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AEROSPACE
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2017
YEAR IN REVIEW

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AIAA
Shaping the Future of Aerospace

Andrew Lofthouse/CREATE-AV Quality Assurance

The angel in the details

On its surface, our annual Year-in-Review special issue adds up to a compendium of the nitty-gritty aerospace engineering and scientific work accomplished in 2017. We depict the often-unsung research that will make it possible for this community to continue achieving astounding operational breakthroughs, such as SpaceX reusing a rocket stage for the first time, as it did in March.

Consider for example the descriptions of novel aerodynamic measurement techniques on Page 17 or the efforts described on Page 10 to turn the uncertain wind responses of rotorcraft into a predictive tool. These and many other projects will empower engineers of the future to achieve extraordinary breakthroughs in the years ahead.

Illuminating that kind of work is one reason this issue is valuable, but I see another reason, too. These pages provide a glimpse into the aerospace technology culture for students or those who work on the fringes of the community or even outside of it. Members of this community value data, knowledge, problem-solving and professionalism. The best of them share data and insights as much as possible. They publish articles in AIAA's technical journals. They attend AIAA forums. They participate on technical committees. They volunteer to write articles for this special issue. They are passionate, but also fact-based. This is not to make a claim that all is perfect in this community, but these pages demonstrate that the trajectory is sound. Outliers are rare. In the years ahead, I'm confident we'll see even more workforce inclusiveness and diversity in the aerospace profession in the U.S. and abroad, and this will fuel even more advances.

It's refreshing to pause at the close of a tumultuous political year to remember what humans can accomplish when they operate in a culture that values respect and dedication to facts. Some of those involved in the research in these pages will no doubt shift out of engineering at some point in their careers, and they will take these values with them. Some will become business executives, entrepreneurs or leaders in government agencies. Some might even dare to enter politics. Of the 535 lawmakers in the U.S. Congress, just eight have engineering backgrounds, according to the Congressional Research Service, which analyzed Congressional Quarterly's "Member Profiles." It shows.

More than once as I read the articles for this special issue, I wondered, "How did they even think to try that?" Innate human creativity and originality partly explain things, but those attributes can flourish only when a culture lets them. What you see in these pages is an aerospace culture that's starting to fire on all cylinders. That should make us optimistic about 2018. ★

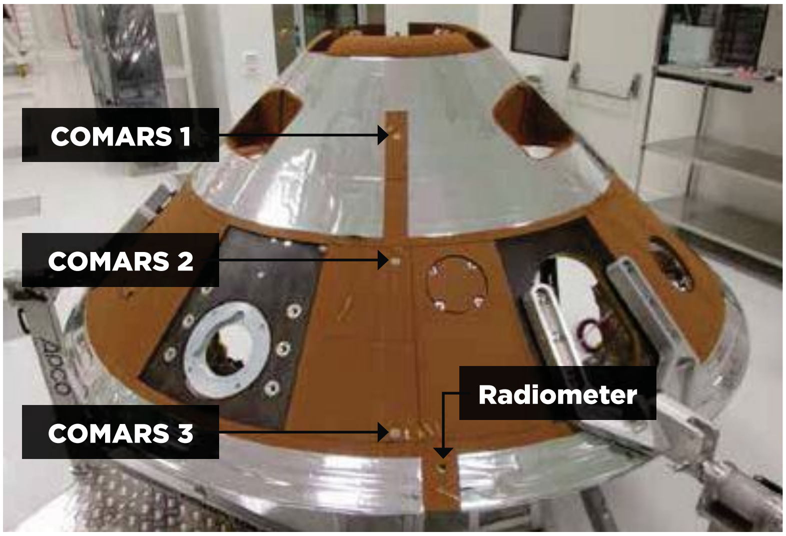
▲ **This CREATE-AV Kestrel simulation** predicts aerodynamic loading during difficult maneuvers. The colors in the wake of the aircraft are the vortical disturbances created due to aerodynamics and engine exhaust.

Ben Iannotta, editor-in-chief, beni@aiaa.org

Validating advanced thermophysics models

BY AARON BRANDIS AND ROSS CHAUDHRY

The **Thermophysics Technical Committee** promotes the study and application of mechanisms involved in thermal energy transfer and storage in gases, liquids and solids.



DLR

▲ **The Combined Aerothermal and Radiation Sensor package on COMARS+** was installed on the back cover of Europe's Schiaparelli spacecraft to measure the aerothermal and radiative loads at different backshell positions during the Mars descent.

In 2017, the thermophysics community obtained aerothermal flight data at Mars, improved the ability to use fundamental chemistry data in design tools, and investigated meteor entry in high-enthalpy experimental facilities.

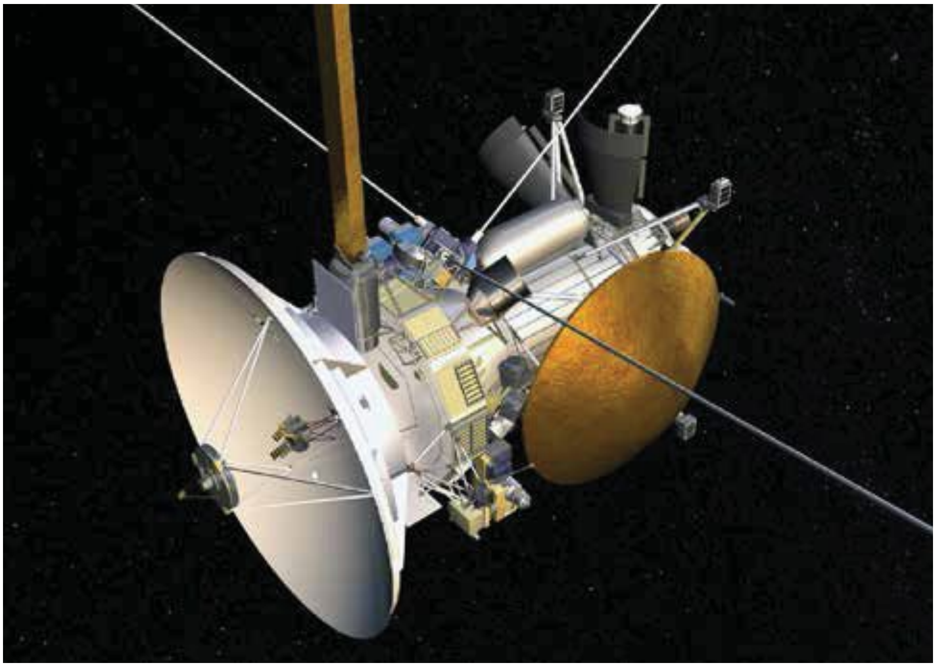
Researchers from the European Space Agency's **ExoMars mission** in June presented flight data from the Schiaparelli module's entry into the Martian atmosphere. The data obtained during Schiaparelli's descent will be invaluable for validating models used to design thermal protection systems for future Mars missions. Reliable flight data is essential for the optimization of heat shield design, which in general is carried out with relatively high safety margins. High margins compensate for the large uncertainties associated with simulation tools when used to predict aerothermal loads on a spacecraft. For example, consider the radiative heating that is created by hot carbon dioxide molecules in the flow around the back-shell. This heating mechanism has not been accounted for in most previous Mars mission designs. Therefore, DLR, the German Aerospace Center, developed the **Combined Aerothermal and Radiation Sensor package, called COMARS+**, to measure the aerothermal and radiative loads at different backshell positions on Schiaparelli. COMARS+ consisted of three combined aerothermal sensors, one broadband radiometer sensor and an electronic box. Because Schiaparelli crashed on the Mars surface, DLR could not retrieve the complete data package. However, communications between the Schiaparelli module and the orbiter during entry allowed data to be transmitted at 10 trajectory points. Ongoing post-flight analysis, including tests in the arc jet facility L2K at DLR Cologne, are providing unique data for future Martian missions.

Computational chemists at the University of Minnesota in July and October published potential energy surfaces, or PESs, for $O_2 + O_2$ and $O_2 + O$ interactions relevant to conditions representative of hypersonic speeds. PESs are high-quality fits of the atomic forces that exist during molecular collisions and are used to investigate the dynamics of a dissociating gas, which are often in thermal non-equilibrium. These investigations lead to an improved understanding of reaction rates implemented in computational fluid dynamic simulations. Researchers in aerospace departments at the University of Illinois at Urbana-Champaign and the University of Minnesota use PESs with two different methods to predict non-equilibrium internal energy distributions. In a collaboration presented at AIAA's 2017 Aviation/Thermophysics Conference, these two methods were demonstrated to be consistent for the case of nitrogen dissociation. PESs are now available for many important reactions relevant to Earth entry, and by correctly modeling non-equilibrium and its effect on chemical kinetics, this work is expected to lower uncertainty margins and enable novel vehicle design.

Thermophysics research groups this year leveraged high-enthalpy experimental facilities traditionally used for testing spacecraft thermal protection system materials to study the complex phenomena of a meteor entering Earth's atmosphere. **Researchers in Japan studied synthetic meteorites in an arc heated wind tunnel** in preparation for a planned artificial meteor shower at the 2020 Olympic Games. Groups in Europe, at the von Karman Institute and the University of Stuttgart, used plasma wind tunnel facilities, including the Plasmatron and PWK1 respectively, to study emission spectra from meteorite samples. At NASA's Ames Research Center in California, meteoroid ablation was studied in detail in the Interaction Heating Facility in July to aid in developing models for asteroid threat assessment. The data from all of these experiments are being used to advance state-of-the-art numerical modeling of meteor entries.

By obtaining aerothermal heating flight data at Mars, understanding how to efficiently use elaborate quantum chemistry data in production design tools, and investigating the physics of meteor entry in high-enthalpy ground tests, the ability to validate complex thermophysics models is greatly improved. ★

***Contributors:** Ali Guelhan and Eric Stern*



NASA

▲ **Cassini,** in an artist's rendering, ended its mission with an intentional dive into Saturn's atmosphere.

Voyagers hit 40 years operating, Cassini mission ends

BY BARBARA MCKISSOCK AND GREGORY CARR

The **Aerospace Power Systems Technical Committee** focuses on the analysis, design, test or application of electric power systems or elements of electric power systems for aerospace use.

This year marked the 40th anniversary of the Voyager spacecraft launches. Voyager 1 launched Sept. 5, 1977, and Voyager 2 launched Aug. 20, 1977. Voyager 2 was the first (and only) spacecraft to visit all four gas giant planets (Jupiter, Saturn, Uranus and Neptune). Voyager 1 visited Jupiter and Saturn prior to the Voyager 2 flybys. The Voyager mission was enabled by nuclear power, specifically radioisotope thermoelectric generators. The original requirement for each of the three Voyager multi-hundred-watt RTGs was to provide 128 watts of electricity four years after launch for the originally planned Jupiter and Saturn flybys. They have more than exceeded that four-year requirement, enabling Voyager 2 to be the first spacecraft to fly by Uranus and Neptune and Voyager 1 to be the first spacecraft to fully enter interstellar space.

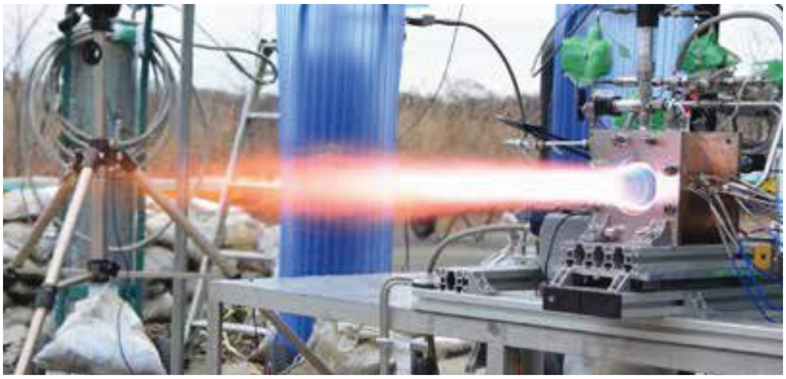
On Sept. 15, NASA's Cassini spacecraft entered the atmosphere of Saturn after having spent almost 20 years in space and 13 years orbiting the ringed planet. The electrical power provided by three general-purpose heat source RTGs made Cassini's mission possible.

The U.S. Department of Energy, on NASA's behalf, continued to progress on the production of new plutonium-238 for use in radioisotope power systems. Sufficient targets were irradiated this year to conduct the next chemical separation demonstration. This separation campaign will emulate a full-production batch size, predicted to lead to about 300 grams of heat-source plutonium oxide. In addition, the DOE has transitioned to a constant rate production strategy to produce 10-15 fueled clads each year. This will reduce plutonium-238 production and NASA mission risks with a steady production and ready supply of heat sources for RPS-enabled missions. This constant rate production approach has the added benefit of reducing the cost to missions using an RPS by approximately 25 percent over the prior mission-fueling surge campaign model.

In July, NASA completed an RPS system study that provided guidance toward future technology investments in modular deep-space thermoelectric generators scaled to notionally produce 50-470 W of power. Based on continued mission need, NASA also initiated four technology development contracts for dynamic energy conversion research.

Preliminary testing of the Kilopower (a small fission reactor power system for space missions needing 1-10 kilowatts electric) nuclear technology demonstration assembly using an electrically heated depleted reactor core simulator was conducted at NASA's Glenn Research Center in Ohio in January. The full Kilopower demonstration features a 4 kilowatt thermal uranium-molybdenum reactor core, sodium heat pipes for heat transfer and Stirling power convertors developed during the Advanced Stirling Radioisotope Generator program. A highly enriched uranium core was fabricated in July in three sections at the DOE's Y-12 National Security Complex in Oak Ridge, Tennessee, for shipping to the DOE Nevada National Security Site's National Criticality Experiment Research Center, where it will be integrated into the heat pipe. Power conversion assembly will be tested at Glenn. The demonstration is a partnership between NASA and the DOE National Nuclear Security Administration.

On Jan. 13, astronauts completed installation of lithium-ion batteries on two of the eight power channels on the International Space Station, replacing the old nickel-hydrogen battery technology on the S4 truss. The old batteries were sent to the ISS in early 2007 and were approaching the end of their design life. ★


Nagoya University

Advances made toward rotating detonation engines

BY STEPHEN HEISTER AND V. TANGIRALA

The **Pressure Gain Combustion Technical Committee** advances the investigation, development and application of pressure-gain technologies for improving propulsion and power generation systems and achieving new mission capabilities.

▲ **Japanese researchers** developed and tested a 900 N-class oxygen/ethelene rotating detonation engine.

With the promise of performance gains of 10-15 percent, researchers are advancing the technologies required to make unsteady detonation-based engines a reality for aerospace propulsion and stationary power-generation applications. The rotating detonation engine, or RDE — a device that exploits continuous detonative combustion in a thin annular channel — is the main focus of research, and several critical advances were made in 2017.

Russia's NPO Energomash and Lavrent'ev Institute of Hydrodynamics conducted a long-duration firing of a large-diameter oxygen/kerosene liquid rocket engine with RDE combustion. The U.S. Air Force Research Laboratory in April demonstrated thermally steady operation of an air-breathing RDE with a ceramic matrix composite outer body. In February, AFRL also tested an RDE integrated into a T63 gas turbine as the combustor; results show low nitrogen oxide production and good combustion efficiency, indicating promise for the technology.

The U.S. Department of Energy's National Energy Technology Laboratory continued leading the **implementation of RDE technology into stationary power-generation systems**. Aerojet Rocketdyne planned to conduct hot-fire testing of an air-breathing, natural gas-fueled RDE in November under a $6 million contract awarded in 2016. And efforts at Purdue University, the universities of Michigan, Alabama and Central Florida, and the Southwest Research Institute complemented the NETL program with advanced measurements and fundamental studies.

Detonation-based engine research expanded internationally. Japan has a large number of efforts in both RDE and pulse detonation engine technology. In August, a team from Nagoya and Keio universities, the Japan Aerospace Exploration Agency and Muroran Institute of Technology conducted **a 330-second specific-impulse, near-vacuum and 895-newton high-thrust experiment with an ethylene/oxygen RDE** with combustion efficiency exceeding 95 percent.

In China, several university groups are working to advance RDE technology. Peking University studied ignition delay time and re-initiation phenomenon. National University of Defense Technology conducted air-breathing RDE experiments and established operability limits. Nanjing Institute of Technology achieved detonative performance in a gasoline-oxygen RDE. Tsinghua University conducted experimental research on RDE combustion instability.

Russia's Semenov Institute of Chemical Physics and Institute of Theoretical and Applied Mechanics focused on a hydrogen-fueled scramjet of significant scale (1.05-meter long and 0.31 m in diameter) demonstrating specific impulse as high as 3,600 seconds in wind tunnel tests over a Mach 4-8 range. Both rotating detonation and longitudinal pulsation modes were observed.

In France, national research center CNRS and the University of Poitiers tested different inner cylinder sizes, while MBDA developed a full-scale RDE for ground tests. ONERA's numerical simulations focused on optimization of injector performance. Warsaw University of Technology studied gaseous methane-oxygen RDE combustors of 150 millimeters and 200 mm outer diameters. The first International Constant Volume and Detonation Combustion Workshop was held in June at ENSMA near Poitiers.

In the U.S., military researchers advanced both rocket and air-breathing RDE technology. The Naval Research Lab studied inlet/combustor interactions in a ramjet RDE operating at 42,000 feet and Mach 2.5. NRL also developed detonation models for fuel blends, quantifying the effect of blending hydrogen with methane through propane on induction times and detonation stability.

The Naval Postgraduate School explored the impact of engine inlet characteristics on the performance of an air-breathing RDE. The investigation involved hot-fire testing with detonation zone imaging, optical diagnostics and collaborative computational efforts with NRL. Purdue tested a high-pressure rocket RDE fed by gas from a liquid oxygen preburner using both natural gas and methane fuels. Operation was demonstrated at pressures exceeding 400 psi. ★