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AEROSPACE AMERICA

2016

YEAR IN REVIEW

AIAA
Shaping the Future of Aerospace

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Blue Origin

▲ **Blue Origin's New Shepard booster** executes a controlled vertical landing.

The year of living tenaciously

As a magazine editor, I've never been more eager to chronicle and explore the future than I am now.

One reason is the 2016 work described in this special issue, from development of clean aircraft technologies to efforts by Blue Origin and SpaceX to master rocket reusability.

Tenacity is the word that comes to mind when I review the articles in this issue. Last year, when we produced the year-end issue, Blue Origin had not yet reused its New Shepard rocket and SpaceX was 0 for 2 on attempts to land a Falcon 9 first stage. Now, Blue Origin has proved it can fly its New Shepard booster again and again, and SpaceX has landed a Falcon 9 first stage on land and at sea on a drone ship. 2017 promises even greater advances.

There's another reason for eagerness. Aerospace America stands ready to explore the big changes promised by the incoming administration of President-elect Donald Trump. We'll examine those changes as they relate to your work and the aerospace community. We'll do that in the same manner we always do: by putting aside assumptions and exploring issues in a no-nonsense, in-depth way, always with an eye toward technology and science.

We'll want to see how the new administration treats funding for the satellites and aircraft that gather climate data. We'll look at related issues, such as the potential for global regulation of greenhouse gas emissions by satellites, and whether an approach like that can succeed without the U.S.

We'll want to learn whether a Trump administration, and a Republican-controlled Congress, can clear the way for solutions to tracking airliners, and whether expenditures on clean aviation and supersonic transport will continue. The Trump campaign gave some clues in our "10 questions for the candidates" article in May. The campaign said the impact of aviation on climate change is "minimal" and that resources must always "advance and protect" U.S. interests. On supersonics, Trump said: "The free market will determine if supersonic air transport is feasible."

In the space realm, much of what NASA does right now centers on the vision of getting human explorers to Mars in the 2030s, and honing skills at an asteroid that would be dragged within reach of astronauts. That idea will have to compete for resources against a proposal favored on Capitol Hill to robotically explore Jupiter's moon Europa, which could harbor life of some kind under its ice.

We don't know whether a Trump administration will share the excitement for Mars and Europa. In the "10 Questions" article, the Trump campaign said human exploration depends on the country's "economic state."

We're ready to work tenaciously on these and many other topics. ★

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


SpaceX

▲ **In April, SpaceX for the first time landed** the first stage of the Falcon 9 on a drone ship.

Launch vehicles get commercial push

BY RYAN S. PARK

The **Astrodynamics Technical Committee** advances the science of trajectory determination, prediction and adjustment, and also spacecraft navigation and attitude determination.

This was an exciting year for astrodynamics, with an emphasis on commercial space industry that pushed the envelope on launch vehicle and space business capabilities.

Followed by a successful recovery of a reusable **Falcon 9** booster on a landing pad on solid ground in December 2015, SpaceX accomplished an even more challenging success. On April 8, the company launched the two-stage Falcon 9 and delivered a robotic Dragon cargo vehicle carrying crew supplies to the International Space Station for NASA. After separation, the first stage of the Falcon 9 landed back onto a SpaceX drone ship off the Florida coast, marking a huge step toward development of a reusable launch vehicle that may be a paradigm shift for the astrodynamics community.

In April, Rep. Jim Bridenstine, R-Oklahoma, introduced the **American Space Renaissance Act**, which is meant to synergize and reform space enterprises across the United States and ensure U.S. leadership and success across the national space enterprise. The bill motivates a shift of space situational awareness from being a government-led activity to a civil or commercial solution for that function as well as space traffic management.

In August, NASA approved the **Asteroid Redirect Mission**, ARM, to proceed to the next design phase with $1.4 billion in funding. ARM is a two-step mission that will send a robotic spacecraft to bring back a boulder from a near-Earth asteroid, will return it to cislunar orbit and then send astronauts to visit and study the captured object.

Beyond cislunar space, NASA's **Juno** spacecraft rendezvoused with Jupiter in July and set a record as the most distant solar-powered spacecraft ever flown. Juno will be in a 14-day polar orbit around Jupiter with its perijove inside Jupiter's radiation belt, which was carefully designed to be in view from Deep Space Network antenna in Goldstone, California, during perijove passages. Juno will continue to study the structure of Jupiter's interior and atmosphere over its 18-month primary science phase.

In June, NASA approved the plutonium-powered New Horizons spacecraft to fly by the Kuiper Belt Object known as **2014 MU69** in January 2019. This will be the first visit to a Kuiper Belt Object, and to achieve this the New Horizons spacecraft had to conduct a targeting maneuver farther from Earth than any other spacecraft. In late June, Dawn surpassed all of the objectives of its primary mission at dwarf planet Ceres, despite two failed reaction wheels and a very limited supply of hydrazine available for attitude control. The Dawn team received the prestigious 2015 Robert J. Collier Trophy in recognition of the overall success in exploring Vesta and Ceres and the innovative use of ion propulsion.

Europe's **Laser Interferometer Space Antenna** (LISA) **Pathfinder** spacecraft, formerly called Small Missions for Advanced Research in Technology-2, reached the Sun-Earth L1 Lagrange point in January and demonstrated the ability to detect gravitational waves. While several spacecraft have incorporated low-energy orbits in their mission designs, LISA Pathfinder is the first mission to demonstrate low-energy, low-disturbance formation flying between two test masses, technology that enables detection of gravitational waves in space. ★

Accelerating change on systems engineering tenets

BY ERIC E. NICHOLS

The **Systems Engineering Technical Committee** supports efforts to define, develop and disseminate modern systems engineering practices.

Virgin Galactic

▲ **Virgin Galactic's** second SpaceShipTwo, the VSS Unity, takes its first flight with its carrier plane Eve over Mojave, California, Sept. 8.

Access to space has been limited by the ticket cost to Earth orbit since the start of the space age. Events over the past year, however, represent what may be a permanent change to the existing cost structure. While deceptively subtle, 2016 saw accelerated changes that affect how we approach two bedrock tenets of systems engineering: requirements management and standards compliance.

System requirements management and design standards matured in tandem with the aerospace industry, often in response to tragic accidents. In the 1920s, airplane construction required little more than advanced carpentry skills. Until the 1930s, rocket technology had changed little since the Congreve rocket used at Fort McHenry in 1814. World War II forced radical change to both technologies.

Integration of ever more complex systems ushered in the nascent field of systems engineering. Reliance on individual experience and intuition was replaced by operational requirements and design standards. The transition helped save countless lives but also created impediments to creative problem-solving; the culture became conservative. Radical new designs became scarce as system specifications began to reflect safe point solutions. The prevalent philosophy became: violate design standards and risk millions of dollars, years of development and loss of life.

By the 1990s, restrictive standards became the target of government reform. As cost-reduction efforts continued to stagnate, NASA attempted several programs designed to promote innovation and revitalize a commercial space sector. The **Commercial Resupply Service** contracts began the current trend to limited, grand-vision requirements with minimal compliance constraints. The intent was to emulate Air Mail's impact on aviation's early development. These contracts provided the catalyst for SpaceX and Orbital ATK to develop launch vehicles for a commercial market.

The follow-on Commercial Crew Program continued the trend to focus on "what" and not "how." Similarly, the **Ansari "X Prize,"** modeled after early 20th century aviation prizes, promoted maximum creativity with minimal requirements. The simple requirements to launch a reusable crewed vehicle into space twice within two weeks became the inspiration for the space tourism market. Private ventures, including Blue Origin's New Shepard and Virgin Galactic's SpaceShipTwo, use these basic requirements for their suborbital spacecraft and proved there was money available for a purely commercial launch industry.

In 2016 the trend appears to have achieved critical mass with this year's revisions to the **Air Force Evolved Expendable Launch Vehicle**, or EELV, documents. The new directives support the what and not how approach to launch services. With the renewed freedom, launch vehicle designers are once again questioning the existing paradigms and testing cost-saving technologies. The most visible are the reusable systems flown during the year. Less visible are the reduced recurring costs from test and integration changes. The **EELV New Entrant Certification Guide** accommodates providers with innovative designs and higher developmental risk. The guide recognizes possible failure as an integral part of advancing technology. This represents a radical change in launch systems engineering.

Systems engineering developed in response to the need to incorporate complex systems into advanced aerospace designs. System specifications and standards provided the written record used to pass along knowledge and generate design confidence. As the aerospace industry matured, these documents began to drive solutions toward the safe and known and discourage the risky and innovative. The new projects inspiring today's engineers are demonstrating you can have both creative and safe. They are proving the right requirements and appropriate standards can encourage imaginative designs that reduce the ticket cost to Earth orbit.

The challenge for 2017 and beyond is to improve on the successes and work on getting the right mix of requirements and standards. ★

New and existing systems show progress

BY SCOTT CLAFLIN

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

Nagoya University

▲ **A rotating detonating engine developed in Japan** is being used to evaluate engine thrust and confirm stable operation under vehicle acceleration.

The state of the art in pressure gain combustion advanced significantly this year as numerous government, industry and academic institutions continued to develop new experimental engines and mature analytical models.

In the U.S., both the Defense Department and the Department of Energy are supporting PGC development. Under an Office of Naval Research grant, the Naval Postgraduate School in Monterey, California, explored the impact of engine inlet characteristics on the delivered performance of a **rotating detonation engine**, or RDE. The investigation involved hot-fire testing with detonation zone imaging, optical diagnostics and collaborative computation efforts with the Naval Research Laboratory, NRL, in Washington, D.C. The Naval Postgraduate School also supported a DARPA-funded team comprising HyPerComp Inc. of California, the University of Connecticut and Aerojet Rocketdyne of California in developing a **continuous detonation turbine engine**. The program measured turbine efficiency when driven by the unsteady flow of an RDE.

Under National Energy Technology Laboratory, or NETL, sponsorship, the University of Michigan, Penn State University and Purdue University have begun RDE development on the University Turbine Systems Research Initiative. In September, NETL awarded a three-year phase 2 program to **Aerojet Rocketdyne** to advance air and natural gas RDE technology.

NETL continued its own internal research that includes fundamental bench-scale experiments, lab-scale experiments and computational studies. The bench-scale rig is evaluating RDE fuel and air inlet geometries. The 6-inch lab-scale RDE with ducted exhaust has been tested with variable back pressure control permitting operation at elevated pressures. The rig is currently being modified to permit oxides of nitrogen emissions measurements.

The **Air Force Research Laboratory** is collaborating with NETL on the testing of an RDE combustor coupled to a T63 gas turbine engine. These tests are evaluating RDE-to-turbine interface conditions and potential impact on turbine performance as well as oxides of nitrogen emissions. At NRL, recent numerical simulations of an air/hydrogen RDE using detailed chemistry show that those emissions can be kept to an acceptable level by suitably choosing the equivalence ratio and engine geometry.

The NASA Glenn Research Center in Cleveland continued PGC investigations by demonstrating performance improvements through simulation of a resonant pulse combustor concept. Also, RDE modeling, validation and optimization capability expanded via collaboration with the Air Force Research Laboratory.

Academia made significant progress in PGC development this year. A team from the University of Washington demonstrated success in controlling the spin direction of an **RDE detonation wave** using a system that emits circumferentially phased sequential sparking. Purdue is working on an effort sponsored by the Air Force Office on Scientific Research that focuses on combustion characteristics in high-pressure rocket RDE devices. Three successful test series have been undertaken: two with gaseous hydrogen and one with natural gas fuels. A NASA and Purdue-sponsored effort in pulse detonation engines, PDEs, completed the final round of testing in which natural valveless detonative performance was achieved using high concentration hydrogen peroxide with hypergolic fuels in a nozzleless combustor.

Research on both RDE and PDE technology is robust outside of the U.S. A Japanese research group from Nagoya University, Keio University, JAXA and Muroran Institute of Technology conducted a successful sled test of an RDE, and the group has started development of an RDE-powered sounding rocket. In Russia, the Semenov Institute of Chemical Physics successfully operated an RDE with air and liquid propane by augmenting the detonation process with hydrogen. In Saudi Arabia, the King Abdullah University of Science and Technology has developed and characterized a novel, actively valved and acoustically resonant pulse combustor with pulsed fuel injection. The pulsed combustor is designed to produce meaningful pressure gain with low pollutant emission in a gas turbine engine. ★