Abney, M.; Schnedier, W.; Brown, B.; Stanley, C.; Lange, K.; Wetzel, J.; Morrow, R.; Gatens, R.: Comparison of Exploration Oxygen Recovery Technology Options Using ESM and LSMAC. International Conference on Environmental Systems, 2020.

Guidance, Navigation, & Control

1. Orr, J.; Wall, J.; Dennehy, C.: The Enduring Legacy of Saturn V Launch Vehicle Flight Dynamics and Control Design Principles and Practices. 70th International Astronautical Congress, October 21-25, 2019, Washington, DC.
2. Vertaska, I.; VanZwieten, T.; Mann, J.; Connell, B.; Radke, T.; Bernatovich, M.: Dynamic Characterization of the Crew Module Uprighting System for the NASA Orion Crew Module. OCEANS 2019 Seattle, October 27-31, 2019, Seattle, WA.
3. Ruth, M.: Use of Exponential Damping Functions as Basis-Coordinates for Analyzing Slosh-Decay Data. JANNAF 10th Spacecraft Propulsion (SPS) Subcommittees, December 9-13, 2019, Tampa, FL.
4. VanZwieten, T.: Overview of Nonlinear Propellant Slosh Damping Testing and Analysis. JANNAF 10th Spacecraft Propulsion (SPS) Subcommittees, December 9-13, 2019, Tampa, FL.
5. VanZwieten, T.: Nonlinear Damping Results for Bare and Baffled Tanks. JANNAF 10th Spacecraft Propulsion (SPS) Subcommittees, December 9-13, 2019, Tampa, FL.
6. Hall, R.; Bertaska, I.; Powers, J.: Space Launch System Implementation of Nonlinear Slosh Damping Models for Flight Control System Design. JANNAF 10th Spacecraft Propulsion (SPS) Subcommittees, December 9-13, 2019, Tampa, FL.
7. VanZwieten, T.; Brodnick, J.; Reese, S.; Ruth, M.; Marsell, B.; Parks, R.: Nonlinear Slosh Damping Testing and Analysis for Launch Vehicle Propellant Tanks. 2020 AIAA SciTech Forum, January 6-10, 2020, Orlando, FL
8. Dennehy, C.: Codename Corona: America's First Imaging Reconnaissance Satellite. 43rd Annual AAS Guidance, Navigation and Control Conference, January 30 - February 5, 2020, Breckenridge, CO.
9. Orr, J.: Modeling and Simulation of Rotary Sloshing in Launch Vehicles. 44th Annual AAS Guidance, Navigation and Control Conference, Breckenridge, CO.

Human Factors

1. Novak, B.: Human Systems Integration for Safety-Critical Range Operations at Wallops Flight Facility. NASA Human Factors Community Webcast, October 8, 2019, Hampton, VA.
2. Null, C.: Why Human Errors are a Good Thing, and the Unintended Consequences for Human Factors. BBCSS Fall 2019 Meeting, November 20, 2019, Washington, DC.
3. Holbrook, J.: Using Worker-Generated Data to Characterize Resilient Performance Strategies. Quality and Safety in Children's Health Conference, March 9-11, 2020, Kansas City, MO.
4. Holbrook, J.: A Data-Driven Approach to Recognizing and Understanding Human Contributions to Aviation Safety. 73rd Annual International Air Safety Summit, Virtual Global Event.

Loads & Dynamics

1. Matt Griebel, M.; Wilson, J.; Johnson, A.; Erickson, B.; Doan, A.; Flanigan, C.; Bremner, P.; Sills, J.; Bruno, E.: Orion E-STA Nonlinear Dynamic Correlation and Coupled Loads Analysis. 2019 Spacecraft and Launch Vehicle Dynamic Environments Workshop.
2. Doan, A.; Johnson, A.; Griebel, M.; Flanigan, C.; Bremner, P.; Sills, J.; Bruno, E.: End-to-End Assessment of Development Flight Instrumentation for Vibration Modes Identification on SLS Exploration Flight EM-1. 2019 Spacecraft and Launch Vehicle Dynamic Environments Workshop.
3. Kammer, D.; Blelloch, P., Sills, J.: SLS Uncertainty Quantification Based on Component Level Modal Tests. 2019 Spacecraft and Launch Vehicle Dynamic Environments Workshop.
4. Majed, A.; Henkel, E., Sills, J.: A Deformed Geometry Coupling Technique for Determining Preloads of a Stacked Fueled Launch Vehicle. 2019 Spacecraft and Launch Vehicle Dynamic Environments Workshop.
5. Allen, M.; Schoneman, J.; Scott, W.; Sills, J.: Leveraging Quasi-Static Modal Analysis for Nonlinear Transient Dynamics. 2019 Spacecraft and Launch Vehicle Dynamic Environments Workshop.
6. Allen, M.; Schoneman, J.; Scott, W.; Sills, J.: Application of Quasi-Static Modal Analysis to an Orion Multi-Purpose Crew Vehicle Test Article. IMAC 38, February 10-13, 2020, Houston, TX.
7. Doan, A.; Johnson, A.; Loogman, T.; Bremner, P.; Sills, J.; Bruno, E.: End-to-End Assessment of Artemis-1 Development Flight Instrumentation, IMAC 38, February 10-13, 2020, Houston, TX.
8. Johnson, A.; Griebel, M.; Erickson, B.; Doan, A.; Flanigan, C.; Wilson, J.; Bremner, P.; Sills, J.; Bruno, E.: Orion E-STA Nonlinear Dynamic Correlation and Coupled Loads Analysis, IMAC 38, February 10-13, 2020, Houston, TX.
9. Kammer, D.; Blelloch, P.; Sills, J.: Variational Coupled Loads Analysis using the Hybrid Parametric Variation Method. IMAC 38, February 10-13, 2020, Houston, TX.
10. McManamen, J.; Sills, J.: The Artemis Challenge: Another Revolution in Structural Dynamics. IMAC 38, February 10-13, 2020, Houston, TX.
11. Napolitano, K.: Feasibility Study to Extract Artemis-1 Fixed Base Modes While Mounted on a Dynamically Active Mobile Launch Platform. IMAC 38, February 10-13, 2020, Houston, TX.
12. Sills, J.; Majed, A.; Henkel, E.: A Deformed Geometry Synthesis Technique for Determining Stacking and Cryogenically Induced Preloads for the Space Launch System. IMAC 38, February 10-13, 2020, Houston, TX.
13. Akers, J.; Sills, J.: Space Launch System Mobile Launcher Modal Pretest Analysis. IMAC 38, February 10-13, 2020, Houston, TX.
14. Johnson, D.; Shaker, J.; Hunt, R.: International Space Station (ISS) Cargo Tool Loads Analysis - Independent Verification and Validation (IV&V). NASA/TM-2020-5001542/NESC-RP-18-01370, April 2020
15. Sills, J.: Multidisciplinary Dynamic Testing Challenges in Validating the NASA Artemis Architecture. 13th AICE Annual Congress, October 2020.
16. Sills, J.: Fusion of Test and Analysis: Artemis I Booster to Mobile Launcher Interface Validation. IMAC, Orlando, FL.

Materials

1. Glendening, A.; Russell, R.: New Technologies Additive Manufacturing: AM from Customer's Perspective. CQSDI Conference, March 9-10, 2020, Cape Canaveral, FL.
2. Russell, R.: NASA's Philosophy for the Qualification and Certification of Additively Manufactured Components, The Aircraft Airworthiness and Sustainment Conference, August 26, 2020.
3. Russell, R., Wells, D., West, B.; Glendening, A.: NASA's Plans for the Release of Standards for Additive Manufactured Components, JANNAF Additive Manufacturing for Propulsion Applications TIM, September 14-17, 2020.
4. Russell, R.; Wells, D.: NASA-STD-6030 Additive Manufacturing Requirements for Crewed Spaceflight Systems Foundational Principles, ASTM F42.07.02 Spaceflight Applications Subsection, September 2020.
5. Kobyashi, T.; Shockey, D.; Wells, D.: Identifying Microstructural Features that Control Fracture in Additive Materials. International Journal of Fracture, September 2020.

Mechanisms

1. Howard, S.; DellaCorte, C.; Dube, M.: Magnetic Levitation for Long-Life Space Mechanisms: Technology Assessment and Remaining Challenges. NASA/TM-2019-220052.
2. Dube, M.; Fisher, J.; Loewenthal, S.; Ward, P.: Recovery and Operational Best Practices for Reaction Wheel Bearings. 45th Aerospace Mechanisms Symposium, May 13-15, 2020, Houston, TX.

Passive Thermal

1. Walker, W.; Rickman, S.; Darcy, E.; Darst, J.; Calderon, D.; Brown, R.; Hagen, R.; Sauter, A.; Hughes, P.; Bayles, G.; Petrushenko, D.; Comick, S.: Status and Preliminary Results for the Large Format Fractional Thermal Runaway Calorimeter (L-FTRC), NASA Aerospace Battery Workshop, November 21, 2019, Huntsville, AL.
2. Rickman, S.: Small-format Fractional Thermal Runaway Calorimetry (S-FTRC), University of Texas, March 2020, El Paso, TX.
3. Rickman, S.: Introduction to Orbital Mechanics and Spacecraft Attitudes for Thermal Engineers. NESC Academy presentation, TFAWS, August 19, 2020, Hampton, VA.
4. Rickman, S.: Introduction to Orbital Mechanics and Spacecraft Attitudes for Thermal Engineers. Virtual Thermal and Fluids Analysis Workshop, August 2020.
5. Wehmeyer, G.: Passive Heat Switching Using Temperature-Dependent Magnetic Forces. NESC Academy Presentation.

Propulsion

1. Marcum, J.; Gabl, J.; Dorney, D.: Effects of Common Engine Variables on MMH/RFNA Combustion Stability. JANNAF Journal Manuscripts, Volume 12, Issue 1, November 2019.
2. Marcum, J.; Gabl, J.; Dorney, D.: Effects of Material Composition, Condensed Reaction Products, and Temperature on Combustion Stability of MMH/NTO Thrusters. JANNAF Journal Manuscripts, Volume 12, Issue 1, December 2019.
3. Harrigan, G..; Peralta, S.: Material Compatibility Assessments for Spacecraft Oxidizer Systems. JANNAF, September 11, 2020.
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5. Marcum, J.; Manheim, J.; Boulos, V.; Updike, B.; Kenttämaa, H.; and Pourpoint, T.: Investigation of the MMH/NTO Reaction Mechanism Using Mass Spectrometry and Laser Desorption/ Ionization. 42nd JANNAF PEDCS Meeting, Virtual Event, September 29, 2020.
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Papers and presentations as of October 2020

Acronyms

AA	Ascent Abort
ABSL	ABSL Power Solutions
ACCP	Aerosols and Cloud-Convection Precipitation
AD2	Advancement Degree of Difficulty
AFRC	Armstrong Flight Research Center
AFRL	Air Force Research Laboratory
AIAA	American Institute of Aeronautics and Astronautics
AIT	Autogenous Ignition Temperature
Al-Li	Aluminum-Lithium
AM	Additive Manufacturing
ANSI	American National Standards Institute
ARC	Ames Research Center
ARTEMIS	Acceleration, Reconnection, Turbulence and Electrodynamics of the Moon's Interaction with the Sun
ASME	American Society of Mechanical Engineers
ATK	Alliant Techsystems
BON	Badhwar-O'Neill
CAA	Crew Access Arm
CAD	Computer-Aided Design
CADRe	Cost Analysis Data Requirements
CARA	Conjunction Assessment & Risk Analysis
CCP	Commercial Crew Program
CDRA	Carbon Dioxide Removal Assembly
CFD	Computational Fluid Dynamics
CLA	Coupled Loads Analysis
CLPS	Commercial Lunar Payload Services
CM	Crew Module
COG	Ceramic Oxygen Generator
CoP	Community of Practice
COPV	Composite Overwrapped Pressure Vessel
COTS	Commerical off the Shelf
CS	Core Stage
CSFSU	Core Stage Forward Skirt Umbilical
CSITU	Core Stage Intertank Umbilical
CVN-78	USS Gerald R. Ford
D&C	Design and Construction
DARPA	Defense Advanced Research Projects Agency
DART	Double Asteroid Redirection Test
DARTS	Dynamics And Real-Time Simulation
DCR	Design Certification Review
DFI	Development Flight Instrumentation
DGS	Deformed Geometry Synthesis
DIC	Digital Image Correlation
DoD	Department of Defense
DTA	Debris Transport Analysis
EAC	Environmentally Assisted Cracking
EC	Eddy Current
ECLSS	Environmental Control & Life Support System
EDL	Entry, Descent, and Landing
EEE	Electrical, Electronic, and Electromechanical
EFT	Exploration Flight Test
EGS	Exploration Ground Systems
ELC	ExPRESS Logisitcs Carrier
EMU	Extravehicular Mobility Unit
EPC	Error-Producing-Conditions
ESA	European Space Agency
ESD	Exploration Systems Development
ESM	Entry Systems Modeling
EVA	Extravehicular Activity
ExMC	Exploration Medical Capability
ExPRESS	Expedite the Processing of Experiments to the Space Station
FEM	Finite Element Model
FPMU	Floating Potential Measurement Unit
FTS	Flight Termination System
GG	Gas Generator
GGFV	Gas Generator Fuel Valve
GGOV	Gas Generator Oxidizer Valve
GNC	Guidance, Navigation, & Control
GOES-R	Geostationary Operational Environmental Satellite-R
GRC	Glenn Research Center
GSFC	Goddard Space Flight Center
H2	Hydrogen Monohydride
HALO	Habitation and Logistics Outpost
HCFC	Hydrochlorofluorocarbon
HEA	Human Error Analysis
HDBK	Handbook
HM	Henkel-Mar
HP	High Purity
HPH	High Purity Hydrazine
IC	Initial Condition
ICON	Ionospheric Connection Explorer
ICPS	Interim Cryogenic Propulsion Stage
ICPSU	Interim Cryogenic Propulsion Stage Umbilical
IOP	Ignition Overpressure
IPA	Isopropyl Alcohol
ISRO	Indian Space Research Organisation
ISS	International Space Station
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
KSC	Kennedy Space Center
L2	Lagrange Point 2
LaRC	Langley Research Center
LC	Launch Complex
LDI	Laser Desorption/Ionization
LEFM	Linear Elastic Fracture Mechanics
LEO	Low Earth Orbit
LH2	Liquid Hydrogen
Li-ion	Lithium Ion
LISA	Laser Interferometer Space Antenna
LLIS	Lessons Learned Information System
LO2	Liquid Oxygen
LSP	Launch Services Program
LV	Launch Vehicle
MBSE	Model Based Systems Engineering
MCC	Main Combustion Chamber
M-COG	Medical Ceramic Oxygen Generator
MDP	Maximum Design Pressure
MFV	Main Fuel Valve
MIAMI	MBSE Infusion and Modernization Initiative
MIL	Military
MIMU	Miniature Inertial Measurement Unit
ML	Mobile Launcher
MLG	Main Landing Gear
MMH	Monomethylhydrazine
MMOD	Micrometeoroid and Orbital Debris
MON-3	Mixed Oxides of Nitrogen
MOV	Main Oxidizer Valve
MOWG	Mission Operations Working Group
MPa	Megapascals
MPCV	Multi-Purpose Crew Vehicle
MPVS	Multipurpose Pressure Vessel Scanner
MS	Mass Spectrometry
MS	Meteoroid Shield
MSFC	Marshall Space Flight Center
MTSO	Management and Technical Support Office
N2O	Nitrous Oxide
NAFTU	NASA Automated Flight Termination System
NASA	National Aeronautics and Space Administration
NASCAP	NASA/Air Force Spacecraft Charging Analyzer Program
NASTRAN	NASA Structural Analysis
NCE	NESC Chief Engineer
NDE	Nondestructive Evaluation
NDSB2	NASA Docking System Block 2
NEP	Nuclear Electric Propulsion
NESC	NASA Engineering and Safety Center
NIO	NESC Integration Office
NIST	National Institute for Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NOVICE	A software suite for space systems radiation effects
NRB	NESC Review Board
NPR	NASA Procedural Requirement
NSC	NASA Safety Center
NTO	Dinitrogen Tetroxide
NTP	Nuclear Thermal Propulsion
OCFO	Office of the Chief Financial Officer
OFT	Orbital Flight Test
ORDEM	Orbital Debris Engineering Model
OSAM-1	On-orbit Servicing, Assembly, and Manufacturing-1
OSMU	Orion Service Module Umbilical
OTBV	Oxidizer Turbine Bypass Valve
PAMELA	Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics
PBA	Pilot Breathing Assessment
PE	Principal Engineer
PE	Physiological Episodes
PF	Performance Fluid
POD	Probability of Detection
PRF	Performance
RefProp	Reference Fluid Thermodynamic and Transport Properties Database
RDBE	Ring Double Bond Equivalents
RFI	Request for Information
RP	Rocket Propellant
RPCM	Remote Power Control Modules
RPO	Rendezvous and Proximity Operations
S&MA	Safety and Mission Assurance
SBKF	Shell Buckling Knockdown Factor
SE	Systems Engineering
SE&I	Systems Engineering and Integration
SET	Systems Engineering Team
SLS	Space Launch System
SM	Service Module
SME	Subject Matter Expert
SOFIA	Stratospheric Observatory for Infrared Astronomy
SOW	Statement of Work
SRB	Solid Rocket Booster
ST-7	Space Technology 7
STD	Standard
STMD	Space Technology Mission Directorate
STS	Space Transportation System
SysML	Systems Modeling Language
TDT	Technical Discipline Team
TEA-TEB	Triethylaluminum-Triethylborane
TF	Technical Fellow
TFAWS	Thermal Fluids Analysis Workshop
THEMIS	Time History of Events and Macroscale Interactions during Substorms
Ti-NTO	Titanium Nitrogen Tetroxide
TM	Technical Memorandum
T0	Liftoff Time
TPS	Thermal Protection System
TR	Thermal Runaway
TRADES	TRAnsformative DESign
TRL	Technical Readiness Level
TSMU	Tail Service Mast Umbilical
μl	Microliter
μm	Micrometer
USAID	United States Agency for International Development
VAB	Vehicle Assembly Building
VITAL	Ventilator Intervention Technology Accessible Locally
VSP	Vehicle Support Posts
VSS	Vehicle Stabilizer System
WFF	Wallops Flight Facility
WIO	Wind-Induced Isolation
WSTF	White Sands Test Facility

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