January 2016

AEROSPACE AMERICA

EXCLUSIVE INTERVIEWS

CHALLENGER'S LEGACY

The loss of invincibility, the cultural shakeout and the lessons that shaped today's NASA

Page 18

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AEROSPACE AMERICA

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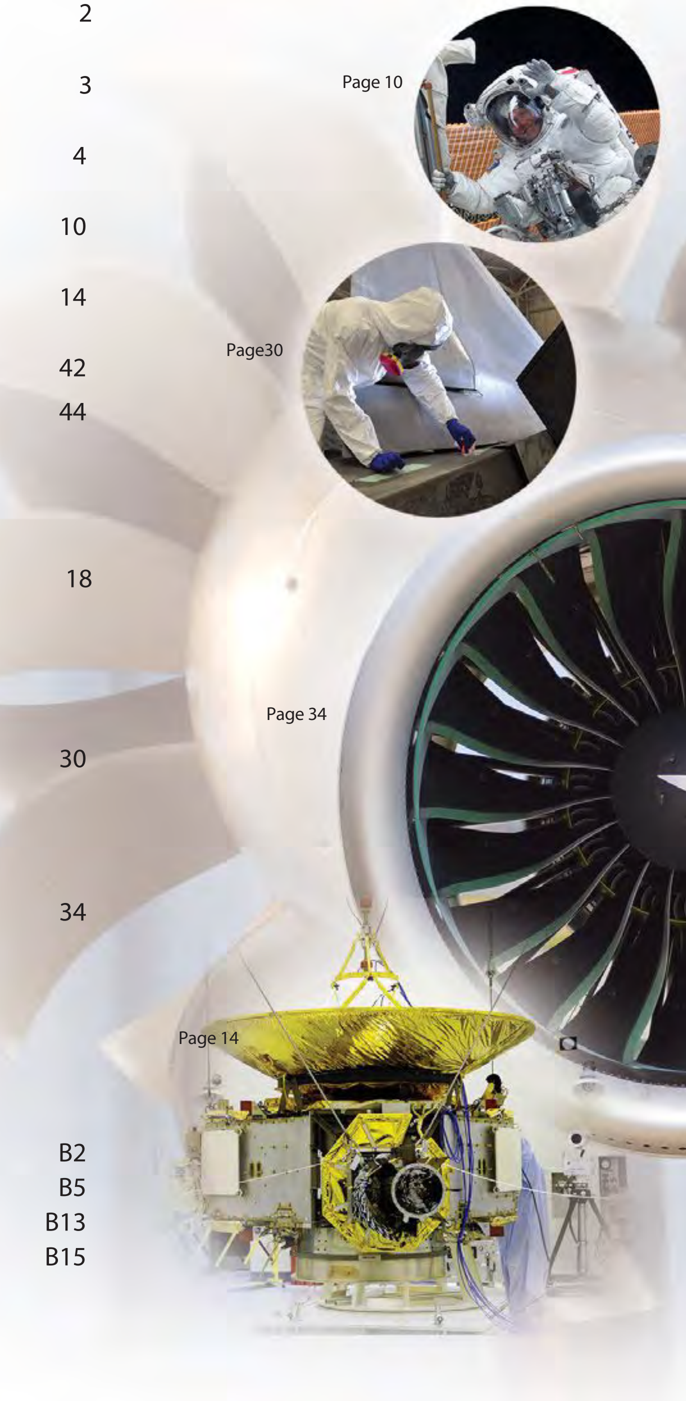
DEPARTMENTS



FEATURES

BULLETIN

ON THE COVER
Space shuttle Challenger launches from Kennedy Space Center on January 28, 1986.
Image credit: NASA

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The new year

We decided to jump into 2016 by publishing memories and insights from those with direct connections to the Jan. 28, 1986, Challenger tragedy. The loss of the Challenger crew still hurts even after 30 years, but our thinking was that many of the brightest minds in aerospace today were too young to remember the accident and the months of investigation that followed. We felt there was value in providing fresh, unfiltered words about that chapter in spaceflight history.

As photos of the interviewees rolled in, I realized that most of them, naturally, showed the subjects smiling. The pictures seemed to say: "Yes, it is possible to heal even after a terrible tragedy." That's something that would surely please the crew. I can't help but wonder what they would think about the hiatus in America's ability to launch humans into space and bring them home.

This month's edition also points to some potentially breakthrough moments in 2016.

We'll learn this year about the performance of Snecma's open rotor engine when it is run on a test rig in Southern France. The feature article, "The green engine debate," explores the tradeoffs between open rotor concepts like this one versus next-generation geared turbofans. Which of these will be the secret to a greener future? Is it even an either-or question? Researchers are beginning to explore the answers.

In our Briefs section, the article, "Next step eyed toward circular runways," suggests that a flight trial could be on the horizon if Europe decides to continue the research. The computer rendering accompanying the article made me think that maybe the idea isn't crazy after all.

Our Case Study with physicist Yanping Guo, who designed the New Horizons flight geometry, got me to thinking about whether NASA should fund an extended mission past another Kuiper Belt object. An extended mission sounds like a slam dunk, given the excitement over the Pluto flyby, but these are tight budget times. NASA must weigh what can be learned in the Kuiper Belt against early funds for the next unmanned missions, such as one that might tell us whether Jupiter's moon Europa nurtures primitive life under its icy surface.

The new year is setting up to be an eventful one, that's for sure.

Ben Iannotta
Editor-in-Chief

Sharing the skies

Some points need to be made about the article "Close Encounters of the Drone Kind" (November, page 18). The article has a couple of sentences about bird-strike testing: "We have a big Daisy BB gun, with a 4-inch diameter barrel. In place of your BB, you load up your anesthetized or recently deceased chicken."

Using a live bird, even an anesthetized one, in these tests is just plain senseless and cruel.

Also, the 138,257 bird strikes listed in the article are the fault of human beings. We have been seeing birds on radar since World War II. There is no technical reason why many flocks of birds could not be tracked on radar and incorporated into our air traffic control system. It is also possible that birds could be turned away from airports with infrared lasers that are not powerful enough to injure, but powerful enough to make the birds want to leave the area.

I think the aviation industry is in the best position to find ways to limit bird strikes in humane ways. This is the best way to protect both birds and aircraft.

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All letters addressed to the editor are considered to be submitted for possible publication, unless it is expressly stated otherwise. All letters are subject to editing for length and to author response. Letters should be sent to: Correspondence, Aerospace America, 12700 Sunrise Valley Drive, Suite 200, Reston, VA 20191-5807, or by email to: beni@aiaa.org.

Events Calendar

25 - 28 January 2016
Reliability and Maintainability Symposium (RAMS)
Tucson, Arizona

14 - 18 February 2016
26th AAS/AIAA Space Flight Mechanics Meeting
Napa, California

5 - 12 March 2016
2016 IEEE Aerospace Conference
Big Sky, Montana

8 - 10 March 2016
AIAA Defense and Security Forum (AIAA DEFENSE 2016)
AIAA National Forum on Weapon System Effectiveness
AIAA Strategic and Tactical Missile Systems Conference
Missile Sciences Conference
Laurel, Maryland

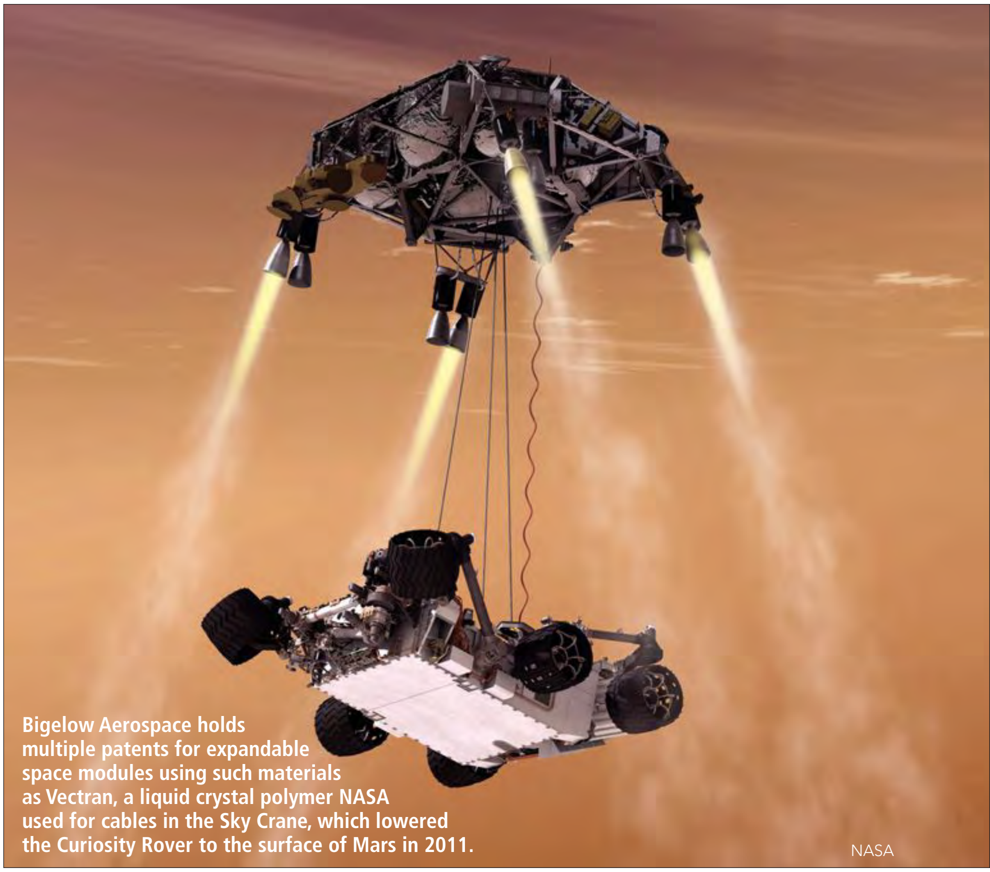
16 March 2016
Congressional Visits Day 2016
Washington, D.C.

Bigelow module poised to join space station

NASA is on the verge of testing a non-metallic space habitat for astronauts, the Bigelow Expandable Activity Module, or BEAM. The test could lead to widespread use of similar structures if the new module proves to be as good or better than metal spacecraft at protecting crews from micrometeoroids, orbital debris and radiation.

NASA plans to send BEAM to the International Space Station on the next flight of the SpaceX Dragon cargo capsule. The module will be stowed inside Dragon's unpressurized trunk, and in orbit it will expand to four meters long and nearly three meters wide.

Unlike the flimsy fabric structure where Mark Watney worked in the novel and film "The Martian," BEAM is composed of multiple layers of high-strength materials that form a hull nearly half a meter thick. Citing proprietary data and export control restrictions, Bigelow Aerospace declined to discuss the precise combination of materials used in the cylindrical module, but the company has obtained multiple patents for expanding space modules that use Kevlar, the synthetic fiber used in bulletproof vests; Vectran, a liquid crystal polymer that strengthened the cables NASA used to lower the Curiosity Rover to the Martian surface from the Sky Crane in 2011; Nomex, a flame-resistant polymer used in protective clothing worn by astronauts, fire fighters and race car drivers; and Nextel, a woven ceramic fabric designed to remain strong and flexible at temperatures up to 1,100 degrees Celsius.



Bigelow Aerospace holds multiple patents for expandable space modules using such materials as Vectran, a liquid crystal polymer NASA used for cables in the Sky Crane, which lowered the Curiosity Rover to the surface of Mars in 2011.

NASA

These materials offer strength without the weight of metal, but most did not yet exist when NASA began evaluating the potential merits of inflatable space stations in the 1960s and '70s.

"Materials have advanced to where they are more capable to withstand the space environment and able to handle the loads from inflation pressures," says Judith Watson, a senior structures research engineer at NASA's Langley Research Center in Virginia.

BEAM's outer skin is a shield for micrometeoroids and orbital debris covered with multiple layers of foam insulation to break up debris particles and slow them down so successive layers can prevent them from entering the crew compartment.

Bigelow has been preparing for humans to ride in its modules for more than a decade. In 2006, the company launched an unmanned prototype module called Genesis 1, followed by Genesis 2 in 2007, to test technologies for the commercial space stations the company ultimately plans to launch. Bigelow engineers conducted hypervelocity-impact tests before the Genesis missions to compare the company's micrometeoroid and orbital-debris protection with a space station debris shield loaned by NASA's Johnson Space Center.

"The tests proved our micrometeoroid and orbital debris layer is as good if not better than what exists on the ISS today," says Mike Gold, director of Washington, D.C., operations and business growth for Bigelow.

There is still a chance that debris can breech any spacecraft hull. If that happens BEAM is designed to leak air rather than burst. The module's interior gas bladder, which will hold pressurized air, is covered by a restraint layer reinforced with an aluminum alloy frame. BEAM's hatch also will seal it from the rest of the space station, ensuring that any air leak will be isolated to that node.

NASA and Bigelow officials declined to discuss BEAM's aluminum frame, but Robert Bigelow patented the design in 2001 for a soft tubular structure with aluminum elements to add strength, rigidity and anchor points for equipment, docking ports and hatches. Bigelow, a hotel and real estate entrepreneur, spent about $275 million of his personal fortune developing expandable space habitats before NASA awarded his company a $17.8 million contract for the BEAM test flight in 2013.

During BEAM's two-year mission, astronauts plan to open the hatch leading into BEAM once every three months to inspect it and gather data from sensors measuring structural loads, temperature, pressure, microbial growth and radiation. NASA plans to equip BEAM with two types of radiation sensors: The Radiation Area Monitors used throughout the space station to reveal the number and type of charged particles and relay that information to mission control and Radiation Environment Monitors. And small battery-powered dosimeters like those used in nuclear power plants to provide immediate readings on a person's radiation exposure.

Those measurements are likely to show that BEAM protects astronauts from radiation as well if not better than the space station's metal modules, because the average thickness of BEAM's hull is about .46 meter, says Ronald Turner, a radiation expert at Anser, a nonprofit research institute in Virginia. BEAM's exterior fabric is unlikely to scatter charged particles inside a spacecraft the way metal structures do, he adds.

If BEAM performs well during its trial run, NASA and commercial companies envision a bright future for expandable modules. Bigelow is eager to develop commercial space stations and NASA is exploring the use of such modules in cislunar orbits between the Earth and moon, or as habitats on the moon or Mars.

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Printing B-52 parts on demand

The 1950s-era impellers for B-52s were made of thin sheet metal folded like origami.

Some of the U.S. Air Force's decades-old B-52s are now flying with additively manufactured impeller fans produced by Elevate Systems of San Antonio as a solution to at least one of the aging fleet's sustainment woes. The new impeller fans are made of a flame-retardant thermoplastic called Ultem 9085, and they were designed and manufactured according to instructions from the Air Force Sustainment Center, which manages parts and logistics for Air Force Material Command.

"We now are logistically supportable as a print-on-demand item," says the Air Force's Edward Ayer, technical director for engineering and technical management at the center, by email. "The manufacturer can print additional impellers in a day, versus lengthy lead times for casting, forging or older manufacturing techniques."

The fans draw in cooling air from outside the aircraft and have been added as replacement parts in the cooling systems for the avionics in some B-52s.

The Air Force turned to additive manufacturing because it had limited data on the 1950s-era design of the original metal fans, and it could no longer repair them. The solution to this particular B-52 maintenance problem came together relatively quickly. In April 2013, the sustainment center began redesigning the B-52's Avionics Cooling Fan Assemblies. About 12 months of design iterations and qualification testing were required.

New impellers for the B-52 avionics assembly are made of a thermoplastic resin called Ultem 9085.

The Air Force tapped Elevate Systems to produce the impeller fans via additive manufacturing. The company used a technique called fused deposition modeling to deposit layers of Ultem 9085. Other parts of the assembly – the stator, rotor and housing of the motor – were not considered for additive manufacturing because of technical risks.

Not all aircraft parts, of course, are suitable for additive manufacturing with plastic.

"Metals manufacturing is the next major technology on the horizon," Ayer says.

But the new impellers are a big improvement. The original impellers were constructed of folded thin sheet metal, "sheet-metal origami," Ayer says. The impeller had 37 airfoils with attach flanges and four components with attach points, whose edges folded to capture airfoil flanges.

"This was manpower intensive and no longer supportable," Ayer says.

Elevate got the airfoil count down to 30, which made it start up easier in its housing.

Ayer says the new design was easily executed in one solid piece, instead of more than 40 in the old impeller. He predicts that new additive projects will be defined over the coming years to expand understanding of design, qualification and certification.

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Next step eyed toward circular runways

Landing an aircraft or taking off on a circular runway sounds like a bizarre idea, but the concept has European advocates who hope to conduct flight trials now that a European Commission-funded study has produced data suggesting that the idea has merit.

The next stage of research, should funds become available, would be to begin operational trials on the concept, says Henk Hesselink of the Netherlands Aerospace Centre and one of the leaders of the initial study that concluded in early 2015.

"Such a trial would not require a full circle, but maybe one part of the circle. We think it would be entirely possible to carry out performance tests maybe using drones, which will help in getting acceptance for the concept, using an automobile test track," Hesselink says.

Circular runways offer a number of advantages over straight runways, according to the European Commission's "Endless Runway" report released in March. An airport with a circular runway with a radius of 1.5 to 2.5 kilometers could handle more flights, with reduced taxi times in a much smaller area than a conventional four-runway airport, according to the report.

The research team began looking at the concept in 2012 as part of a "level zero" project, the commission's term for research into radically new concepts of operations once continuing improvements to conventional systems have reached their optimum level.

The circular runway concept is certainly radical. The idea of aircraft landing and taking off while they turn a bend might be counter intuitive to many in the aviation industry but there are precedents, Hesselink says.

"In the 1960s there were some real trials with the concept. Pilots reported that at first it was a bit scary but they did eventually get used to it."

The capacity of a circular-runway airport would be at least similar to, or more likely higher than, that of a conventional airport with three or four runways. Compared to Charles de Gaulle Airport in Paris, researchers found that a circular-runway airport would have a capacity of 110 to 146 movements an hour against 115 movements an hour. Taxi times would be reduced by between 40 percent and 90 percent, depending on where the plane lands or take offs on the circle relative to the location of the terminal inside the circle. Also, by reducing the time spent flying along fixed flight paths in the terminal maneuvering area, airlines would be able to reduce the time in the air by 1 percent to 2 percent on an average 700-nautical-mile short-haul flight. An airport with a circular runway would also be comparatively small; one with a circular runway with a radius of 1.5 kilometers would take 36 percent of the space needed for Charles de Gaulle Airport.

There would be no problems with the issue of crosswinds reducing capacity, either. The runway can be used in any wind direction — it would be able to operate to its maximum capacity level no matter the direction or the speed of the wind.

It is not all good news. Although a circular-runway airport would have a smaller land footprint than a conventional runway, it would be more expensive to build because of the amount of concrete needed.

"The cost benefit analysis shows that costs for constructing an airport with an endless runway is typically 110 percent to 160 percent of that for a conventional airport," the report says. "Extensions to the airport will be difficult. Contrary to today's airports, the Endless Runway cannot be extended to the outside. Also, contrary to today's airports, the runway radius is fixed and therefore the runway cannot be stretched out and the room available for the infrastructure within the runway boundary remains limited."

One of the areas of greatest interest from the aviation community in the project has been in the work undertaken to use curved approaches and departures into and out of the airport, relying on satellites to navigate the aircraft to the exact take-off and landing spot on the runway which would vary given the speed and direction of the wind.

The researchers concluded: "The project did not find any show stoppers and demonstrated feasibility of the concept, including the use of the airport for current-day aircraft."

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Circular runways, as in this artist's rendering, would take up less land and offer shorter taxi times than conventional runways. But pilots might take awhile to feel comfortable landing and taking off while turning on a bend.

Solar flight attempt set to resume

Solar Impulse 2 landed in Hawaii in July after flying for 118 hours over the Pacific Ocean from Japan on solar power. It was the eighth leg of a circumnavigation attempt.

Solar Impulse 2, the all-electric plane with a wingspan of a Boeing 747 but the weight of an SUV, is scheduled to restart its step-by-step circumnavigation of the globe in April.

The circumnavigation was paused in July after the craft's batteries overheated during the 4,471-mile trip from Nagoya, Japan, to Hawaii, the eighth leg of the mission. Pilot and co-founder André Borschberg was able to land safely.

After flying a prototype in the U.S., the project's Swiss founders had begun the journey with Solar Impulse 2 in Abu Dhabi, United Arab Emirates, in March, taking turns piloting the plane on each leg of the trip. Their overarching goal is to demonstrate the "importance of clean technologies for sustainable development," according to their website.

The overheating problem has now been solved with back-to-basics engineering. To cool the batteries, technicians cut a vent in each of the four wing gondolas, or nacelles, housing the plane's electric motors and batteries.

"We made a mistake with our batteries," said the project's initiator and self-described aeronaut, Bertrand Piccard, during a media briefing. "A human mistake."

The mistake was not accounting for the stress on the batteries as the plane's four motors and propellers climbed to 27,000 feet during the day to harvest maximum sunlight. Solar Impulse has 17,248 micro crystalline cells that form a 135-micron-thick skin over much of the airplane. The cells feed four lithium-ion batteries that allow the plane to stay aloft overnight at 5,000 feet.

The mistake also involved too much insulation in the nacelles housing the electric motors, each of which generates about as much power as a riding lawnmower.

While repairs and alterations were made in Hawaii, the Swiss partners traveled to conferences to tout the virtues of energy efficiency and to raise money for the project. Solar Impulse 2 burns no fuel, but the project has burned through $170 million. The Guardian newspaper reported in December that $20 million more has been raised.

The partners' pitch has been cost vs. investment.

"In cost, you lose your money," Borschberg said at the climate change conference held in Paris in November, according to a broadcast. "In investment, you make money." He suggested that the return-on-investment would come through future energy efficiency.

The Solar Impulse 2 team says its

electric motors are 97 percent efficient. Perhaps just as importantly, the team says the batteries are showing that lightweight materials can serve multiple functions in a design.

The cockpit, for example, was constructed from a multi-tasking polyurethane.

"It provided the insulation, but also shaped the cockpit while providing the aerodynamic quality of the aircraft and taking part of the structure loads. It's like one stone, three birds," Borschberg told an audience at the Polyurethanes Technical Conference in Orlando, Florida, in October, according to a recording.

Demonstrating the potential of clean energy is the project's overarching aim, but an aviation record was also on the team's mind during Borschberg's flight from Japan last year. Piccard tweeted: "My solar brother @andreborschberg just broke the record for the longest ever solo flight!"

He was referring to the record held by the late Steve Fossett, who flew the jet-powered Virgin Atlantic GlobalFlyer nonstop around the world in 76 hours and 45 minutes in 2005. Solar Impulse 2 took 117 hours and 52 minutes to fly just a fraction of the way around the world, because it beetles along at 63 mph during the day and 43 mph at night, compared to Fossett's average speed of 342.2 mph.

That said, "Breaking records is not the aim of Solar Impulse," according to Piccard. Instead, it's about efficient electric motors and the use of lightweight, strong, versatile materials to build the airplane.

Ahead lies a leg from Hawaii to the U.S. mainland. That will be undertaken when the team judges that springtime days are long enough to offer sufficient sunlight. That will be followed by segments back to Abu Dhabi, where the mission began. Energy evangelism aside, Borschberg predicts there will be tangible impact on aviation technology.

"I think this airplane has great potential for the future of aviation," he wrote on the Solar Impulse blog. "When you look back five years from now, I think you'll find it's the start of a new paradigm" of solar-powered aviation.

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Flying after Challenger

Former astronaut Tom Jones spent a total of 53 days orbiting Earth in the years after the Challenger tragedy. He explains why he accepted the risk of spaceflight and why he believes there will always be volunteers ready for the next journey into space.

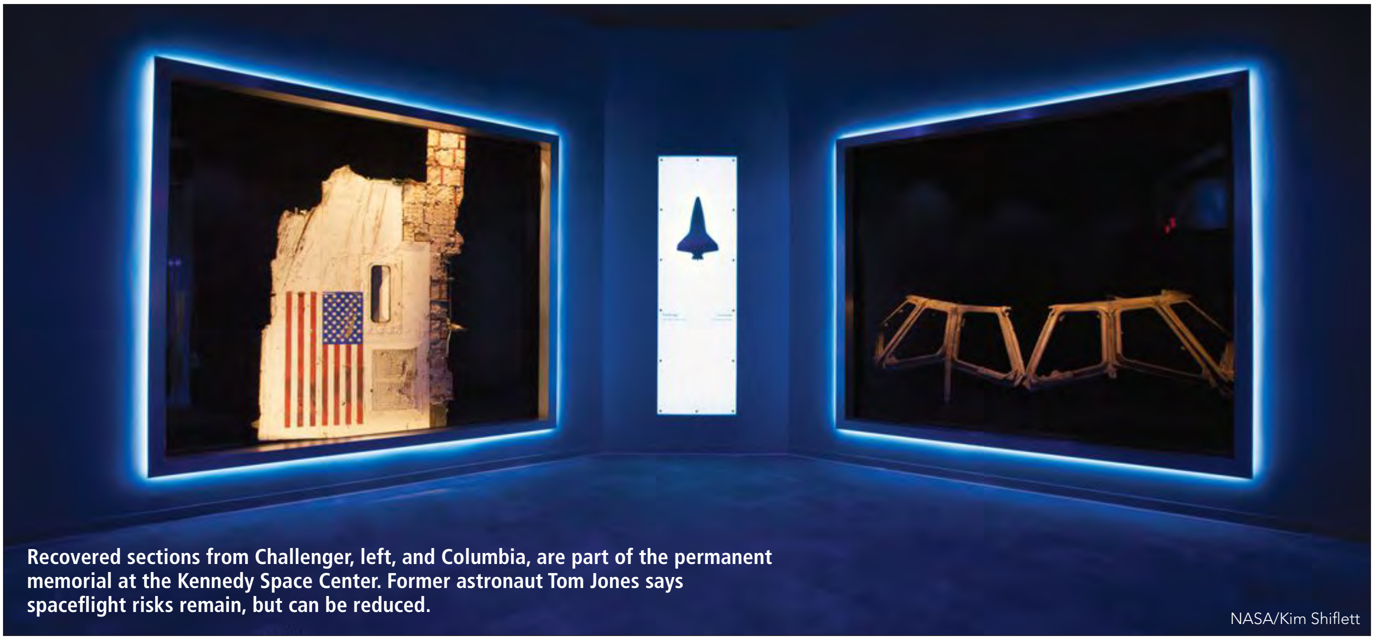
Dick Scobee was the first space shuttle astronaut I ever met. The veteran pilot of 1984's STS-41C Challenger mission had been assigned soon after to command the STS-51L Challenger mission. One evening in 1985, when I was a Ph.D. student at the University of Arizona, I found myself shaking hands with Scobee, saying, "I'd sure like to have a job like yours." Not the most original conversational opening when meeting a real astronaut, but standing in front of the man, I admit I was dazzled.

Scobee, who'd earned his bachelor's degree in aerospace engineering at Arizona, had come back to campus to speak. Both Scobee and his wife, June [interview, page 24] were gracious and at ease as they answered questions about an astronaut's professional and family life. The pair were stellar ambassadors for NASA.

Less than a year later, I watched with millions of others as Dick Scobee and his crew perished on live television. Viewing the launch broadcast with me at the university's planetarium were several dozen school children, all eager to see teacher Christa McAuliffe soar into orbit. When Challenger came apart amid a fireball of blazing propellants, all of us were silent for long seconds, unable to comprehend the scene. A few students yelped an uncertain cheer when one of the errant solid rocket boosters kicked out a recovery parachute, but I knew the crew was gone. All I could think of was the Scobee family.

Two years later, I was finishing up my doctorate and submitting my own application to NASA's astronaut program. What was I thinking? I had a wife and a baby daughter, and I'd seen what risk in human spaceflight meant to a family's future. What I told Liz was that if Dick Scobee, a professional test pilot who knew the dangers inherent in aviation and spaceflight, could commit his life to work for America in space, that job must be mighty important. I wanted to sign up, too.

So part of my motivation was national service, but I had more per-



Recovered sections from Challenger, left, and Columbia, are part of the permanent memorial at the Kennedy Space Center. Former astronaut Tom Jones says spaceflight risks remain, but can be reduced.

NASA/Kim Shiflett

Tom Jones waves at crewmates inside shuttle Atlantis while working on the International Space Station in 2001.

sonal reasons as well. First, I had wanted that astronaut job for 25 years, and one accident wasn't going to deter me. Second, I wanted to experience spaceflight, personally and physically. What was it *really* like?

I rationalized the risks this way: While piloting B-52s in the Air Force, I'd seen aircraft accidents and lost friends. After Challenger, NASA would fix the shuttle and improve its safety.

Does it sound crazy? Perhaps Liz thought so, but she knew the odds of NASA selecting me were slim to none. She could worry about risk when and if my dream became reality.

After a third application, I was hired by NASA in 1990, just four years after Challenger. Because of the agency's rigorous program of design and safety improvements implemented after the accident, I could reassure my family about the reduced dangers of spaceflight. Yet risks remained. In 2003, a fatal accident once again shocked NASA. And once again, it was caused by hardware failures, faulty communications and the agency's flawed decision-making. The searing lessons from Columbia's disintegration over Texas were all too familiar to those who had analyzed Challenger's avoidable demise.

Today, as NASA begins testing a pair of space taxis, operates an aging International Space Station and makes plans for its first deep space journeys since Apollo, spaceflight risk is still with us. An astronaut nearly drowned inside a flooded space helmet in 2013, and two Soyuz crews survived harrowing reentries after pyrotechnic failures in their descent modules in 2007 and 2008. Space operations remain markedly intolerant of human complacency and hubris.

In deep space, we will confront risk levels not seen since Apollo. NASA's management and its rank and file must not only remember how the agency lost two shuttle crews, but also develop effective methods for dealing with daunting new challenges: radiation, physical debilitation in free fall and prolonged isolation on journeys to the moon, asteroids and Mars.

In an October report, "NASA's Efforts to Manage Health and Human Performance Risks for Space Exploration," the agency's inspector general warned of the difficulties ahead:

" … the Agency's risk mitigation schedule is optimistic, and NASA will not develop countermeasures for many deep space risks until the 2030s, at the earliest … Accordingly, the astronauts chosen to make at least the initial forays into deep space may have to accept a higher level of risk than those who fly International Space Station missions."

Astronauts Memorial Foundation

The Space Mirror Memorial at the Kennedy Space Center in Florida honors 24 astronauts who died, including the 14 men and women aboard space shuttles Challenger and Columbia.

I believe that to reduce these risks, we'll need to mine the moon and asteroids for water and "dirt" for radiation shielding. We will need nuclear energy in space for power and propulsion. We'll also need to test these technologies on the space station, the moon and the nearby asteroids before reaching for Mars.

NASA will always have astronauts who volunteer to face the risks of deep space travel if national and space agency leaders explain clearly why exploring the space frontier remains an important U.S. priority. After Challenger and again after Columbia's loss, two presidents eloquently communicated why America must continue to explore the space frontier. On inauguration day in 2017, the next president should renew our commitment to exploration and pledge the nation's talent, resources, and conscience to protect those who risk all to achieve ambitious goals in space.

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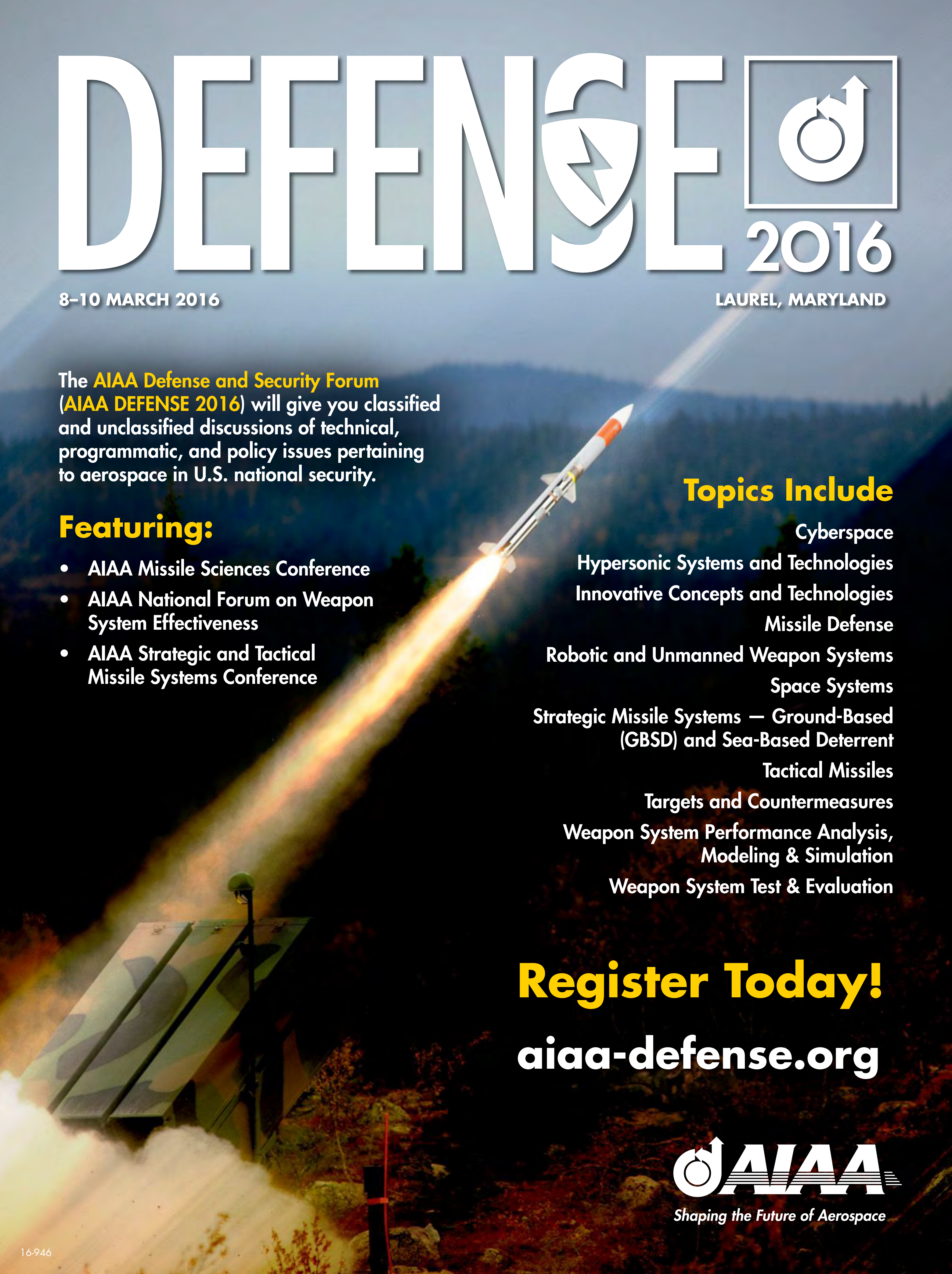
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Orchestrating a cosmic dance

When the New Horizons probe flew by Pluto and its moon, Charon, last year, mission design leader Yanping Guo didn't have long to marvel at the achievement by her and colleagues at the Johns Hopkins University Applied Physics Laboratory. She got back to work planning a possible extended mission past a Kuiper Belt object in 2019. Aerospace America asked Guo to explain how her team managed to precisely direct a grand-piano-sized spacecraft past a dwarf planet 4.8 billion kilometers away.

A haze of hydrocarbon extends 130 kilometers above Pluto's surface in this image showing its atmosphere backlit by the sun during the New Horizons flyby.

NASA/Johns Hopkins University Applied Physics Laboratory/Southwest Research Institute

When we began designing the New Horizons mission 15 years ago, scientists told us that we needed to fly by Pluto as early as possible before 2020. That's when Pluto, now known as a dwarf planet, would enter the part of its 240-year elliptical orbit that takes it farther from the sun. The atmosphere would cool and probably collapse, and it would be up to scientists two centuries from now to determine the composition of Pluto's atmosphere and whether its moon Charon has an atmosphere (scientists didn't know at that time that four additional moons would be discovered between 2005 and 2012). The atmospheric studies were among the key science objectives for the mission, along with studying the geology and surface composition of Pluto and Charon.

The New Horizons trajectory needed to be planned so that after passing Pluto, the sun would light up Pluto from behind as the spacecraft looked back with its ultraviolet spectrometer, called Alice. Pluto's surface would be shaded by this solar occultation, but sunlight passing through the atmosphere would reach Alice, which would measure the spectral absorption to determine the atmosphere's chemical constituents. Scientists planned to do the same when Charon passed in front of the sun in occultation to see if it has an atmosphere. Pluto also needed to be in front of Earth, so that scientists could focus on its lower neutral atmosphere and ionosphere. Radio waves transmitted through Pluto's atmosphere via the NASA Deep Space Network antennas in California and Australia would be collected by the spacecraft's Radio Science Experiment, called REX, which consists of circuitry in the New Horizons communications system. The same would be done when Charon was in front of Earth.

After we achieved that in July, I kept working on the post-Pluto trajectory, changing the trajectory toward 2014 MU69, a Kuiper Belt Object, for a close flyby estimated for January 1, 2019. We needed to make the necessary trajectory adjustment last year, even though NASA has not approved the extended mission operations yet, because doing them later would require expending more fuel. The initial KBO targeting maneuver required a delta-V of 57 meters per second and was divided into four shorter burns. On November 4 New Horizons completed the last of the four series of maneuvers that nudged it onto a path toward this ancient KBO.

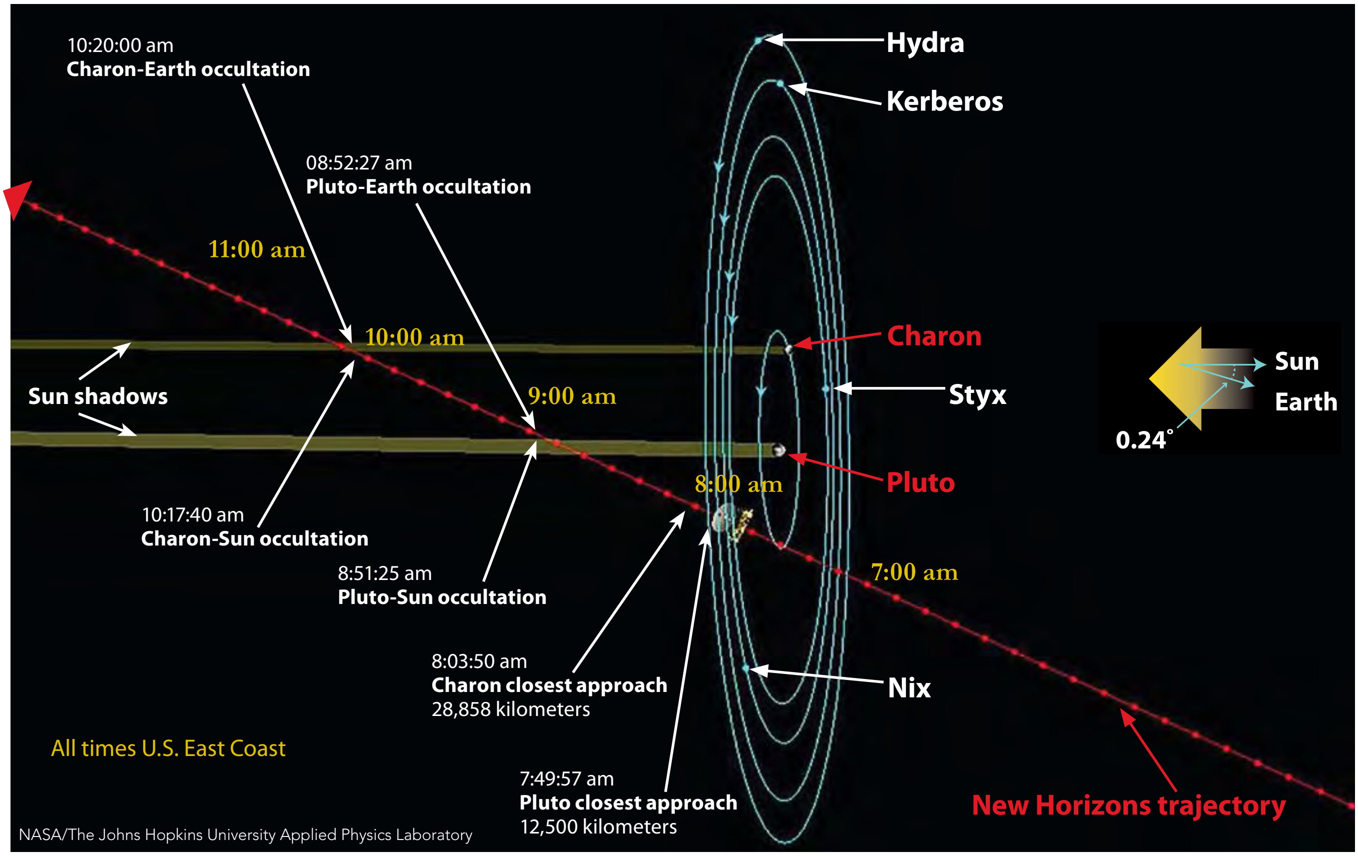
Producing the geometry for the Pluto flyby was complicated and challenging. We had to fly quickly to collect the science data before 2020, and we had to fly precisely to set up the necessary occultations. The movements of four bodies — Earth, Sun, Pluto and Charon — would have to be calculated relative to New Horizons. Because the mission was a flyby, we had only one chance to get it right.

I began the New Horizons mission design in 2000, calculating the mission trajectory based on the predicted coordinates of the celestial bodies that are stored in the Solar System Dynamics database maintained by NASA's Jet Propulsion Lab. Due to funding constraint, the original 2004 launch was later changed to 2006. We used a Jupiter gravity-assist flyby trajectory to shorten the flight time to get to Pluto in 2015. The Jupiter flyby would give New Horizons a crucial gravity assist and accelerate it by nearly 4 kilometers per second. We needed this assist, even though New Horizons was launched on the most powerful version of the Atlas rocket, the Atlas 5 551, and it got a kick 40 minutes after liftoff from a Boeing Star 48B solid rocket motor. It was the fastest spacecraft ever launched, speeding from Earth at approximately 36,000 mph.

The first order of business was to figure a basic geometry that would support the scientific observations. To achieve the Earth and solar occultations, we needed to have the Earth and sun pretty much in the same direction from Pluto during the flyby. That only happens twice a year from the vantage point of Pluto, once in January and once in July. The January occurrence is not a good geometry because Earth is behind the sun relative to Pluto, and you would have to send signals past the sun to reach the spacecraft, which

Feat of calculation

New Horizons' course, July 14, 2015



Six flyby events: The New Horizons path by Pluto and its moons had to be timed so that Pluto would cross in front of Earth from the vantage point of the spacecraft. New Horizons also needed a clear view of Pluto and its largest moon, Charon, and it had to pass through the sun shadows cast by these bodies. These occultations would reveal details that could not be detected any other way. During the Pluto-Earth occultation, for instance, radiowaves from NASA's Deep Space Network grazed Pluto's surface and were received by the spacecraft to measure any subtle bending caused by the dwarf planet's atmosphere.

The Pluto-bound New Horizons at Kennedy Space Center. The spacecraft flew by Pluto in 2015, but calculations for the mission trajectory began 15 years earlier.

would result in a lot of communications noise. We picked the July arrival, which offered the opposite geometry: The sun is behind Earth, so it would not block signals from Earth during the flyby. Once we settled on the July arrival, we had to pick the right Pluto flyby path to have the Earth and solar occultations by Pluto at the desired flyby distance for imaging. The specific Pluto arrival date in July was chosen to get Charon solar and Earth occultations that occur about 90 minutes after the Pluto occultations. The specific Pluto flyby time was selected to allow radio waves transmitting simultaneously from two different Deep Space Network stations during the Earth occultation.

Once all that was figured out, I began calculating the entire trajectory from launch to the Jupiter gravity assist to the Pluto flyby. This included establishing a 35-day launch window and the launch targets that the launch team would inject New Horizons to for the journey to Pluto. The spacecraft would be launched into a parking orbit coasting for about 19 minutes, and then at a precise moment the Atlas upper stage Centaur and Star 48B would inject New Horizons into this launch target.

The design work was done in stages. To figure out the launch window, I used approximate solutions for a quick and broad search of the trajectory space. A quick survey of the interplanetary transfer trajectory from Earth to Pluto via a Jupiter flyby on different launch and Pluto arrival dates was conducted using a commercial mission design software tool called MAnE, short for Mission Analysis Environment. With the launch window nailed down, I then computed integrated trajectories from launch to Pluto for each of the 35 launch dates using high-fidelity mission-specific models with another commercial tool, the STK Astrogator. In addition, I used my own tailor-made tool to verify the calculation results for a double check. We gave the launch team a different launch target for each date within the window.

In the early development phase, I had lots of interaction with Alan Stern, the mission's principal investigator, who was very engaged and wanted to know not just the high-level things but also the details.

The trajectory work did not end once New Horizons was launched. As we approached Pluto, I constantly assessed the trajectory against our science objectives. Long before that, we had developed, tested and re-tested software to calculate the necessary trajectory correction maneuvers or TCMs. The launch team delivered New Horizons to the designated launch target within the predicted accuracy, but it was not possible to perfectly predict all trajectory perturbations during the flight to Pluto. Those perturbations include solar radiation pressure on the spacecraft, the small but accumulating effect of the thermal radiation emitted by the New Horizons radioisotope thermal generator, and the unbalanced hydrazine thruster firings that controlled the pointing and orientation of the spacecraft. In addition to the trajectory perturbations, the predicted positions of Pluto based on the ground observations had large errors. From launch to flyby, we planned 25 TCMs but only nine were needed and executed. This included a final TCM on June 30 with a very small delta-V of 27 centimeters per second. This slightly adjusted the velocity so that the spacecraft would fly through the designated Pluto aim point at the selected time.

After a 9.5-year journey traveling 5.25 billion kilometers across the solar system, New Horizons flew by Pluto at a distance of 12,487 km from the surface, which was only 41.5 km off the designed aim point according to the reconstructed flyby trajectory by the Navigation team. The Pluto flyby time was 88 seconds earlier than the designed one. All four occultations were achieved as planned. Amazing images of Pluto and Charon were gathered during the flyby and continue to be downloaded, along with the atmospheric readings produced from the occultations.

Looking back on the last 15 years, it has been an incredible journey and I feel fortunate to have worked with such a talented team on this pioneering mission.

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Yanping Guo is a principal professional staff and supervisor of the mission design section at the Johns Hopkins University Applied Physics Laboratory in Maryland, where she is currently the mission design lead of the New Horizons mission and the mission design and navigation manager of the NASA Solar Probe Plus mission. She has a Ph.D. in physics from The Catholic University of America in Washington, D. C. She is a member and former chair of AIAA's Astrodynamics Technical Committee.

Challenger's Legacy

NASA

Humanity's determination to go to space for adventure, commerce and exploration has never been stronger, but many of those who will open up this frontier have no direct memory of an unusually cold Florida morning that changed NASA forever. On Jan. 28, 1986, the space shuttle Challenger rose and exploded in front of a live cable TV audience and school children who were watching via a special satellite feed. The crew of seven was killed, including history teacher Christa McAuliffe. The sense of invincibility that had grown at NASA was shattered. Debra Werner asked some of the people connected to the mission to recall that day, its lessons and how NASA summoned the courage to fly again 33 months later.

by Debra Werner
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David Hilmers *flew on the STS-26 Discovery mission in October 1988, the first flight after the Challenger disaster.*

DAVID HILMERS

I was in training for another mission, a very difficult one to launch a vehicle upper stage, called the Centaur, from the shuttle. There were a lot of potential difficulties because it was a liquid [fueled] upper stage and it had its own set-up fuel tanks that were difficult to stabilize. There were a lot of areas where failure scenarios were a little more probable than we like. It was going to require that we launch for the first time at 109 percent of rated thrust. We were discussing flight rules. We stopped the meeting to turn on the video from the Cape. We were all struck by the icicles on the tank and the knowledge that we had never launched in that kind of extreme cold before. There was an uneasiness in the air. As we watched the tragedy unfold, people didn't say anything. The meeting just stopped and we filed out. I was in a daze. I remember going home that night, going to my piano and playing Pachelbel's Canon over and over again with a lot of tears and sadness.

It was the first time we had lost a crew in space. That feel of invulnerability went away. It really sobered us to the care that we have to take. We couldn't expect to let problems slide and hope that they would go away or somehow get fixed. We looked at every document and every part of the space shuttle. We made an enormous number of changes. It set the groundwork for all the successful shuttle missions [to follow until] Columbia, and that was perhaps due to a separate problem. That's a pretty good safety record. We lost my friends and we lost a vehicle but it wasn't in vain.

"It was the first time we had lost a crew in space. That feel of invulnerability went away. It really sobered us to the care that we have to take."

Return-to-flight mission>> It was a privilege to represent NASA and the country [aboard Discovery STS-26] in getting our space program back on its feet. There was also a burden to bear, constant questioning and a lot of pressure on us to be good representatives of NASA for that mission. It was worth that effort and certainly one of the highlights of my career at NASA.

John B. Charles *has been at NASA Johnson Space Center since 1983, helping to improve human spaceflight safety*.

JOHN B. CHARLES

I came to the Johnson Space Center in 1983 as a post doctoral fellow. In 1986, I was a civil servant scientist. I recall being off site at a meeting early in the morning, then walking in the front door of building 37, which was where the life sciences offices largely were and still are. I was in the conference room watching the launch on television. Typically with rocket launches, after blast off people get up and walk away. People were walking out of the conference room. It was [just under] two minutes into the flight and this thing happened. Most people didn't notice. A few of us who were paying attention noticed, but didn't understand what was going on. As you recall, the commentator didn't say anything for a while. We kept saying that doesn't look right. Is that supposed to happen like that? And then the commentator said major malfunction. The rest is a bit of a blur.

Faulty suspect>> In the absence of any definitive information, I assumed like everybody else that it was the turbopumps because I had heard the turbopumps were the engineers' biggest concern on those Space Shuttle Main Engines. And of course, it wasn't the turbopumps. They kept working right up until the vehicle disintegrated. After that, we had to try to understand what happened to the crew members. How they died was our main concern because we are supposed to be thinking of ways to protect them.

One of my dominant recollections is the absence of information. Even as the inspection and recoveries were taking place and review boards were doing their work, there was not that much information shared. Then, within days or weeks, it became clear we were going to resume the shuttle program. That really seemed to help us refocus on crew safety.

NASA "decided the shuttle program needed to be refocused on things that truly justified putting people in space and it was not like a trucking company."

Clearer priorities emerge>> Management decided the shuttle program needed to be refocused on things that truly justified putting people in space and it was not like a trucking company. That led to interest in the Extended

Related reading: "Flying after Challenger," by Tom Jones, page 10

Duration Orbiter, which was going to fly shuttle missions up to 30 days as mini space-station missions to do the research that needed to be done in spaceflight to begin to understand the effect of spaceflight on astronauts in preparation for the space station. Before Challenger, medical research was largely the domain of payload specialists. Toward the end of the pre-Challenger era, the real astronauts kept saying, "Medical experiments? We'll let the payload specialists do those. We are the pilots. You don't ask the pilot on Southwest Airlines to do medical experiments do you? Go bother the payload specialists." After Challenger, with the demise of the payload specialist program at least for a little while, there was also the realization that we're all in this together. The medical research we were doing couldn't have helped the people on Challenger and it could not have prevented Challenger, but it can help us understand the medical problems of spaceflight and can help prevent future problems. So the astronauts to their credit became more enthusiastic or at least less reluctant to participate in medical investigations we developed [for the proposed] Extended Duration Orbiter Medical Project, which never happened, obviously, but shuttle flights became longer, 17-day flights.

New appreciation for medical concerns>> We formed a new healthier, happier relationship with the astronaut office. They were much more supportive, much more willing to participate in the medical investigations. It also helped us to focus our medical investigation on things relevant to crew safety, health and performance and not simply things that we thought were interesting. Internally we'd always been focused on the things that were relevant, but it helped us refocus on what relevant meant.

End of a cringe-inducing term>> After Challenger astronauts began wearing new spacesuits, because it may not have helped the people on Challenger but it made NASA focus on what else could go wrong. Up until that time, a lot of very smart people believed the shuttle was an operational vehicle, even though the folks who were flying it and managing it cringed at that description. Challenger gave NASA the opportunity to focus more on crew safety issues and explore other things that could have go wrong. It was a bit of a new golden age in terms of crew safety research, risk-reduction research.

Rob Kelso *began working in NASA Space Shuttle Flight Operations in 1981 and in 1988 became a shuttle flight director. Today, he runs the Pacific International Space Center for Exploration Systems at the University of Hawaii.*

ROB KELSO

I was in the customer support room, a room for senior business managers that had spacecraft or payloads on shuttle missions. In the customer support room, you can have TVs on because you are not actively monitoring the ascent. I noticed several things. When the shuttle broke apart, just before solid rocket booster separation, it was clear that a major problem had happened by all of us watching on [NASA satellite] TV. But in the control room, it took a number of seconds for that to dawn on people because when the breakup began, all the pieces were still relatively close together so the tracking radars tracked it as one group until it began to disperse.

The people who were standing at the Cape in the viewing area and the people who were watching it on TV, had an earlier sense of the disaster than the people who were sitting in the mission control room because the data appeared to be normal. When that happened, we felt shock, the sick feeling in your stomach. We had never lost anyone in flight before. We lost a crew on Apollo 1 on the pad, but never during dynamic phases of flight or on orbit. The other thing I remember is that there was no indication anything was going wrong with the vehicle until the breakup. Obviously when you look at the very minute data there were signs, but it wasn't evident to anyone in my area until it happened.

Wringing value from down time>> It was hard to recover after that. We were down for years. I remember Tommy Holloway [then NASA's top flight director] telling my flight director class, "When we start flying again, you are going to be extremely busy. While we are not flying,

"After Challenger, people asked, 'Do we really want to fly these big [Centaur] hydrogen and oxygen tanks in the shuttle?' It was pretty dangerous. That program was canceled.

this is your golden time to get all of your studying done and visit all the contractors." He was right. That downtime was our time to get smart, educated and prepared as flight directors.

Rethinking shuttle's purpose>> For about a year before the accident, I had been working [on the] Shuttle Centaur [rocket program] to launch the Ulysses and Galileo missions from the shuttle. We had two crews assigned and we were beginning to do training, procedures development and testing. After Challenger, people asked, "Do we really want to fly these big [Centaur] hydrogen and oxygen tanks in the shuttle?" It was pretty dangerous. That program was canceled. [The Ulysses solar probe and the Galileo Jupiter probe were launched from shuttle orbiters using solid rockets.] Challenger changed the role of the shuttle. It was no longer the National Space Transportation System. We were directed not to fly commercial payloads anymore. We were directed to off-ramp the Defense Department program. The Teacher in Space program went away. It changed the whole complexion of the shuttle program. That didn't show for a number of years because we had flight commitments. We had to fly those out.

Much needed changes>> Obviously there are positive things [that resulted]: management change and an understanding that there was a lot of pressure to launch that led to unacceptable risk.

It also raised the question, "Do we really want to fly Centaur's big hydrogen and oxygen tanks on the shuttle?" We never really sat back as a community and said, "Does this make sense?" On Return to Launch Site abort, we would be too heavy. We would have to dump hydrogen and oxygen. We were already mounting drain pipes and valves to dump propellant out of the Centaur during RTLS [meaning a return-to-launch-site emergency]. After the accident, people said, "What were we thinking?"

We are ingrained in flight control that failure is not an option, but we do learn from failure. We adopt new values on how we assess risk. Flight directors are trained to assess risk versus risk and risk versus gain: doing something versus doing nothing. One of the great outcomes from Challenger from a flight control perspective is that up until that point, we were so busy we never had captured the rationale for all the risk–based decisions in our mission rule book.

New rules>> After Challenger there was enough downtime to go through every flight rule. If we lose a fuel cell, do we continue to fly? Do we come down? What if we lose a star tracker? We debated all those rules and captured the rationale for our decisions. In many cases, rules were changed in that reassessment and a risk review.

Bob Crippen, *a four-time shuttle astronaut and the shuttle operations deputy director from 1986 to 1989 at the Kennedy Space Center.*

BOB CRIPPEN

I had been assigned to be commander of the shuttle's first flight out of Vandenberg Air Force Base. My crew and I were training in Los Alamos on one of the payloads we were supposed to carry. We knew the launch was coming up so [we] asked for a TV to watch the launch. At the time, people thought launches were commonplace enough that right after liftoff they cut away from the launch. We were walking out of the room, griping and complaining about the media coverage when somebody said, "Hey, wait'" because the coverage went back after the explosion. So that's when we saw it. It was heartbreaking. Most of us had good friends on there. The commander of the flight was Dick Scobee, who had been my pilot on my third flight. We said we'd better get back to Houston. It was one of the quietest flights I can remember.

> **"That night when it was so cold, people at the contractor were saying it was too cold for solid rockets to fly. Marshall Space Flight Center knew that. Johnson Space Center did not know that."**

Figuring out what went wrong>> I personally was involved in the investigation. We found out the cause, that the culprit was the solid rocket motor. My buddy Dick Truly had been an astronaut and gone back to the Navy. He got called to come back and take over the Office of Spaceflight. There were a lot of management changes at the top level. That occurred very quickly. He asked me to come help deal with some of the investigation and the Rogers Commission in Washington, which I did. As part of my task, we reorganized the shuttle management. I had made a recommendation that we ought to have more operational people in program management and Richard said, "If you believe that, you'll hang up your flying boots and come help us run the program." That's what I ended up doing. Arnie Aldrich was the director of the shuttle program. One of our recommendations was to be more centered at NASA headquarters. Arnie went to Washington. Dick Kohrs was one of his deputies for engineering in Houston, and I became one of his deputies at the Kennedy Space Center for operations.

Returning to flight>> We set about one of the hardest jobs I've ever worked on, getting the shuttle back flying again. All of us who had been involved with the vehicle knew it had a lot of weaknesses that needed to be corrected. Not just the solid rocket motors. We set about trying to do that. After a couple of years, we accomplished what we set out to do. We had a lot more people telling us why we couldn't fly than why we could, but I felt pretty good when my buddy [astronaut] Rick Hauck [who commanded STS-26] lifted off on the return-to-flight mission.

One thing I was concerned about in particular was the wheels and brakes. They were too weak for the design and the weight of the vehicle. We set about revamping all that along with a large number of other modifications. We went over the entire vehicle, all the failure mode analysis and critical items list.

Improving communications>> One thing that came out of the Challenger investigation was that between Marshall [Space Flight Center] and Johnson and NASA headquarters the communication was poor. Some people knew stuff at one place that people at another place didn't know. That night when it was so cold, people at the contractor were saying it was too cold for solid rockets to fly. Marshall Space Flight Center knew that. Johnson Space Center did not know that. One of the things we worked hard to do was improve communication. If somebody was concerned about something, we needed to hear about it across the program, not just at one particular center. We worked hard at that. When we started back flying again in 1988, it was worth all the effort. I personally and a lot of other people believe the good friends we lost on the Challenger would have wanted that. They would not have wanted that to end the program.

Steve Cash, *a solid rocket motor expert who participated in the post-accident redesign effort and who is now director of safety and mission assurance at Marshall Space Flight Center.*


STEVE CASH

We were in a crowded conference room watching the launch. Everything seemed to be going as expected. Then you had this tragic event. It was unreal. It was a shock. We knew it was going to change how we did business for the rest of our lives.

Learning to listen>> Before Challenger, we all were worried about our little area of the world. I was worried about hold-down studs because that's what I worked on. After Challenger, we realized that we were all in this together. We learned a little bit more about teaming within the center and with the other centers. We built bigger teams and better teams. We opened up communications lines like we never had before. It changed how we looked at problems. We started to realize somebody at JSC looking at one of the problems or issues we had at Marshall may have a good solution. We need to be willing to listen to those other people out there. It was one of those [changes] that evolved. In the early '90s, I was working on the solid rocket motor team, I had moved in to the chief engineer's office at the time and supported the reusable solid rocket motor full time for that area. I started to see a big difference in the relationship that I had with Kennedy Space Center and Johnson Space Center and with our contractors. We started doing more things together. We started meeting more face-to-face rather than being on teleconferences all the time. We got to know people firsthand. I could feel comfortable calling guys down at the Cape. We even began to do details between our office, the Reusable Solid Rocket Motor office and the Kennedy Space Center Launch Operations office. We were starting to exchange ideas and exchange workforce. Several of our team members went to Johnson Space Center for six-month rotations with the shuttle program manager's office. We sent several of our team members to headquarters to work there. It became important to us to reach out and become more of a team.

"Systems engineering 101">> It was a natural output of spending more time looking at our designs and how they affect the other elements. We realized everything we did affected every other element. It was Systems Engineering 101, understanding the space shuttle vehicle as a system. To be successful, we all had to be successful. You couldn't just have a successful booster flight. If you lose an engine, it's just as detrimental. As you started to look deeper at your own systems, it led you to other systems outside the motor project and you started building those relationships with other engineers across the country. We started teaming much better.

Participating in the redesign effort>> We had six trailers full of folks working redesign efforts. I was in charge of the transient pressure test article [TPTA]. It was a full-scale test article but it only had two Reusable Solid Rocket Motor segments and two domes. What we would do in that TPTA is put slabs of propellant in and simulate the rise rate with the correct temperature and pressure. Then we put flaws in our joint design. We tested our

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joints to see that they could withstand flaws. It made it much safer. We were able to start taking more risk in our test program after Challenger. We were capable of running full-scale tests with full-scale pressure with the right loading to demonstrate that our designs were good. That was something we had never done before. We had never done a full-scale flaw program before Challenger. It really changed how we saw the motor. That's the reason the Shuttle Solid Rocket Motor is the safest solid rocket motor today. We even did a full-scale solid rocket motor test, full burn over two minutes out at Utah in the test stand, a static test called PVM-1 [Production Verification Motor-1]. We actually scarred the metal in the crevice joint to get gas to the O-ring to show that the O-ring would seal. We did a lot of things differently after Challenger.

We might put a cut in an O-ring to see how the joint responded. When you did that, you would guarantee gas to your secondary O-ring, that was one of the things we had never done. We had a lot of comfort before Challenger because we had two O-rings. So if one fails, you have the second one. But if you are never able to test that, then you are not sure the design is acting the way you think it should. That was a change in how we did business: that full-scale flaw testing.

It's like everything else. You learn from your mistakes. Challenger was a terrible thing. We lost seven of our very good friends. But it did force us to go back to look at how we designed things and how we tested them to make sure they actually performed the way we thought they would. That is probably one of the biggest things that came out of Challenger: how we changed our test program.

Tommaso Sgobba, *who was an aeronautical engineer before becoming chief of the European Space Agency's independent safety office in 2007.*


TOMMASO SGOBBA

I was recruited by ESA two and a half years after the accident. There were a lot of reverberations inside ESA, which had technical implications and organizational implications. At the time of the accident, the ESA safety organization was at the division level, which is a layer below department and department is a layer below directorate. Because of the accident, the ESA Product Assurance and Safety Division was promoted to the level of department. The idea was to create a centralized function that would have an oversight on all projects.

"Before the Challenger disaster, managers had no idea what a decision meant in terms of risk."

Quantifying risk>> One aspect that changed was how a manager decided to take a risk. Before the Challenger disaster, managers had no idea what a decision meant in terms of risk. NASA [after the accident] recruited experts in probabilistic risk assessment from the nuclear industry. The idea was to quantify the project's various risk factors. That analysis showed that space debris was one of the five top-level risks for the shuttle. Later it was found to be the top-level risk for the space station.

One of the things that people criticized after the accident was the so-called normalization of the anomalies. That means that anomalies occurred in the past but there were no consequences, therefore these things were considered acceptable or "normal." This happened for the Challenger because the seals eroded on earlier flights but nothing had happened. The same thing happened with the shedding of foam that years later led to the Columbia disaster.

Unsolved management conundrum>> The big issue at the core of the Challenger disaster is still unsolved: how to separate the safety responsibility from the project manager's responsibility. The project manager is tasked with flying a complex machine and achieving the mission within certain cost constraints Congress has allocated to the project. If a safety manager raises a problem, there is always someone else arguing that the problem is not as risky as the safety manager believes. These problems are never black and white. The project manager also has to consider a myriad of constraints like launch windows. If you do not launch, the rocket will be on the ground. Other customers are waiting to launch. Money will be lost. All this together creates a situation in which managers tend to believe what they unconsciously want very much to believe. Sometimes they are right. Sometimes they are just lucky.

There was only one tiny part of the shuttle program in which safety responsibility was separated from the project manager's responsibility. This was for the shuttle payloads. In the early days, the shuttle was meant to replace all expendable rockets for launching satellites. Payloads were typically developed outside the shuttle program. The shuttle program established rather conservative rules, and payloads had to meet those rules or they did not fly. NASA exercised this authority, through the payload safety review panel chairman reporting to the program manager, rather strongly and successfully. Harold Battaglia, one of the early payload safety review panel chairs, was a living legend in this respect.

Rhea Seddon, *a veteran of three space shuttle flights, who together with Challenger crew member Judith Resnik was part of the first astronaut cadre to include women*.


RHEA SEDDON

I remember it quite clearly. I was at an off-site building for a meeting. We turned on the television to watch the launch. It was such a beautiful, clear day. We had heard all the news about the ice. I think everyone was afraid that icicles would break off and go up in the engines. So as soon as the launch got off the ground we were in our usual state of elation. Then something happened. We saw the boosters come off and realized it was too soon. For some reason the tank and shuttle were still flying. Then it became obvious that big chunks of stuff were falling in the ocean. I immediately went back to the space center. It was a bad day. A lot of sadness, worry and activity trying to figure out what we had to do next.

Not unbreakable>> There were a number of things. First, it became a reality that we could lose a vehicle in space. We had dodged bullets in the past and thought we were unbreakable and safe. We realized that we weren't.

Planning for the unthinkable>> Secondly, we realized we didn't have plans in case this happened. We had to quickly figure out: Where are the crew members' families? Who do the spouses want here with them? How do we get them back to Houston? Are their kids all here or are they back home with the neighbors? It was a very difficult time to go through the recovery and the Rogers Commission. We all tried to do everything we could to help the families who were going through untold horror, too much publicity and difficult times. Then we all had to make an assessment of whether we were willing to stay [in the astronaut corps] or not. By the time it was clear we were going to continue to fly space shuttle and the redesign of the boosters had been completed, my husband [former astronaut Robert "Hoot" Gibson] and I both had flight assignments. We were committed to those flights and those crews that we had been training with. So it was a fairly easy decision for us. I don't think either of us thought spaceflight was completely safe. So we made the assessment that we would stay. But we had friends who decided it was time to move on. Some had spouses that didn't want to face that.

"There was a big turnover of leadership ... I think the changes were for the better, but it was a terrible time to go through."

There was a big turnover of leadership. That always brings change and new says of doing things. A lot of us wondered what the new NASA was going to be like. We were encouraged by things like the Family Support Plan for astronauts and their families. We had good leadership. We had found the problem and it wasn't unsolvable. It allowed us the time to look at other systems and the reliability of those. We got through it. I think the changes were for the better, but it was a terrible time to go through.

June Scobee Rodgers, *wife of Challenger Commander Dick Scobee, founding chair of the Challenger Center for Space Science Education, which established an international network of Challenger Learning Centers, and author of "Silver Linings: My Life Before and After Challenger 7."*


JUNE SCOBEE RODGERS

I need to go back to the first time Dick Scobee flew in space. He flew as a pilot on [Challenger's 1984] STS-41-C [mission]. When he came back from that important flight, he whisked me aside and said I want to tell you first what it was like. So off we went to our favorite restaurant. The stars in his eyes were as bright as those in the sky as he talked about the mission. It was the first time they repaired a satellite in space. Toward the end of his discussion, I said, "Didn't it make you mad that President Reagan mentioned every person's name on the crew during his phone call to you all but he forgot your name?" Dick said, "Oh no June, what was important was the mission."

Now to move forward, he is the commander of 51-L [Challenger's 1986 mission]. At first it was a five-person crew and then they added a teacher. I was ecstatic. I was a college professor. His dream was to be an astronaut, mine was to be a teacher. I grew to know and love Christa and worked with her on her assignments. She was a history teacher and a little uncomfortable with the science. We worked through it. She was in my home regularly. Their mission became known as the Teacher in Space mission. I was thrilled to be a part of all of it. Dick and I had been married 26 years. We married as teenagers, worked to help each other through college, careers and two wonderful children. Then he's at the top of his goal in life, being a commander of a space mission, and I'm so excited because it involves education. We [were] standing with all the families when we lost the Challenger and we lost that beloved crew. It was the most painful time in our lives. It was stunning, numbing shock. Our personal grieving became much more public. We were at Johnson Space Center a few days later for a memorial service for the crew when President

> **"I was sitting next to Nancy Reagan when the missing-man formation flew over. So many times before with my military husband, we had seen that formation for friends who had died."**

Reagan spoke. I was sitting next to Nancy Reagan when the missing-man formation flew over. So many times before with my military husband, we had seen that formation for friends who had died. The idea behind it is that one pilot flies out of the formation straight toward the heavens in honor of the person who has died and those remaining will continue the mission. I looked to those planes and said I cannot help NASA with their mission but I can continue that education mission. I brought the families together soon after that. By April, we had formed our nonprofit foundation. They elected me chairman. It was a struggle for a couple of years, but there were just enough people who joined our effort. The best person of all was then-Vice President George H.W. Bush.

I wanted to create something like a computer game but instead of one student sitting at a computer, there are people working at different stations, a navigation station, a physician station, technology station, all these different areas and they have to communicate. We built the first one in Houston. It's tremendously rewarding to know we have reached millions of youngsters and made a difference in the lives of some. In a way, I think we are filling the inspiration gap until we have astronauts flying to Mars. It's a marvelous tribute to the Challenger crew and their mission, but even more so to the teachers who work every single day who make learning exciting. Since the first center opened in 1988, Challenger Center has educated more than 4.4 million students. There are more than 40 Challenger Learning Centers around the globe serving hundreds of thousands of kids each year.

Allan McDonald, *Morton Thiokol's top official at Cape Canaveral for the Challenger launch, and author of the book "Truth, Lies and O-Rings: Inside the Space Shuttle Challenger Disaster."*.

ALLAN MCDONALD

As horrible as that day was, which it was, it was most horrible for me because we tried to stop the launch the night before. After hearing the forecast, our engineers in Utah worried whether the O-ring seals would operate properly. The projected temperatures were a long way from the temperatures we had flown the shuttle in before. Because of that concern, the engineers contacted me. I was the senior Morton Thiokol person at Cape Canaveral. They asked me to get actual weather forecasts at the launch site so they could calculate the temperature of the hardware. I agreed to do that. I told them that when I provided that information, I wanted them to get all the engineers together, assess the impact of the temperature and have the vice president of engineering make a specific recommendation on the lowest temperature that would be safe to launch.

Fateful conference call >> I arranged a meeting with the NASA folks at Kennedy Space Center and tied in the engineering folks in Huntsville, Alabama, at the Marshall Space Flight Center on a conference call with our engineers. The Morton Thiokol engineers presented what they knew and didn't know. Bob Lund, Morton Thiokol's vice president of engineering, concluded by saying he would not recommend launching the shuttle in temperatures below 53 degrees Fahrenheit, which I fully agreed with. NASA management really surprised me by challenging the basis for our recommendation. I had been in the program for about two years, and in previous flight readiness reviews, I was always challenged as [to] why I felt it was absolutely safe to fly. We always delivered some hardware that had some very minor defects. In the past, I always had to prove to them beyond a shadow of a doubt that the defect did not compromise shuttle safety.

NASA's eagerness to fly >> We recommended against flying and they would not accept our recommendation because it was based on a qualitative observation. We didn't have any good test data or analysis that said it would not be okay to fly at those temperatures. Our recommendation was based on an experience.

Sooty O-rings >> After a flight one year earlier in January of 1985, when we pulled apart boosters that had flown, we saw soot trapped between two O-rings. We have two O-rings in the Solid Rocket Boosters for redundancy because that's a critical function. We had never seen that soot before and couldn't understand what was unique about that flight. We concluded that it was the temperature. The flight was preceded by the three coldest days in Florida history. Now, NASA was challenging the Morton Thiokol position that it was unsafe to fly.

My boss, Joe Kilminster, said [during the telephone conference], "We'd like to take some time off on a caucus to make sure we presented everything we had." They allowed him to do that. He asked for five minutes. It was a half hour before he came back on. This time Joe Kilminster said they revisited all the data and concluded that its okay to proceed with the launch as planned. He didn't give any specific temperature, which also took me aback. [Kilminster told the Rogers Commission that he changed his mind after analyzing the potential for erosion in the primary O-ring seal and concluding that "we were in the condition of having a safe position for recommending a flight."]

Refusal to sign off on flight >> I refused to sign [the launch recommendation], which I said in my book was the smartest thing I ever did in my life. As a result, my boss had to sign it. I was so upset by all that, I argued for over a half hour. I told the NASA folks that I didn't care who made the decision, I didn't care if it was the CEO, I said they couldn't accept it because "you know and I know those motors have never been qualified to the environment you are asking us to fly in. As far as I am concerned, they are supposed to be qualified from 40 to 90 degrees. I know they were never tested there but there was analysis done at 40 that said they'd be okay."

They just stared at me. I said, "If I were the launch director, I would cancel this launch for three reasons. The first one is this discussion on the affect of temperature on the capability of the O-rings. Also, I talked to our head of space services. He is in contact with our ships at sea to retrieve these boosters. They are in a survival mode. They are in seas over 30 feet with winds over 50 knots gusting to 70. They won't be in the recovery area in the morning. The third reason was I heard NASA's comments about freeze protection."

NASA had all these water systems at various levels on the fixed surface structure. When they are building up the shuttle and payload and checking it out, they have no freeze protection. They were just going to leave the spigots open so water could drip and the pipes wouldn't break. I said, "If it gets as cold as projected, there is going to be ice all over that place tomorrow morning. It's got to be a big debris issue and may change acoustics. I don't know. I'm making a recommendation not to launch not based on what I know, but based on what I do not know."

They never argued with me. They said, "We'll take those comments in an advisory capacity, Al. These are not your responsibility."

Then I said, "I'll tell you something, I hope nothing happens tomorrow, but if it does, I'm not going to be the person to stand before a board of inquiry and explain why I gave you permission to launch my boosters in an environment I knew they weren't qualified in." That ended the conversation that night.

When I went out there the next morning, the temperature was about 22 degrees. I sat down at my console and put on my headset. The first thing I did was panned the camera on the launch pad. I couldn't believe all the ice. Icicles were hanging on the boosters, hanging on the orbiter, hanging on the surface structure. I thought, "They obviously are not going to launch this. No way." NASA sent an ice team to knock it all down. They did that the best they could and eventually NASA resumed the count.

I didn't find out until later, that ice team also made some temperature measurements on the vehicle and the structure, including the boosters, tank and orbiter. For some strange reason, they reported temperatures of 7 to 9 degrees Fahrenheit at the aft field joint of the right hand booster. That was not reported to the Mission Management Team because the ice team's primary assessment was for the ice on the tank. When the Challenger launched, I figured that if it failed because the O-rings did not work properly, the whole thing would blow up before it cleared the tower. That did not happen. It failed 73 seconds later.

It was horrible. I remember hearing people sobbing in the background because they knew this was not survivable. I kept hearing the Capsule Communicator saying RTLS, Return to Launch Site, and nothing of course coming back.

I thought this whole explosion occurred from a tank

The names of the seven Challenger astronauts are among the 24 names on the Space Mirror Memorial at the Kennedy Space Center in Florida.

NASA

or engine failure. The only things that kept flying were the solid rocket boosters. I didn't find out otherwise until I went to the Marshall Space Flight Center the next day as part of the failure analysis team.

Jim Kingsbury, who was the head of science and engineering at Marshall, called and said he'd just reviewed some films and saw fire coming out of the side of the solid rocket booster. I walked in the conference room and told him he didn't know what the hell he was looking at because solid rockets don't go flying around with fire coming out of the side of them. They blow up.

[In a film of the launch from a NASA camera] we saw a puff of smoke coming out at 6/10th of a second after ignition, which indicated it failed at exactly the time we thought it would. Then I knew this whole failure was caused by an O-ring failure in the manner we thought might well happen because of cold temperatures.

One of the hardest things I ever did in my life was to call home and tell my wife about it. My youngest daughter, Megan, who was four then, answered the phone. When she heard my voice, she said, "When is the space shuttle going up, daddy?" I couldn't believe she hadn't seen this but was thankful she didn't. She knew I always came home when the space shuttle went up. I couldn't answer her.

It was a horrible time from then on because I got so involved in the accident and found the problem. Within two or three days, I presented the problem to NASA in detail. It was very clear they didn't want to hear it. I understood that. They were under a lot of pressure to keep the shuttle program going and show they could actually make two shuttle flights a month in a couple of years, which was the goal. They just got blinded by the fact that we didn't have absolute proof that it would fail. We certainly had absolute proof that it wasn't safe.

Looking back on that, the thing that bothers me today more than the fact that it was a bad decision to launch in the first place, was people trying to cover it up later. That to me was a bigger error. When you are under a tremendous amount of pressure and making a big decision in a short period of time, that's tough for anybody. But when you decide to cover it up, that is a decision one makes after thinking it through. To me that's more disingenuous than just making a bad mistake.

It was a very difficult time because then I had to tell a Presidential Commission that what they heard from NASA wasn't true. [EDITOR'S NOTE: When the Rogers Commission convened, NASA officials said they did not know what caused the accident and had no reason to suspect the solid rocket booster joints.]

Rogers Commission learning of O-ring problem>> In his book, "What Do You Care What Other People Think," Dr. Richard Feynman [winner of the Nobel prize in physics and member of the Rogers Commission] said the strangest thing that ever happened was when this fellow McDonald was in a meeting of the Presidential Commission he wasn't suppose to be in and he walked out of the audience and told the commission what they heard from NASA wasn't true. Chairman Rogers was so shocked he asked McDonald to repeat it.

I feel good about that part of it, but my testimony ruined a lot of peoples' lives, both at my company and within NASA. A lot of their friends still have great animosity towards me. The broader spectrum of people was thankful I did what I did.

Immediately after Challenger, when the shuttle began flying again, NASA made a few great improvements. At the time of Challenger, the Mission Management Team was in a separate room and it was 100 percent NASA people. After Challenger, a senior representative from each of the major suppliers became part of that Mission Management Team. If I had been sitting with the Mission Management team that morning, they would have known of my concerns.

"We recommended against flying and they would not accept our recommendation because it was based on a qualitative observation. We didn't have any good test data or analysis that said it would not be okay to fly at those temperatures."

Marshall-Johnson rivalry>> NASA also recognized it had some intimidating managers and tried to create an environment where people feel comfortable throwing on the table anything that bothered them. They told NASA managers, "There may be one person in the room who thought of something that nobody else did and it may be extremely important. If they don't feel comfortable putting in on the table, you've lost it."

I headed up the solid rocket booster redesign [at Thiokol]. I'm proud how well it came out. At the end of the shuttle program, it was the safest piece of hardware on the shuttle.

For at least the first three flights after [Challenger], communications were very open. People were willing to say anything. I saw a huge change for the good. There also was a lot more communication between the NASA centers and between the agency and the contractors.

Immediately after the Challenger accident, I heard people at Johnson directed a lot of anger at Marshall. Marshall and Johnson were competing with each other for a share of the shuttle program and a share of the work. That led to people failing to share information. If that competition had not been there, the Marshall folks would have told the Mission Management Team about their discussion with Thiokol. That might have made the mission management team cancel the launch. A

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Learning from

VIEWPOINT

*As technically impressive as the U.S.'s F-22 and F-35 may be, they arrived over budget and late, something the Pentagon can ill afford when it gets down to work on development of a sixth-generation fighter. Analysts **Robert Haffa** and **Anand Datla** describe the lessons from these difficult acquisitions.*

Before the U.S. Air Force and the Navy begin to think about requirements for their sixth-generation fighter aircraft, it would behoove them to learn lessons from the acquisition of their current fighters — the F-22 and the F-35. Taking into account the challenges of procuring those aircraft could help smooth the acquisition of fighters for the future.

The F-22 acquisition proved to be a monumental disappointment for the Air Force. In 1991, the service's request for proposals for an advanced tactical fighter envisioned up to 750 ATFs at an approximate cost of $26.2 billion. By 2009, following numerous cost and schedule overruns, the secretary of defense terminated the F-22 buy at 187 aircraft and a program cost of $79 billion. That works out to a quarter of the planned purchase at three times the price.

Lessons identified from that troubled acquisition were unfortunately not applied in the procurement of the second fifth-generation fighter, the Joint Strike Fighter, or F-35. In 2001, the military services, working through a Joint Program Office, called for 2,200 aircraft for the Air Force, the Navy and the Marine Corps for about $200 billion, and an initial operating capability of 2010. As of 2015, the projected program cost has nearly doubled, and only the Marine Corps has declared IOC for its version of the plane, the F-35B.

In the early 1990s, the U.S. Air Force initially envisioned buying 750 F-22s for about $26.2 billion. In 2009, the Pentagon terminated the F-22 program after spending three times that for a quarter as many fighters.

US Air Force/Rachelle Elsea

acquisition history

by Robert Haffa
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What went wrong? How did the Air Force fail to execute, on time and on budget, the F-22 program so dear to the service's essential mission of air dominance? And how did the Air Force and its partners repeat those failures in acquiring the multirole F-35?

Providing some insight into these failures, a 2014 research report from the federally-funded Rand Corp. titled, "Prolonged Cycle Times and Schedule Growth in Defense Acquisition," examined literature from the 1960s to now citing a range of possible causes for schedule growth and cost overruns in major weapons systems acquisitions.

At the top of the list, Rand cites the combination of overly optimistic assumptions and lack of focus on schedule. The timeline projected to reach production was unrealistic for both the F-22 and the F-35 given their technical challenges. With a contract award in 1991, F-22 production was expected to begin by 1994, but it took until 2001 to initiate low-rate production. The F-35 was similarly plagued with delays. Lockheed won the F-35 contract in 1997, flew a test version in 2006 and produced the first aircraft in 2011 — way past schedule.

Longer cycle times and schedule delays do not occur in a vacuum. Excessive technical, manufacturing or integration risk and program complexity, as noted by the Rand investigators, go in hand with schedule overruns. Lockheed Martin increased its manufacturing risk for the F-22 by relocating its research and development work on the aircraft from California to Georgia, as noted in a 2005 Rand report, "Lessons Learned from the F/A-22 and F/A-18 E/F Development Programs."

Key personnel chose not to relocate, and the management of the Georgia plant had little experience in fighter aircraft en-

Development on the F-35 Joint Strike Fighter is years behind schedule and billions of dollars over budget.

Lockheed Martin


A U.S. Air Force airman applies a layer of low observable coating to an F-22. The Raptor's state-of-the-art stealth technology has added to the program's delays.

U.S. Air Force

gineering and manufacturing development. Resulting component assembly and delivery delays caused early schedule stretch-outs in the program.

The F-35 similarly struggled with integration risk, as managers attempted to weave together a complex supply chain of contractors from 47 states supporting F-35 development and production at a single facility in Fort Worth, Texas. The Defense Department inspector general concluded later that the Fort Worth facility lacked an adequate quality assurance structure to manage program oversight.

The issue of infeasible or unrealistic requirements proved a significant source of schedule delays for both fifth-generation fighter programs. The F-22's operational requirements document contained such mandates as an infrared search-and-tracking system to detect objects out of the line of sight and radar arrays to generate imagery from the side of the aircraft. After cost increases and schedule delays, these requirements were adjusted or removed. The F-35 program, attempting to develop an aircraft with variants to please three different services and multiple missions, was inherently structured on unrealistic requirements. Cost and schedule overruns plaguing the F-35 acquisition resulted from trying to produce a single aircraft meeting the multiple requirements — including carrier operations and short takeoff/vertical landing — of three services.

Immature technology and the difficulty of concurrently developing and integrating technology at varying readiness levels also caused problems. State-of-the-art stealth technology has been particularly problematic. The F-22's stealth technology faced aircraft-skin challenges requiring repeated fixes to adhere stealth components and to shape apertures on the outer mold line of the aircraft. While the F-35 also faced low-observability challenges, its latest failure, as reported by Air Force Times in October, is a $400,000 pilot helmet designed to provide greater battle space visibility by integrating multiple sensors into a head-up display. The helmet has proved to be too large, bulky and heavy, interfering with aircraft control and endangering aircrew health and survivability, according to Air Force Times.

The 2014 Rand report also draws attention to unanticipated engineering design and technology integration issues. Among a long list, a prominent unanticipated technical factor causing test failures in both the F-22 and F-35 has been software writing and integration. The choice by F-22 managers to use the rare, commercially-supported Ada programming language proved particularly problematic, making it difficult to find support for over 1.7 million lines of code. Software glitches interfered with the aircraft's basic functionality as well as in integrating various sensors. The F-35's lines of software code grew from eight million to 15 million and then to 24 million, according to a September 2012 article in IEEE Spectrum, causing years of delay and forcing IOC to be determined by software development and application rather than by aircraft delivery or aircrew readiness.

Unstable program funding and budget cuts are another challenge. The F-22 best illustrates this problem in its descent from the original planned fleet of 750 aircraft to the final number of 187. This self-perpetuating cycle results from unsatisfactory performance and schedule delays and reduction in total buy and, as a result, increased aircraft unit cost as development and production costs are spread across a decreasing number of aircraft. This procurement "death spiral" leads to further cuts in the total buy, soaring fly-away costs and increased program scrutiny.

In the case of the F-22, Congress imposed a $43.4 billion limit for aircraft production, turning the F-22 from a requirements-driven program into a budget-driven one. When Pentagon watchdogs determined in 2010 that the F-35 exceeded its original cost estimates by 50 percent, then-Defense Secretary Robert Gates deemed these cost overruns and delays unacceptable. He characterized previous cost and schedule projections as inaccurate, removed the program director, penalized the prime contractor and delayed the program one year. At this juncture, the F-35 was in danger of slipping into an F-22-like procurement death spiral. In 2012, the Defense Department's then-acting acquisition chief, Frank Kendall, reportedly described the F-35 as a case of "acquisition malpractice." He spoke during an appearance at a forum organized by the Center for Strategic and International Studies.

The two weapons acquisition case studies we have examined briefly here tell a tale of woe. But if these lessons were not learned, they certainly have been identified by think tanks such as Rand, by the Government Accountability Office and by the Pentagon's own studies. Overly optimistic assumptions, lack of focus on schedule, excessive risk, infeasible or unrealistic requirements, immature technology, all played significant roles in these procurement failures. Before acquisition professionals in the joint services begin to contemplate a sixth-generation fighter, they would be wise to identify, heed, learn, and apply these lessons.

Retired Air Force Col. Robert Haffa is a defense analyst and adjunct professor at Johns Hopkins University. He retired from Northrop Grumman in 2010, where he directed the Analysis Center, the company's think tank charged with understanding the future path of American defense and security policies.

Anand Datla is a consultant based in the Washington, D.C., area. He is a former Defense Department strategic planning analyst and was a professional staff member of the House Armed Services Committee.

THE GREEN

Geared turbofans, like those approved in November for the Airbus A320neo, will square off against open rotor designs in the coming years, as the industry seeks solutions for cleaner-operating airliners. Keith Button spoke to the experts about the trade-offs, the latest research and the work to come.

First of its kind: Pratt & Whitney's PW1100G-JM geared turbofan will power some Airbus A320neo jets.

Airbus

Engineers in Europe and the U.S. face a vexing challenge as they develop the jet engines that will power airliners a decade or more from now. The designs must deliver 20 to 30 percent better fuel efficiency than today's engines if they are to meet the bold CO_2 emission standards now under discussion. Safety, of course, can't be compromised either.

As yet, there is no consensus in the industry about the best design to safely achieve those efficiencies. Improved versions of geared turbofan engines are one option. Such an engine will look conventional on the outside, but a gearbox inside will let its front fan turn at a slower, more efficient speed, while blades in the engine core turn faster to maximize

ENGINE DEBATE


NASA

For bypass ratios of 50 or higher, open rotors may be the only choice.

compression of incoming air. Pratt & Whitney's PW1100G-JM engine is the first of the new breed, and in November the FAA and European Aviation Safety Agency certified these engines as one option to power Airbus' new fuel-efficient airliner, the A320neo.

Geared turbofan engines face competition from a more technically daring, but potentially higher-payoff concept. Why not make an engine without a protective nacelle? That way, the diameter could be expanded without a weight penalty from the nacelle. The Snecma engine company plans to test such an open rotor engine later this year in Southern France.

With the best way forward so unsettled, the stage has been set for years of research and development from Derby in the U.K., where Rolls-Royce is developing its UltraFan geared turbofan, to Munich, where Pratt & Whitney's partner, MTU Aero Engines, is testing geared turbofan components, to Istres, France, where Snecma plans to put its open rotor concept to the test even as it also researches geared engines. NASA could one day play a research role in the development of open rotor engines, following tests of open rotor blade configurations that wrapped up in 2012. At stake is the future performance of airliners and whether the ambitious CO_2 reductions from future airliners can be met.

The competition might not turn out to be a winner-take-all affair.

"We could imagine that these architectures" [open rotors and geared turbofans] "would compete for decades next to each other" on the aircraft of the future, says Ron van Manen, a Dutch aerospace expert and program manager for the European Union's Clean Sky 2 engine initiative based in Brussels.

Europe in the lead

Much of the work on geared vs. open rotor concepts will be funded under Clean Sky 2. The first of these funds were allocated in 2014, and Europe plans to spend 4 billion euros on the program through 2024, with 40 percent contributed by European governments and the balance by the private sector, including aircraft and engine makers. Clean Sky 2 is targeting a minimum gain in fuel efficiency of 20 percent by 2025 and up to 30 percent by 2035.

Clean Sky 2 has set up a faceoff of sorts between Snecma's open rotor concept and geared turbofans. Researchers are after the

by Keith Button
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highest possible bypass ratio, which is the amount of air that bypasses the engine core relative to the air moved through the core. A higher bypass ratio means that an engine's front fan, or a pair of counter-rotating propellers in the open rotor concept, is cleaving lots of air compared to the amount that must be channeled into the core to keep combustion going. That's good, because the fan or rotors produce thrust more efficiently than the engine core.

Pratt & Whitney's geared turbofans have bypass ratios up to 12. The ungeared Leading Edge Aviation Propulsion 1A engine, or LEAP 1A, has a bypass ratio of 11 and will fly on some A320neos; the ungeared GEnx has a ratio of 9.6; and the ungeared Trent XWB has a 9.3 ratio.

"There seems to be a lot of concurrence in the industry at the moment that beyond a certain bypass ratio — maybe one would say 8, others would say 10 or 11 or beyond — there are certainly some thresholds somewhere beyond which we don't get there without gear," van Manen says. "It's all about having low-speed and low-pressure-ratio fans moving the highest possible mass flow of air. At the lowest speed, you have the highest propulsive efficiency."

The case for open rotors

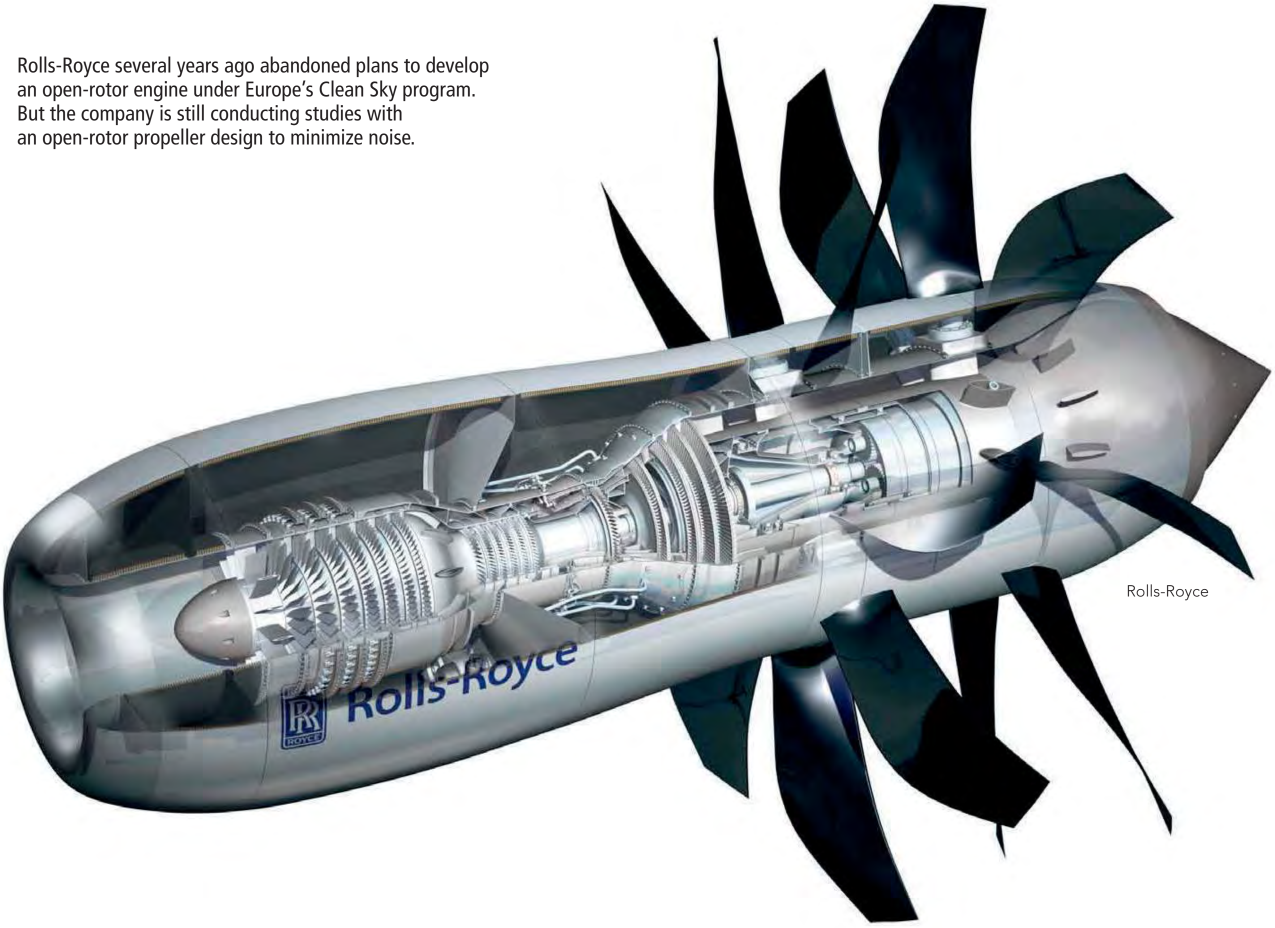
At a ratio of about 20, the weight of a geared engine with its nacelle becomes unwieldy. This is where open rotor advocates say their engines will shine. They could take the bypass ratio up to 50 or higher, a level that the enclosed designs will almost surely never reach, because the nacelles would be too heavy. The open rotor's impressive bypass ratio would be accomplished by installing two sets of eight to 10 curved blades — engineers call the shape scimitar for its resemblance to a Middle Eastern sword. The scimitar shape allows the propeller to operate at high flow velocities, near Mach 1, with the sweep of the blade tip minimizing the effects of air compression that occurs near the speed of sound. This double propeller design would move the same volume of air as a larger, single-propeller open rotor design. Either concept — geared turbofans or open rotors — would require accommodating huge diameter engines onto an aircraft.

Open rotor concepts are bold, and this boldness could require many years of research. Such engines probably won't be flown commercially before 2030 or 2035, says Jean-François Brouckaert, a Clean Sky 2 project officer. The very high-bypass ratio geared engines are expected to be flying in 2020 or 2025. Under Clean Sky 2, Snecma later this year plans to test an Airbus-selected pusher configuration at the 15 million-euro, 100-ton concrete-and-steel test rig it is building in Istres. The test engine

Regulators in the U.S. and Europe in November certified Pratt & Whitney's PW1100G-JM geared turbofan engines for the A320neo, Airbus's new fuel-efficient airliner.

Pratt & Whitney

Rolls-Royce several years ago abandoned plans to develop an open-rotor engine under Europe's Clean Sky program. But the company is still conducting studies with an open-rotor propeller design to minimize noise.



Rolls-Royce

will be bolted to a pylon 18 meters above the ground. Snecma has begun assembling the engine from components delivered from European suppliers. Testing is expected to take four to six months, says Vincent Garnier, Snecma's strategy director.

Based on the test results and Airbus' opinion, Snecma will decide between flight-testing the open rotor engine or its geared turbofan, which it calls the Ultra High Propulsive Efficiency engine. Snecma will permanently eliminate from consideration the engine design that is not chosen, Garnier says.

The safety factor

One challenge for the open rotor design is the "blade out" scenario: What happens if a bird or other object hits one of the rotor blades and it breaks or flies off? Precisely how engineers will meet that challenge will depend on the safety requirements that the FAA and the European Aviation Safety Agency come up with, van Manen says. But engineers will probably have to do one of the following: Demonstrate the safe handling of the aircraft and the hull in the event the aircraft were struck by a flying blade. Or convince regulators that a blade-out won't happen, or if it does happen, that the blade would be engineered to shatter into thousands of harmless pieces.

The level of energy exerted by a conventional blade out would present "an almost insurmountable challenge" in terms of the damage it could cause to an aircraft hull, van Manen says. Designing hubs and blade roots that are strong enough to be virtually unbreakable would be difficult, but reinforcing the hull to withstand the force of a blade would almost certainly be unfeasible.

"If you put five tons of extra weight on the aircraft because you're building it like a submarine to shield against blade out, then you're going to lose a lot of the benefits," van Manen says.

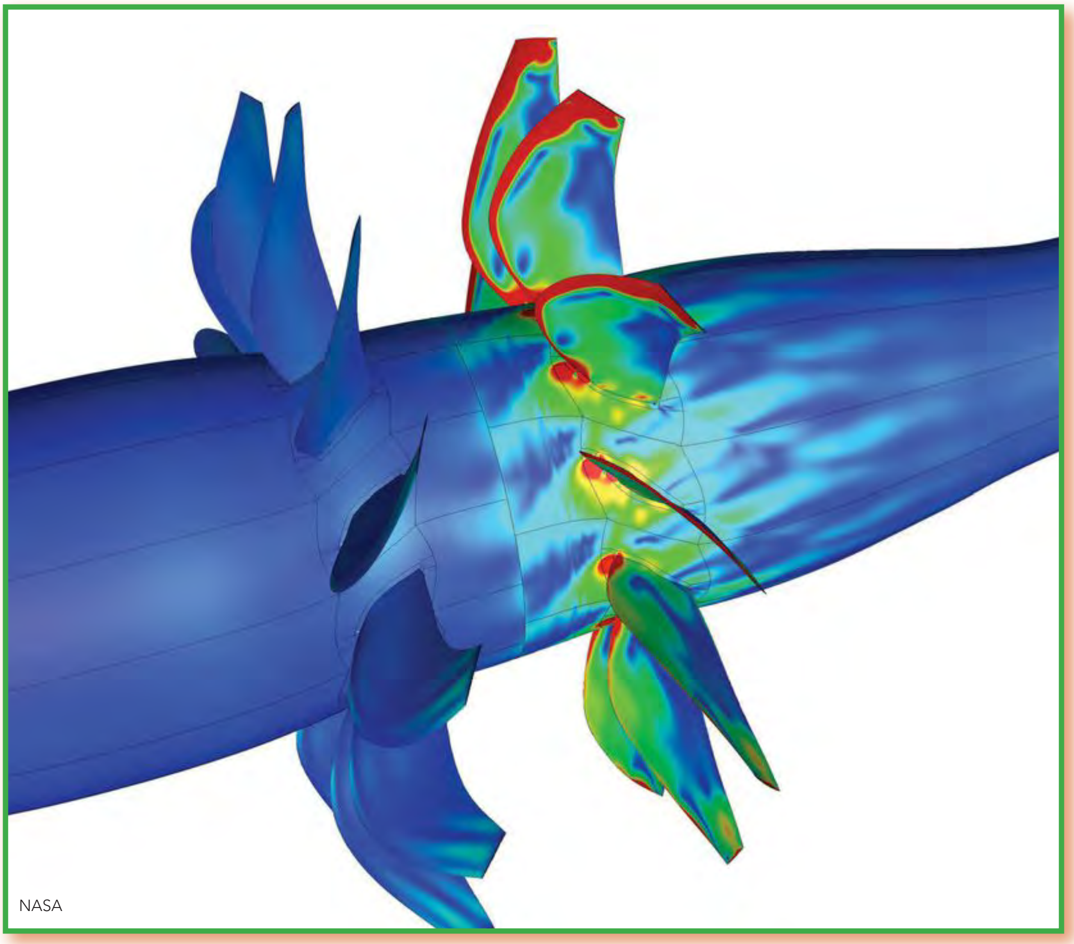
Passenger safety is why some engineers prefer a pusher open rotor configuration, in which the engine is mounted at the back of the airplane and the rotors ride at the back of the engine. This puts the hot and moving parts as far as possible from the pressurized portion of the cabin. Also, open rotors are loud because of the absence of a nacelle, and the pusher configuration would make it easier to shield the cabin from the noise, says Brouckaert, the Clean Sky 2 project officer. A big challenge, though, is that the pylon that attaches the engine to the airplane can distort the airflows to the rotors, which are behind it.

The puller configuration, in which the rotor blades would turn in front of the hot part of the engine, also has proponents. Having the blades away from the hot engine means less worry about the effects of heat on the rotating parts. In a tube-and-wing aircraft, the extreme diameter of the blades would probably force aircraft designers to place the wings at the top of the cabin to create clearance with the tarmac.

Battling noise

NASA aerospace engineer Dale Van Zante headed a program in partnership with General Electric from 2009 to 2012 to test different blade designs for open rotor engines, using engine models that were about 1/6th the size of the engines on a Boeing 737 and 1/5th the size of those on regional jets. Ten blade sets in a pusher configuration were analyzed in wind tunnels at NASA's Glenn Research Center in Ohio for fuel efficiency and noise performance. The engineers varied the tip speeds of the blades by adjusting the angle of attack of the blades and also experimented with tweaking their curvature. A lower tip speed usually requires a larger rotor diameter to produce the same thrust. Lowering the load, or thrust, required from the spinning disc of blades improves efficiency and lowers noise. The engineers knew going into the tests that "sometimes the two things, performance and noise, will fight against each other," Van Zante says.

In the 1980s NASA demonstrated that the open rotor designs were very fuel efficient, but noise was still an issue. The 2009-12 test program showed that advances in computer aided design since the



The red in this computational fluid dynamics model of an open rotor engine depicts high levels of fluctuating pressure.

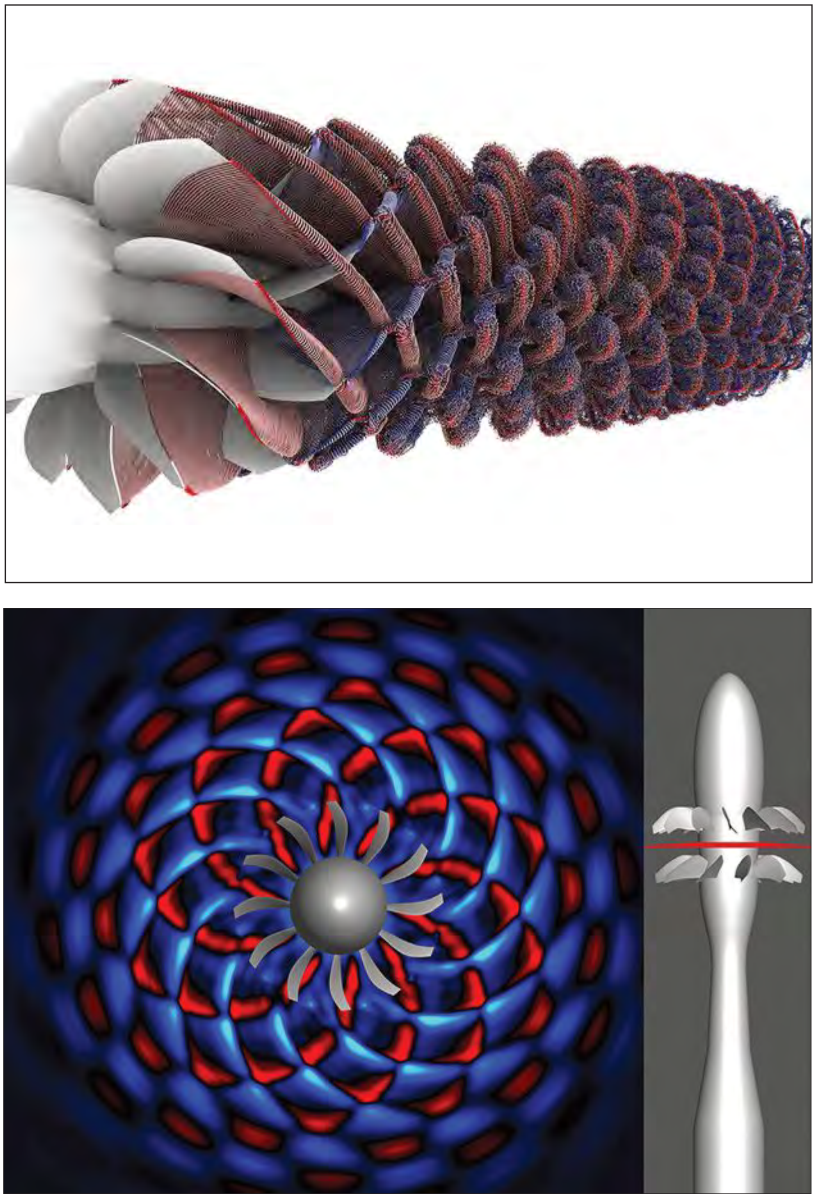
1980s made it possible to create blades that were more efficient than the best of the 1980s designs and significantly quieter at the same time, Van Zante says.

Using the propeller blade performance and noise data from the wind tunnel testing, the engineers checked the open rotor designs on computer-simulated aircraft. Van Zante says these simulations showed that open rotor engines had a significant fuel efficiency advantage over even the most advanced geared turbofan concepts. The simulated engines would beat current and pending noise regulations with room to spare. Assuming the open rotor and geared turbofans would use the same core engine technology, the fuel efficiency advantage was nearly 10 percent over the advanced geared-turbofan concepts, which were estimated to have a bypass ratio of about 14 compared to more than 30 for open rotors. The geared turbofans were quieter than the open rotor-engines, but the open rotor engines were quieter than some of the current engines in use today, such as on the Boeing 737-800.

Noise standards can be tougher to meet with open rotor engines than with conventional turbofans, because the open rotors emit tones over a wider range of frequencies. Some tones are generated by the spin of the forward rotor, and others come from the rear rotor, and others are created by the interaction of the sound waves. In fact, when charted on a frequency spectrum graph, the tones from a conventional turbofan typically show a few peaks and wide valleys, while an open rotor looks like a porcupine, Van Zante says.

Pusher configurations can be especially troublesome. The pylon creates a wake of interrupted airflows through the blades, creating "a fairly nasty noise source," Van Zante says. One strategy for reducing that noise calls for blowing air behind the pylon to fill in the wake. This strategy could be implemented during takeoffs and landings, when noise is an issue for the communities surrounding an airport. Putting the engine on top of a hybrid wing body airplane, for example, also could help. The structure would act as a noise shield for people below the aircraft.

"I suspect the ducted systems may always have noise advantages," Van Zante says using a term for nacelles. "Putting that



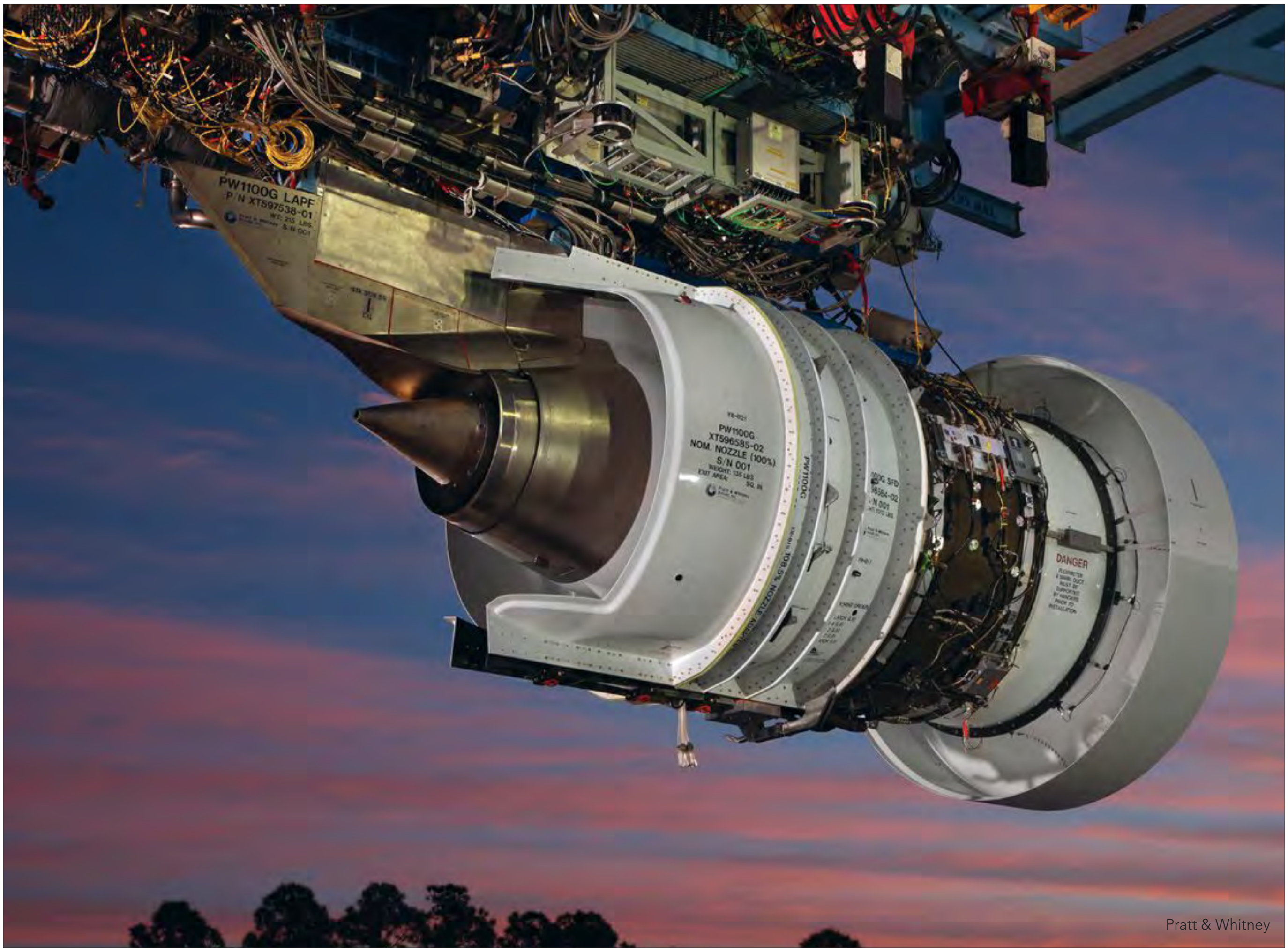
NASA/Ames

Predicting open rotor performance: Researchers at NASA's Ames Research Center made these computational fluid dynamics models to compare against data collected during engine tests at NASA Glenn. Results are to be reported at AIAA's SciTech Forum in January. **Top:** Red represents flow from the forward blades interacting with the downstream blades; blue shows the wake flow from the rear blades. **Above:** The red in the image on the right shows the location of the pressure-contour cross section depicted in the image to the left. Red in the image at left shows the high pressure values and blue shows the low pressure values.

duct around it is really useful for blocking noise. It's going to be difficult to trick the physics of an open propeller to make it as quiet as" a conventional, ducted design.

The heat nemesis

For the geared/ultra-high bypass turbofan, the gearbox is the main technical hurdle. Even assuming that the gearbox can achieve 99 percent efficiency, which would be very high, a 50-megawatt gearbox would generate 500 kilowatts of heat into


Pratt & Whitney

Pratt & Whitney's PW1100G-JM looks conventional on the outside, but a gearbox inside increases the bypass ratio.

the lubrication oil due to the friction of the gears. A home heating system for a small or medium sized apartment, by contrast, generates 10 kilowatts of heat, depending on the furnace, with 1 kilowatt equal to about 3,412 BTU per hour, Brouckaert says. The issue for the engine designers is how to increase the efficiency of the gearbox and dissipate the heat created for the lubrication oil for the gears and bearings in the gearbox.

On the plus side, the gearbox will be simpler than an open rotor gearbox. It will be a reduction gearbox, with one input shaft from the turbine into the gearbox, where the fast-spinning turbine shaft is geared down, and one output shaft from the gearbox to the slower-turning front fan. By contrast, the open rotor gearbox will be a differential gearbox, which transfers the power from the spinning turbine's shaft to two shafts spinning the rotor blades in opposite directions.

The geared/ultra-high bypass engines also will face weight challenges, especially with their gearboxes. Thinner nacelles, with added functions to eliminate unnecessary tubing and wiring, will be required in the new designs. A bit of good news is that thrust reversers, which divert an engine's exhaust forward to slow a plane after landing, won't be needed on future geared engines. Instead, the turbofan blades will be designed to be pitched or turned to different angles to optimize the engine's efficiency at different speeds, and so they can be pitched in the opposite direction to act like a brake.

Geared turbofan developers also must create new, lightweight fans built from composite materials, plus highly efficient core and variable fan nozzles.

Each side in the great engine debate has plenty of work ahead.

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- Liquid Propulsion
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- Propellants and Combustion
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- Propulsion Education
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AIAA
Shaping the Future of Aerospace

15-885

Out of the

25 Years Ago, January 1991

Jan. 17 Operation Desert Storm begins when U.S.-led coalition forces send waves of air strikes against Iraq in the first stage in the war to expel Iraqi forces from Kuwait. These strikes are led by U.S. Army Apache helicopters that knock out Iraqi early-warning radar and Lockheed F-117 "stealth fighters" that drop highly accurate precision-guided bombs. Over 1,300 sorties are made on this day alone. David Baker, "Flight and Flying," p. 483.

Jan. 18 Eastern Airlines goes out of business. After flying while in bankruptcy for two years and losing $2.5 million each day, Eastern runs out of money as numerous drastic and draconian reorganization attempts fail to stem the losses. Thousands of people are left unemployed and the first of the so-called "Big Four" trunk carriers disappears. R.E.G. Davies, "Eastern: An Airline and Its Aircraft," p. 100.

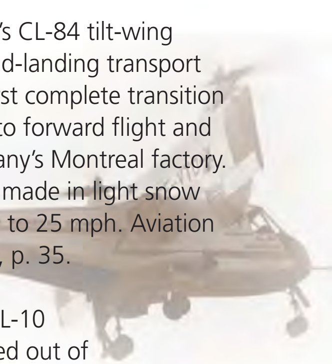
50 Years Ago, January 1966

Jan. 6 The Air Force/North American Aviation six-engine, Mach 3 XB-70A No. 1 Valkyrie makes its longest and heaviest flight to date in its test program. The flight takes three hours and 40 minutes. The aircraft's gross weight at takeoff is 530,000 pounds. The XB-70 had been the prototype of the nuclear-armed, deep-penetration B-70 strategic bomber but that program was canceled in 1961, and the aircraft was used in a test program to study the effects of long-duration supersonic flight. Two prototype aircraft were built and designated the XB-70A. Aviation Week, January 17, p. 39.

Jan. 10 The first prototype Model 206A Jet Ranger helicopter from Bell Helicopter makes its initial flight at the Greater Southwest International Airport at Fort Worth, Texas. The Model 206A is a commercial version of Bell's OH-4A entry in the Army light observation helicopter competition. Aviation Week, January 17, p. 39.

Jan. 13 The High-E Boost Experiment (HIBEX) missile is fired in a vertical trajectory at the White Sands Proving Ground, New Mexico. The short conical body, solid-fuel-powered HIBEX is a design predecessor and competitor to the two-stage solid-fuel Sprint anti-ballistic missile and there is a later technological transfer from that program to the Sprint development. HIBEX's rocket motor produces some 490,000 pounds of thrust in about one second. Missiles and Rockets, January 24, p. 9.

Jan. 14 Sergei Pavlovich Korolev, probably the most important man in the Soviet space program, dies of complications during surgery in Moscow at age 59. However, due to the top secrecy of the program, Korolev's identity has been unknown to the vast majority of the Russian people until now and he has been referred to only as the "Chief Designer." Born in 1906, Korolev was responsible for spearheading the design and carrying out the construction and launch of the vehicle that orbited Sputnik 1 in 1957. He also created the designs of several other key Soviet space projects, including the launch of Yuri Gagarin, the first man into space in 1961 and the Luna series of unmanned spacecraft. He started as an aircraft designer, then in the 1930s joined the GIRD (Group for the Study of Reactive Motion) that experimented with rocket motors. From 1945, he was involved in the development of the Soviet Union's first missiles and by 1957 had developed the country's first ICBM, the R-7, that Korolev converted, with upper stages, to the world's first satellite launch vehicle. David Baker, "Spaceflight and Rocketry — A Chronology," p. 189; Aviation Week, January 24, p. 37; New York Times, January 16, p. 82.



Jan. 17 Canadair's CL-84 tilt-wing vertical-takeoff-and-landing transport plane makes its first complete transition flight from hover to forward flight and back at the company's Montreal factory. The VTOL flight is made in light snow with wind gusting to 25 mph. Aviation Week, January 24, p. 35.

Jan. 18 NASA's HL-10 Lifting Body is rolled out of Northrop's Norair division plant in Hawthorne, California, and is delivered to the Flight Research Center at Edwards Air Force Base in California. The tri-finned, delta-shaped craft with flat underside is to be used to help solve control problems of future manned spacecraft entering Earth's atmosphere. The HL-10 is carried up by a B-52, then released at about 45,000 feet and glides down to a landing. Bell X-1 type XLR-11 rocket engines are afterward installed and used for power. The aerodynamic data acquired later become important in the development of the space shuttle. David Baker, "Spaceflight and Rocketry — A Chronology," p. 189; Aviation Week, January 24, p. 33.

Past

An Aerospace Chronology
by **Frank H. Winter**
and **Robert van der Linden**

Jan. 27 British Overseas Airways Corp.'s new Boeing 707-320C freighter begins twice-weekly service over its North Atlantic route. Aviation Week, January 17, p. 46.

Jan. 28 The huge Saturn 5 "crawler" road transport vehicle completes its first load-carrying run at Kennedy Space Center. The crawler lifts the 447-foot, 10.6-million-pound Launch Umbilical Tower No. 1 and moves it .75 mile in about nine hours. The $7 million crawler is made by the Marion Power Shovel Co. Missiles and Rockets, February 7, p. 34.

Jan. 20 The solid-fuel powered Little Joe 2 launch vehicle completes an Apollo abort test in boosting a 5-ton unmanned "boilerplate" Apollo spacecraft to a 10-mile altitude at the White Sands Missile Range in New Mexico, even though telemetry is lost seconds after the launch. This is the first abort test with a flight model of the Apollo spacecraft. Aviation Week, January 24, p. 38; New York Times, January 21, p. 10.

Jan. 31 The Soviet Union launches its 3,500-pound Luna 9 spacecraft. It soft-lands at Oceanus Procellarum, west of the craters Reiner and Marius, on February 3 and transmits TV pictures for about 20 minutes. Luna 9 is the first spacecraft to soft-land on the moon or any planetary body other than Earth. The lander weighs 218 pounds. A total of 27 individual photographs of the lunar surface images are transmitted, including five panoramas. But the mission ends when the batteries run out. Aviation Week, February 7, p. 31 and February 14, pp. 29, 32.

75 Years Ago, January 1941

Jan. 5 Amy Johnson Mollison, Britain's most famous female pilot, drowns in the cold waters of the Thames Estuary when she is forced to bail out of the twin-engined trainer aircraft she is flying for the Royal Air Force's Air Transport Auxiliary. Mollison, who began flying in the 1920s, made one of her greatest flights between England and Australia in 1930 in a second-hand Gipsy Moth light airplane. She subsequently made many great and hazardous flights, and at the beginning of World War II became an ATA ferry pilot. Flight, January 16, p. 50; "The Aeroplane," January 17, p. 67.

Jan. 9 The Manchester 3, prototype of the Avro Lancaster, takes to the air for the first time. This version has a modified fuselage and is fitted with four Rolls-Royce Merlin engines instead of the two unreliable Rolls-Royce Vulture powerplants. The plane, which enters service early in 1942, becomes the RAF's most famous and successful heavy bomber of the war. Owen Thetford, "Aircraft of the Royal Air Force Since 1918," p. 56.

Jan. 15 Lord Wakefield, the British philanthropist known as the "Patron Saint of Aviation" because of his generous financial support of aviation in Britain, dies at age 81. Among many aviation events, Wakefield financed the long-distance Australian and South African flights of Sir Alan Cobham, the Australian flight of (then) Amy Johnson, and Amy Johnson Mollison's first flight from Australia to England. He also provided Wakefield scholarships for RAF cadets, and as vice president of the Institution of Aeronautical Engineers presented an annual gold medal for the best invention for safety in flight. He also bestowed aviation's Wakefield Cup and similar awards. Flight, January 23, p. 71; "The Aeroplane," January 24, p. 103.

Jan. 18 China National Aviation, a subsidiary of Pan American Airways, begins a survey flight on a new route between China and India with a Douglas DC-2. The flight is made between Chungking and Calcutta. Meanwhile, negotiations are ending for a regular service between Calcutta and Hong Kong. "The Aeroplane," January 31, p. 152.

100 Years Ago, January 1916

Jan. 12 Famed German aces and brilliant tacticians Max Immelmann and Oswald Boelcke are given the first Order Pour le Merite awards for aviators. This, the famous "Blue Max," is awarded to aviators who down at least eight enemy aircraft. David Baker, "Flight and Flying," p. 83.

Jan. 13 The Curtiss Aeroplane and Motor Corp. is formed with the merger of several disparate Curtiss enterprises and quickly expands to become one of America's largest aviation manufacturers. The new corporation builds over 5,000 aircraft and engines before the end of World War I, particularly the famous JN-4 "Jenny" trainer and a series of excellent combat flying boats. Peter Bowers, "Curtiss Aircraft: 1907-1947," p. 70.

Jan. 30 The third and last airship attack against Paris occurs when German L.Z. 79 bombs the city. A. van Hoorebeeck, "La Conquete de L'Air," p. 115.

UCLA Engineering

University of California, Los Angeles
Mechanical and Aerospace Engineering Department

The Mechanical and Aerospace Engineering Department is accepting applications to fill two full-time tenure track faculty positions open in all ranks.

The position (Tracking #JPF01762) is in ***Aerospace Engineering***. Candidates should have demonstrated technical strength and research focus in the fundamentals that underlie advanced aerospace applications. Areas of particular interest include but are not limited to: (1) advanced aircraft, with emphasis on autonomous systems and/or fuel efficient air vehicles, or (2) advanced spacecraft, with emphasis on formation flight, spacecraft interactions, space exploration, remote sensing/communications, and/or mission design.

The position (Tracking #JPF01763) is in ***Mechanical Engineering***. Areas of interest include but are not limited to: distributed transducers for mechanical systems such as robots; adaptive transducers capable of changing bulk or surface properties; transduction networks with local intelligence; and emerging manufacturing technologies for such transducers. Candidates whose technical interests complement and augment the Department's existing strength in the fields of MEMS/Nanotechnology and Design/Robotics/Manufacturing are of particular interest.

We are interested in outstanding candidates who are committed to excellence in teaching and scholarship and to a diverse campus climate. The University of California is an Equal Opportunity/Affirmative Action Employer. All qualified applicants will receive consideration for employment without regard to race, color, religion, sex, sexual orientation, gender identity, national origin, disability, age or protected veteran status. For the complete University of California nondiscrimination and affirmative action policy, see: UC Nondiscrimination & Affirmative Action Policy.

Please apply by submitting your materials via our online application site, https://recruit.apo.ucla.edu/apply. Only online applications will be accepted and evaluated on a rolling basis while the submission site is open until March 31, 2016.

TEXAS A&M UNIVERSITY

IT'S TIME FOR MORE AGGIE ENGINEERS

FACULTY POSITION - DEPARTMENT OF AEROSPACE ENGINEERING
TEXAS A&M – DWIGHT LOOK COLLEGE OF ENGINEERING

The Department of Aerospace Engineering at Texas A&M University invites applications for a tenured or tenure-track faculty position at the assistant, associate, or full professor level with expertise in aerothermal sciences with applications to aerospace systems. The successful applicant will be expected to teach at the undergraduate and graduate levels, develop an independent, externally funded research program, advise graduate students, participate in all aspects of the department's mission, and serve the profession.

Texas A&M is located in the twin cities of Bryan and College Station, with a population of more than 175,000, and is conveniently located in a triangle formed by Dallas, Houston and Austin. Texas A&M has more than 55,000 graduate and undergraduate students enrolled. Research expenditures at Texas A&M total more than $820 million annually, ranking in the top tier of universities nationwide. With an endowment valued at more than $5 billion, the university ranks fourth among U.S. public universities and 10th overall. Texas A&M is aware that attracting and retaining exceptional faculty often depends on meeting the needs of two careers and having policies that contribute to work-life balance. For more information visit http://dof.tamu.edu/content/balancing-work-and-life. With over 400 tenured/tenure-track faculty members and more than 13,900 students, the Dwight Look College of Engineering is one of the largest engineering schools in the country. The college is ranked seventh in graduate studies and eighth in undergraduate programs among public institutions by *U.S. News & World Report*, with seven of the college's 13 departments ranked in the Top 10. The Look College is also ranked 10th in the Academic Ranking of World Universities compiled by Shanghai Jiao Tong University. The American Society for Engineering Education ranks the Look College second in research expenditures.

The Department of Aerospace Engineering was formed in 1940. It has 36 core faculty members, 6 jointly appointed faculty members, including 5 National Academy of Engineering Members. We currently enjoy an enrollment of over 500 undergraduate and 150 graduate students. Our students are offered a modern curriculum that is balanced across the three principal disciplines of aerospace engineering: aerodynamics and propulsion, dynamics and control, and materials and structures. In recent years, the department has built a strong national program based on the quality of its faculty and programs; among public institutions, its graduate aerospace engineering program ranks 5th in the most recent *U.S. News & World Report* rankings.

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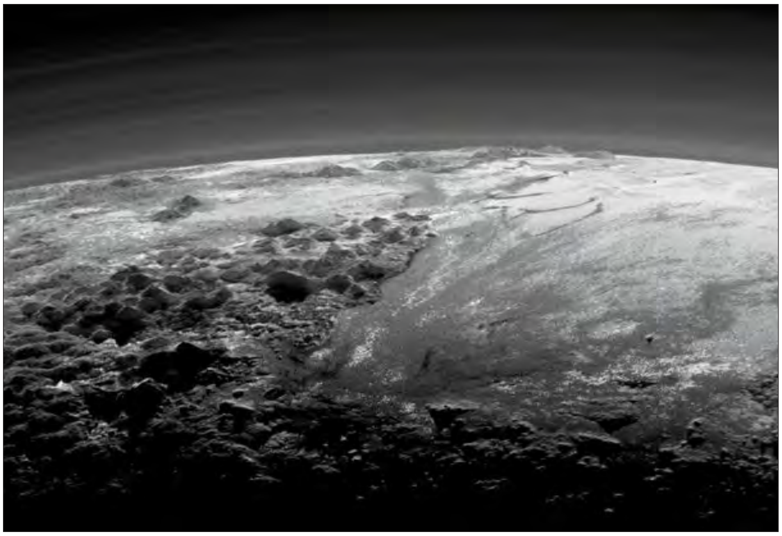
Applicants must have an earned doctorate in aerospace engineering or a closely related engineering or science discipline. Strong written and verbal communication skills are required. Applicants should consult the department's website to review our academic and research programs (http://engineering.tamu.edu/aerospace).

Applicants should submit a cover letter, curriculum vitae, teaching statement, research statement, and a list of four references (including postal addresses, phone numbers and email addresses) by applying for this specific position at www.tamengineeringjobs.com. Full consideration will be given to applications received by January 15, 2016. Applications received after that date may be considered until positions are filled. It is anticipated the appointment will begin fall 2016.

The members of Texas A&M Engineering are all Equal Opportunity/Affirmative Action/Veterans/Disability employers committed to diversity. It is the policy of these members to recruit, hire, train and promote without regard to race, color, sex, religion, national origin, age, disability, genetic information, veteran status, sexual orientation or gender identity.

AIAA Bulletin



The AIAA Niagara Frontier Section recently hosted a lecture by Alice Bowman, Mission Operations Manager at the Johns Hopkins University Applied Physics Laboratory for the New Horizons mission to Pluto. Her talk covered the responsibilities of Mission Operations, and the challenges and accomplishments of New Horizons, including imaging a volcanic eruption on Io while passing Jupiter for a gravity assist, losing contact with the spacecraft as it approached Pluto, and her favorite image of Pluto (see above).

The above image was taken on 14 July 2015, after the New Horizons spacecraft had its closest approach to Pluto and looked back toward the sun to caption this view. More information on the Niagara Frontier Section's event can be found on page **B11**. (Image credit: NASA/JHUAPL/SwRI)

JANUARY 2016

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Event & Course Schedule

DATE	MEETING (Issue of *AIAA Bulletin* in which program appears)	LOCATION	ABSTRACT DEADLINE
2016			
2–3 Jan	**2nd AIAA CFD Aeroelastic Prediction Workshop**	San Diego, CA	
2–3 Jan	**Guidance of Unmanned Aerial Vehicles**	San Diego, CA	
2–3 Jan	**Systems Requirements Engineering**	San Diego, CA	
3 Jan	**Structural Dynamics of Rocket Engines Tutorial**	San Diego, CA	
3 Jan	**General Standards and Architecture Tutorial**	San Diego, CA	
4 Jan	**AIAA Associate Fellows Recognition Ceremony and Dinner**	San Diego, CA	
4–8 Jan	**AIAA SciTech 2016 (AIAA Science and Technology Forum and Exposition)** **Featuring:** **24th AIAA/AHS Adaptive Structures Conference** **54th AIAA Aerospace Sciences Meeting** **AIAA Atmospheric Flight Mechanics Conference** **15th Dynamics Specialists Conference** **AIAA Guidance, Navigation, and Control Conference** **AIAA Information Systems—Infotech@Aerospace Conference** **AIAA Modeling and Simulation Technologies Conference** **18th AIAA Non-Deterministic Approaches Conference** **57th AIAA/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference** **9th Symposium on Space Resource Utilization** **3rd AIAA Spacecraft Structures Conference** **34th Wind Energy Symposium**	San Diego, CA	**2 Jun 15**
25-28 Jan†	**Annual Reliability and Maintainability Symposium (RAMS)**	Tucson, AZ (Contact: Sean Carter, seancarter67@gmail.com, www.rams.org)	
Feb–Jun	**Introduction to Computational Fluid Dynamics**	Home study course	
Feb–Jun	**Advanced Computational Fluid Dynamics**	Home study course	
Feb–Jun	**Computational Fluid Turbulence**	Home study course	
Feb–Jun	**Spacecraft Design and Systems Engineering**	Home study course	
14–18 Feb†	**26th AAS/AIAA Space Flight Mechanics Meeting**	Napa, CA (Contact: Ryan Russell, 512.471.4190, ryan.russell@utexas.edu, www.space-flight.org/docs/2016_winter/2016_winter.html)	
8–10 Mar	**AIAA DEFENSE 2016 (AIAA Defense and Security Forum)** **Featuring:** **AIAA Missile Sciences Conference** **AIAA National Forum on Weapon System Effectivenss** **AIAA Strategic and Tactical Missile Systems Conference**	Laurel, MD	**8 Oct 15**
5–12 Mar†	**2016 IEEE Aerospace Conference**	Big Sky, MT (Contact: Erik Nilsen, 818.354.4441, Erik.n.nilsen@jpl.nasa.gov, www.aeroconf.org)	
16 Mar	**AIAA Congressional Visits Day**	Washington, DC	
19–21 Apr†	**16th Integrated Communications and Surveillance (ICNS) Conference**	Herndon, VA (Contact: Denise Ponchak, 216.433.3465, denise.s.ponchak@nasa.gov, http://i-cns.org)	
5 May	**Aerospace Today ... and Tomorrow—An Executive Symposium**	Williamsburg, VA	
16–20 May†	**SpaceOps 2016: 14th International Conference on Space Operations**	Daejeon, Korea	**30 Jul 15**
30 May–1 Jun†	**22nd AIAA/CEAS Aeroacoustics Conference**	Lyon, France	**9 Nov 15**
30 May–1 Jun†	**23rd Saint Petersburg International Conference on Integrated Navigation Systems**	Saint Petersburg, Russia (Contact: Ms. M. V. Grishina, +7 812 499 8181, icins@eprib.ru, www.elektropribor.spb.ru)	
13–17 Jun	**AIAA AVIATION 2016 (AIAA Aviation and Aeronautics Forum and Exposition)** **Featuring:** **32nd AIAA Aerodynamic Measurement Technology and Ground Testing Conference** **34th AIAA Applied Aerodynamics Conference**	Washington, DC	**5 Nov 15**

DATE	MEETING (Issue of *AIAA Bulletin* in which program appears)	LOCATION	ABSTRACT DEADLINE
	AIAA Atmospheric Flight Mechanics Conference **8th AIAA Atmospheric and Space Environments Conference** **16th AIAA Aviation Technology, Integration, and Operations Conference** **AIAA Flight Testing Conference** **8th AIAA Flow Control Conference** **46th AIAA Fluid Dynamics Conference** **17th AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference** **AIAA Modeling and Simulation Technologies Conference** **47th AIAA Plasmadynamics and Lasers Conference** **46th AIAA Thermophysics Conference**		
15 Jun	**Aerospace Spotlight Awards Gala**	Washington, DC	
16–17 Jun	**6th AIAA CFD Drag Prediction Workshop**	Washington, DC	
5–8 Jul†	**ICNPAA 2016 Mathematical Problems in Engineering, Aerospace and Sciences**	University of La Rochelle, France (Contact: Prof. Seenith Sivasundaram, 386.761.9829, seenithi@gmail.com, www.icnpaa.com)	
25–27 Jul	**AIAA Propulsion and Energy 2016** **(AIAA Propulsion and Energy Forum and Exposition)** **Featuring:** **52nd AIAA/SAE/ASEE Joint Propulsion Conference** **14th International Energy Conversion Engineering Conference**	Salt Lake City, UT	**12 Jan 16**
13–16 Sep	**AIAA SPACE 2016** **(AIAA Space and Astronautics Forum and Exposition)** **Featuring:** **AIAA SPACE Conference** **AIAA/AAS Astrodynamics Specialist Conference** **AIAA Complex Aerospace Systems Exchange**	Long Beach, CA	**25 Feb 16**
25–30 Sept†	**30th Congress of the International Council of the Aeronautical Sciences (ICAS 2016)**	Daejeon, South Korea (Contact: www.icas.org)	**15 Jul 15**
25–30 Sept†	**35th Digital Avionics Systems Conference**	Sacramento, CA (Contact: Denise Ponchak, 216.433.3465, denise.s.ponchak@nasa.gov, www.dasconline.org)	
26–30 Sept†	**67th International Astronautical Congress**	Guadalajara, Mexico (Contact: www.iac2016.org)	
17–20 Oct†	**22nd KA and Broadband Communications Conference and the 34th AIAA International Communications Satellite Systems Conference**	Cleveland, OH (Contact: Chuck Cynamon, 301.820.0002, chuck.cynamon@gmail.com)	
2017			
9–13 Jan	**AIAA SciTech 2017** **(AIAA Science and Technology Forum and Exposition)** **Featuring:** **25th AIAA/AHS Adaptive Structures Conference** **55th AIAA Aerospace Sciences Meeting** **AIAA Atmospheric Flight Mechanics Conference** **AIAA Information Systems — Infotech@Aerospace Conference** **AIAA Guidance, Navigation, and Control Conference** **AIAA Modeling and Simulation Technologies Conference** **19th AIAA Non-Deterministic Approaches Conference** **58th AIAA/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference** **10th Symposium on Space Resource Utilization** **4th AIAA Spacecraft Structures Conference** **35th Wind Energy Symposium**	Grapevine, TX	

For more information on meetings listed above, visit our website at www.aiaa.org/calendar or call 800.639.AIAA or 703.264.7500 (outside U.S.).

†Meetings cosponsored by AIAA. Cosponsorship forms can be found at https://www.aiaa.org/Co-SponsorshipOpportunities/.

AIAA Continuing Education courses.

Aerospace Spotlight Awards Gala
Wednesday, 15 June 2016
Ronald Reagan Building and International Trade Center
Celebrate!
AIAA members like Orville Wright and Charles A. Lindbergh have been celebrating outstanding accomplishments in aerospace since the first Honors Night Meeting held on the 34th anniversary of the Wright Brothers flight in 1937. We continue that worthy tradition this year at the 2016 Aerospace Spotlight Awards Gala on 15 June 2016.
Winner of the 1937 Reed Award, Eastman N. Jacobs said, "In honoring others, we honor ourselves." As a member of our aerospace community we hope that you will join fellow colleagues, constituents, and officials from the DoD, NASA, the FAA, and other government agencies for an evening of socializing and celebration.
We will be celebrating the recipients of the following awards:
• AIAA Foundation Award for Excellence
• Goddard Astronautics Award
• Reed Aeronautics Award
• International Cooperation Award
• Public Service Award
• Distinguished Service Award
• Daniel Guggenheim Medal
• 2016 AIAA Fellows and Honorary Fellows
Purchase tickets and tables online at www.aiaa.org/gala2016
AIAA
Shaping the Future of Aerospace
16-965

From the Corner Office

EXPERIENCING AN AEROSPACE RENAISSANCE

Sandy H. Magnus, Executive Director

As I start my fourth year with AIAA and reflect back on all of the things I have learned in the past three years I have to say: What an amazing time to be in aeronautics and astronautics! Across all sectors—industry, academia, and government—innovative and entrepreneurial aerospace students and professionals are transforming our community at a dizzying pace. In my position I am fortunate to hear from members about the latest aerospace-related innovations that are making the world safer, more connected, more accessible, and more prosperous. This work is going on all over the industry but is not obvious to those outside of our aerospace family. For our members, the Daily Launch highlights all of the progress, achievements, and milestones that we are accomplishing, but mainstream media does not focus on highlighting this work. What we do in the aerospace industry touches people all over the world, and the general public remains largely uninformed of the benefits they receive from it. Mass media tends to focus on the "problems" or negative news while rarely balancing that approach with the daily stories involving success and innovation. Consequently, the public easily can reach the skewed conclusion that aerospace is in distress. My conclusion is exactly the opposite—the aerospace industry is experiencing a renaissance and our community generates a lot more amazing and inspiring "good news" than "bad news" every year.

Far above us, large and small aircraft transport nearly 3 billion people a year on trips near and far, and it is nine times safer to fly than if those same people had driven to their destinations. Without question, aviation is the safest it has ever been. While we hear word of plant closures and company failures, we don't often hear that aviation employs more than 55 million people around the world and provides trillions of dollars to the global economy. And we are seeing marvelous innovations in design and efficiency—3D manufacturing is making an impact on airplane and engine design and production. New engines, like the LEAP engine and geared turbofans, are being explored to lower fuel consumption, making aircraft more efficient and environmentally friendly. This year also brought the first viable plans for supersonic air transportation since the 1970s. We saw Solar Impulse attempt to become the first solar-powered aircraft to fly around the world. We have seen new aircraft arrive in the marketplace, like the Gulfstream Aerospace G-650, which continues to earn industry accolades; Japan's Mitsubishi Regional Jet; and Honda Aircraft Company's HondaJet, which in December achieved type certification from the FAA. The aero sector is thriving.

In space exploration, we stand on the brink of a new age of exploration and discovery—not since the Apollo project has our nation been so poised to move forward in its physical exploration of our solar system. We are steadily moving toward the day when astronauts will be able to launch from the United States to the ISS, the moon, and to Mars. Every time I consider the age we are about to enter, I can't help but wonder if this is how the explorers of old felt when they stood at the edge of the age of exploration. The Orion-SLS program is progressing as it prepares for the next test milestone, EM-1. Beyond the Orion-SLS program, our community is currently working on plans to visit and acquire part of an asteroid for closer study as well as to demonstrate technology required for missions farther out in the solar system. Also, in late 2015, President Obama signed a bill that approves asteroid mining—which means in one lifetime, humanity will have gone from digging for minerals in the dirt to digging for them in space, an amazing step forward thanks to our community's inventiveness and resourcefulness.

In private space development there have been some notable challenges over the past few years, but as Bill Gerstenmaier said, "Launching rockets is an incredibly difficult undertaking, and we learn from each success and each setback." We have already seen Orbital ATK's Cygnus successfully return to the ISS, and at this writing we are eagerly anticipating the SpaceX Falcon 9's return to flight. We have seen Blue Origin and SpaceX advance the technology necessary to have reusable rockets. With a thriving entrepreneurial community engaging in space, we will continue to see new startups, new ventures, and new technology driving us to new levels of success and knowledge. The halcyon days of private space are still ahead of us, which is very exciting. In all, the global space economy reached a total of $330 billion dollars worldwide in FY2015, a nine percent expansion over previous years.

Because the aerospace industry has been and continues to be so incredibly successful, I suspect that the public, media, and others outside of our community take us and our incredible record of success for granted. We have a society that is used to seeing spacecraft send back pictures from other planets and doesn't consider the 100,000 flights per day around the world that *DO* depart and arrive safely as anything remarkable. These are testaments to the commitment to safety, security, and reliability for which the aerospace industry strives every day. We all know how much passion, energy, and effort we put into achieving each and every milestone that we reach. It is important to continue to tell our stories and AIAA is committed to doing just that. The things that our industry routinely accomplishes are, in fact, extraordinary, and those extraordinary things deserve positive coverage too.

We have so many reasons be proud of our community, even if those reasons are not well advertised or apparent to society at large. It is indeed a great time to be in aerospace. As a professional, you are shaping the future of our community daily; as a student you are preparing to help take what today's professionals are doing and go farther. As an AIAA member you are helping drive the collaboration and conversations necessary to make today's aerospace dreams tomorrow's reality. And we have so much fun doing it!

Registration Now Open for Congressional Visits Day

Make a difference in the future of aerospace at AIAA Congressional Visits Day (CVD; **http://www.aiaa.org/CVD**) on 16 March 2016. This event brings together passionate aerospace professionals and students in Washington, D.C., for a day of advocacy and awareness with lawmakers. Join us and let your voice be heard by your state's congressional delegation and staff on key policy issues that matter most. To register, go to **http://www.aiaa.org/CVD2016**.

AIAA ROCKY MOUNTAIN SECTION 4TH ANNUAL TECHNICAL SYMPOSIUM

Pamela A. Burke

On 6 November 2015, an amazing event occurred at the Colorado School of Mines—the 4th AIAA Annual Rocky Mountain Section (RMS) Annual Technical Symposium (ATS). This event brought together participants from Colorado's academic, industrial, and government aerospace communities. As is the tradition of the RMS ATS, the range of topics addressed in panels, presentations, and special guest speakers was aerospace eclectic, representing the community that the RMS serves.

The day was full with four parallel presentation tracks on a wide variety of aerospace topics running throughout the day, interspersed by four panel discussions. Breakfast, mid-morning snacks, lunch, and an afternoon break provided an opportunity for networking and follow-up discussions. In addition to the presentation and panel sessions, there were sponsor and vendor booths and exhibits and participant posters available to browse through during the day.

The day started with the ATS 2015 Chair Tyler Franklin welcoming attendees and participants and introducing the ATS kickoff speaker, Colorado School of Mines President Dr. Paul Johnson. The next speaker was Dr. Roger McNamara, representing Diamond Sponsor Lockheed Martin, who discussed the history and future of the Orion Program. Later in the day, John Cuseo of Advanced Solutions, Inc., and Steve Bailey of Deep Space Systems Inc., the other ATS Diamond sponsors, presented an overview of the fascinating things their companies accomplish.

The keynote speaker, Dr. Alton D. Romig Jr., executive officer of the National Academy of Engineering, gave an enlightening talk on the National Academy Engineering. Starting with its initiation under President Abraham Lincoln, Dr. Romig brought the audience through its evolution into today's authoritative technical advising body for Congress and the U.S. presidents on matters involving engineering and technology. He told a fascinating story of how the National Academies have aligned with the nation's growth and continue to serve in identifying and overcoming today's toughest challenges.

The two morning panels were "Aerospace Initiatives in the Rocky Mountain Region," which addressed policy and governmental roles and interfaces and included the participation of Congressman Ed Perlmutter, whose district includes the Colorado School of Mines, and "Higher Education and Industry: Partners in Flight," which featured experts from local academia and industry. Afternoon panels were "The Next Frontier: New Aerospace Technologies," which included Dr. Merri Sanchez, and "Aerospace Leadership: Navigating a Successful Career," which included Dr. Romig and Adm. Richard Truly.

Dr. Paul Johnson (Photo credit: Chris Zeller)

In addition to the three Diamond Sponsors—Lockheed Martin, Advanced Solutions, and Deep Space Systems, other ATS sponsors included Ball Aerospace & Technologies Corp, Surrey Satellite Technology US, SEAKR Engineering, United Launch Alliance (ULA), Red Canyon Engineering & Software, ISYS Technologies, and the University of Wyoming. Several of the sponsors were represented on the panels.

By the numbers this was the biggest ATS yet with four panels made up of 22 panelists, 32 tech talk presentations (with students and professionals representing 25 different organizations), and 14 poster presentations. There were 264 registrants representing over 60 organizations, up more than 40% from 2014. Student participation increased to 36% in 2015, and there were 11 sponsors. The new RMS professional and student attendees were encouraged to join AIAA as part of their ATS experience with the added benefit of a special ATS sign-up deal.

Closing remarks by Paul Anderson, RMS Chair, and Tyler Franklin brought another successful ATS to an end. Of note, through the evolution of the ATS, the AIAA RMS has found that having a university as the venue and partner has many benefits, including enhancing the cost effectiveness of the ATS. Partnership with a university provides benefits for all, including school participation in logistics, exposure, and support of the event (including the draw of high profile, university-related speakers); visibility for the school as a member of the aerospace community; greater student participation in the ATS both as part of the ATS team and as attendees and presenters; greater opportunities for industry/academia and professional/student interaction; and a growth opportunity for the Section and Student Branch membership.

More information about the 2015 ATS can be found at the RMS website: **www.aiaa-rm.org**.

Tyler Franklin opening ATS 2015 (Photo credit: Chris Zeller)

Dr. Al Romig, Keynote Speaker (Photo credit: Chris Zeller)

AIAA PARTICIPATES IN INTERNATIONAL SPACE EVENT

The International Astronautical Congress (IAC) is the premiere annual event of the International Astronautical Federation (IAF) and its partner organizations, the International Academy of Astronautics (IAA) and the International Institute of Space Law (IISL). The event brings together thousands of decision makers from across all sectors of the global space industry to discuss the latest space discoveries and developments, as well as to explore opportunities to partner and collaborate. Many AIAA members participate in the IAC, and some are active on the committees that comprise the IAF, IAA, and IISL.

Hosted in October by the Israel Space Agency in Jerusalem, Israel, this year's week-long Congress included plenary sessions highlighting the ongoing activities and advances of the world's leading space agencies (China, the European Space Agency (ESA), India, Israel, Japan, Russia, and the United States), as well as a discussion on the merits of international cooperation in addressing exploration goals and terrestrial challenges, 50 years of spacewalking history, ESA's Rosetta mission, and NASA's Orion EFT-1 mission. With over 2,100 delegates representing 60 nations, IAC 2015 provided an excellent opportunity to engage across the international space community. Of particular note, at this year's IAF General Assembly, one of our AIAA Board members, Mary Snitch of Lockheed Martin Corporation, was elected as a Vice President on the governing Bureau of the IAF.

The AIAA staff delegation at IAC 2015 focused its efforts on engaging with its existing partners, while also exploring opportunities for further collaboration with new organizations and IAF members. To this end, AIAA Executive Director Sandy Magnus met with representatives from our sister society, l'Association Aéronautique et Astronautique de France (3AF), as well as the German Society for Aeronautics and Astronautics (DGLR), Women in Aerospace (WIA)-Europe, and the Space Generation Advisory Council (SGAC), to discuss collaboration opportunities. These discussions yielded concrete approaches to partnering with our international counterparts in a variety of ways, including speaker and article exchanges and promoting technical committee member networking opportunities. IAC 2015 also provided AIAA with an opportunity to promote its intention to bid to host IAC 2019 in Washington, DC. On the second afternoon of IAC 2015, AIAA hosted a reception, providing members and conference attendees with an informal opportunity to interact with the AIAA delegation and learn more about the bid.

The IAF was founded in 1951 to allow the spacefaring nations of the time to engage freely at the height of the Cold War. Its primary missions include promoting cooperation, advancing international development, sharing knowledge, recognizing achievements, preparing the workforce of tomorrow, and raising awareness of global space activities. As a founding member, AIAA has remained active over the years, partnering with the IAF on a number of occasions to host previous IACs, two World Space Congresses, and the Global Space Exploration Conference. To learn more about the IAF, please visit: **http://www.iafastro.org**.

For more information about the IAC, including instructions for submitting a paper to present at IAC 2016 in Guadalajara, Mexico, please visit: **http://www.iafastro.org/events/iac/**.

To learn more about AIAA's bid to host IAC 2019 in Washington, DC, please visit: **http://www.iac2019dc.org**.

CELEBRATE 20 YEARS WITH A $20 DONATION

The AIAA Foundation is excited to be celebrating our 20th anniversary with a fundraising campaign to engage your support. With the goal of 10,000 members each donating $20, the AIAA Foundation hopes to raise $200,000.

Your generous support of the AIAA Foundation will significantly enhance our educational programming and provide the funding necessary to support our K–12 STEM programs, including classroom grants and hands-on activities, university design competitions, student conferences, and recognition awards.

The AIAA Foundation has already accelerated the future of aerospace by:

- Funding more than 1,200 K–12 Classroom Grants, impacting over 120,000 precollege students
- Awarding aerospace scholarships to more than 1,300 undergraduate and graduate students
- Supporting more than 400 student conferences, engaging more than 13,000 students with practical, hands-on STEM-based projects
- Sponsoring design competitions that have generated more than 1,200 teams, engaging more than 14,000 students
- Inspiring more than 200 student branches, 8,000 student members, and 4,000 Educator Associates with resources to further their career path

With your support of this campaign, the impact to our programming will be significant. Please consider making a $20 tax-deductible donation — $20 for the 20 years of leadership and resources that the AIAA Foundation has provided.

AIAA strongly believes in the importance of our educational programs and will match individual and corporate donations up to $1 million dollars (of unrestricted funds).

To learn more and to donate, please visit **www.aiaafoundation.org**.

CALL FOR PAPERS FOR *JOURNAL OF GUIDANCE, CONTROL, AND DYNAMICS*
Special Issue on Space Domain Awareness

The *Journal of Guidance, Control, and Dynamics* (*JGCD*) is devoted to the advancement of the science and technology of guidance, control, and dynamics through the dissemination of original archival papers disclosing significant technical knowledge, exploratory developments, design criteria, and applications in aeronautics, astronautics, celestial mechanics, and related fields. The journal publishes qualified papers on dynamics, stability, guidance, control, navigation, optimization, electronics, avionics, and information processing related to aeronautical, astronautical, and marine systems.

Space Domain Awareness (SDA) is the actionable knowledge required to predict, avoid, deter, operate through, recover from, and/or attribute cause to the loss and/or degradation of space capabilities and services. The only purpose for SDA is to provide decision-making processes with a quantifiable and timely body of evidence of behavior(s) attributable to specific space threats and/or hazards. SDA encompasses all activities of information tasking, collection, fusion, exploitation, quantification, and extraction to end in credible threat and hazard identification and prediction. Understanding the synergy between the space environment, the interaction of this space environment with objects (astrodynamics), the effects of this space environment on objects (operational and not), and the available sensors and sources of information are critical to meaningful SDA. Included in the SDA purview is collecting raw observables, identifying physical states and parameters (e.g., orbit, attitude, size, shape), determining functional characteristics (e.g., active vs passive, thrust capacity, payloads), inferring mission objectives (e.g., communications, weather), identifying behaviors, and predicting specific credible threats and hazards. Intuitively, SDA is a natural "big data" problem, drawing from a surfeit of existing and potential metadata and data sources. The problem at hand is 1) how these articulated needs can be rigorously addressed using first-principles, 2) what methods, techniques, and technologies must be leveraged from other fields or targeted for development, and 3) what sensors, phenomenology, sensor tasking, or additional data are needed to support the SDA mission.

Existing research and technology focus largely on collecting observables, identification of physical states and parameters, and determining functional characteristics. Selected examples include extracting observations and new information from non-traditional sensors, improving track association and initiation using admissible regions, using finite set statistics methods to improve detection and tracking, and classifying space objects using ontology and taxonomy approaches. Substantial recent progress on these topics has been presented at the AIAA/AAS Spaceflight Mechanics Meetings and AIAA/AAS Astrodynamics Specialist Conferences over the past decade.

The special issue on SDA will consolidate the latest results and key accomplishments of research performed to date in addressing this important and difficult problem, and will include the following topics:

- Fundamental theoretical results that directly support SDA efforts
- Novel application of methods, techniques, or technologies from other fields to the SDA problem
- Investigation of wholly new methods to achieve desired SDA outcomes

More information about this special issue as well as guidelines for preparing your manuscript can be found in the full Call for Papers on the journal website in Aerospace Research Central (**http://arc.aiaa.org/loi/jgcd**).

Deadline: Submissions are due by **15 May 2016**, with prior approval of the Guest Editor
Contact Email: Ping Lu, Editor-in-Chief of *JGCD* (plu@iastate.edu)
Guest Editors: Moriba Jah (moriba.jah.1@us.af.mil) and Marcus J. Holzinger (holzinger@gatech.edu)

AIAA UNIVERSITY OF SOUTH ALABAMA STUDENT BRANCH KICKOFF

On 11 November, AIAA members, aerospace enthusiasts, and students gathered around the University of South Alabama's Shelby Hall fountain with pizza, drinks, and quadcopters to celebrate the beginning of the official AIAA University of South Alabama Student Branch. Under the faculty advisor, Dr. Carlos Montalvo, the student branch was established at the University of South Alabama in fall 2014. It received the official charter in August 2015, and is part of the AIAA Greater Huntsville Section.

Since its initial establishment, the branch has participated in volunteering opportunities with Jubilee BEST Robotics, Alabama Coastal Cleanup, and Engaging Youth through Engineering (EYE), in addition to hosting several keynote speakers for educational lectures and touring the Airbus Defense and Space facility in Mobile, AL.

The student branch aims to branch out to aerospace industry in Mobile to foster an environment for aerospace to flourish and grow to be an influential part of Mobile's culture. Through partnerships with aerospace industry, AIAA hopes to engage students and prepare them for future careers, as well as enrich the local industry.

AIAA SUSTAINED SERVICE AWARDS ANNOUNCED

Congratulations to the following members who will receive an AIAA Sustained Service Award during 2016. Without their passion for aerospace engineering and science as well as their dedicated efforts and significant and sustained contributions to the Institute, AIAA could not fulfill our mission to inspire and advance the future of aerospace.

Region 2

Joseph Majdalani, AIAA Greater Huntsville Section

For 24 years of dedicated service as a Faculty Advisor, Professional Development Course Instructor, Chair and Education Chair—Hybrid Rockets Technical Committee, TAC Member, and Session Chair.

Joseph Majdalani

Region 3

Sanjay Garg, AIAA Northern Ohio Section

For three decades of significant and sustained contributions advancing AIAA's technical activities as an active member of multiple technical committees and standing committees.

Sanjay Garg

INTRODUCING AIAA'S NEWEST PUBLICATION

Our newest publication—the *Journal of Air Transportation* (*JAT*)—debuts January 2016! Currently being published by the Air Traffic Control Association Foundation (ATCA) as *Air Traffic Control Quarterly* (*ATCQ*), the *Journal of Air Transportation* will be an online, peer-reviewed journal devoted to the dissemination of original archival papers describing new developments in air traffic management and aviation operations of all flight vehicles operating in the global airspace system, including unmanned aerial vehicles (UAVs) and space vehicles.

The scope of the journal includes theory, applications, technologies, operations, economics, and policy. Among the subjects addressed are: collision avoidance, separation assurance, traffic flow management, en route and terminal airspace operations, airport surface operations, air-ground collaboration for traffic management, trajectory-based operations, avionics, aviation weather, flight operations, standards, procedures, training, and certification, aviation policy, airline economics, and cost/benefit analyses of aviation systems.

Also included are aviation-specific aspects of some broader subjects: communications, navigation, and surveillance (CNS); operations research; systems engineering and complexity; system safety and resilience; human factors; decision support tools; human-machine interaction; and automation/autonomy.

Papers are sought that report on quantitative studies, results of original research, and innovative applications. If you are interested in submitting an article or subscribing, please visit the AIAA website for more information: **www.aiaa.org**.

Rafael D. Apaza (middle) of NASA Glenn Research Center, was the 2015 recipient of the AIAA Dr. John C. Ruth Digital Avionics Award. He was presented with the award by Tom Smith (left), AIAA Fellow, and Denise Ponchak, chair of the AIAA Digital Avionics TC (right). The award was presented on September 17 at the 34th Digital Avionics Systems Conference in Prague, Czech Republic.

MAKE PLANS TO CELEBRATE ENGINEERS WEEK 2016

AIAA is proud to be a co-chair, along with Boeing and SAE International, of the 65th Engineers Week (21–27 February 2016). We will once again bring you great resources and exciting outreach opportunities. Here are some ways you can join us as we celebrate Engineers Week 2016!

Be a Regional Competition Judge for Future City

DiscoverE's Future City Competition, a project-based engineering experience for middle-school students, needs *YOU* to be a competition judge! You can choose to review SimCity slideshows, short essays, or team models and presentations. Opportunities are available in January across the country and include both at-home and in-person options. Learn more about judging at **www.FutureCity.org** and visit **www.futurecity.org/register** to sign up as a Regional Competition Judge!

Calling All Introduce a Girl to Engineering Day Role Models!

As an engineer or engineering student, you are a powerful role model. In just a single visit you can inspire and introduce girls to this exciting career path. It's easy—we have all the tools and resources you need to bring out the engineer in every girl. Sign up to be an Introduce a Girl to Engineering Role Model at **www.DiscoverE.org/GirlDay**.

Make a Difference. Become a Global Day Partner!

Help build worldwide awareness and support for Global Day of the Engineer by becoming an organizational partner. DiscoverE is calling on engineering employers, universities, governments, and associations around the world to participate in Global Day on February 24, 2016. An organizational partner commits to co-branding with Global Day, generating events, and promoting the day widely. As a partner, DiscoverE will feature your logo on our website and promote your Global Day activities. Contact **GlobalDay@DiscoverE.org** to learn more and sign up.

DISCOVER ENGINEERS WEEK
FEBRUARY 21-27, 2016

1951-2016 65th ANNIVERSARY

AIAA K–12 STEM ACTIVITIES

Supriya Banerjee and Angela Diggs, AIAA K–12 STEM Section Engagement and Best Practices Committee

The AIAA Foundation recently established the K–12 STEM Committee; the committee has several working groups focused on various aspects of K–12 STEM programming across AIAA. The Section Engagement Working Group's role is to maintain awareness of K–12 STEM activities in the sections and communicate those activities to sections/regions to promote strong K–12 STEM programming across AIAA. Each month we will highlight an outstanding K–12 STEM activity; if your section would like to be featured, please contact us directly.

AIAA Associate Fellow Jeff Jones working with the students.

Virginia Aerospace Science and Technology Scholars Program

Ian M. Cawthray

The Virginia Aerospace Science and Technology Scholars (VASTS) program (**http://vasts.spacegrant.org/**) is an interactive semester-long online science, technology, engineering and mathematics learning experience for 11th grade students in Virginia, highlighted by a seven-day residential summer academy at NASA Langley Research Center in Hampton, VA. Students apply to the program in early fall each year, and the online portion of the program runs November through April.

High performing students are selected to attend the prestigious Summer Academy each May. Students who are selected are immersed in the design of a hypothetical human sample return mission to Mars through interaction with NASA Langley Research Center scientists, engineers, and technologists. At the culmination of the Summer Academy, students present their Mars mission design to a panel of NASA and aerospace industry experts. VASTS is modeled after the highly successful, NASA award-winning Texas Aerospace Scholars program developed by NASA Johnson Space Center. The VASTS program is a partnership between the Virginia Space Grant Consortium, NASA Langley Research Center, the Commonwealth of Virginia, and aerospace industry partners such as CSRA, Lockheed Martin, Sierra Lobo Inc., SSAI Inc., Analytical Mechanics Associates, and the National Institute of Aerospace.

The VASTS program aims to impact students in the fields of engineering and technical writing, preparing students for entry into the modern STEM workforce, developing engineering workplace "soft skills," and providing an introduction to aerospace concepts that are not adequately covered by the traditional classroom curriculum. To measure these impacts, students are longitudinally tracked for 6 years beyond their participation in the program. Students have reported increased confidence in their writing abilities and their soft skills. Further results from the program's longitudinal tracking also show that VASTS alumni overwhelming choose STEM disciplines as college majors, and a number of students have already entered into the aerospace workforce at NASA and related employers. The impacts of the VASTS program have shown to be meaningful and on target, making it a point of pride for its partners.

Many AIAA members have been active in the VASTS program, including Jeff Jones, an AIAA Associate Fellow, who works with the students as a mentor and who is also on the AIAA STEM K–12 Committee.

For more information on the Virginia Space Grant Consortium (VSGC), please visit **http://vsgc.odu.edu** or contact VSGC Director Mary Sandy at msandy@odu.edu.

CSRA Senior Vice President—Civilian Agencies Ben Gieseman speaking with the students.

Some of the students with mentor Jeff Jones.

Alice Bowman, Mission Operations Manager of the New Horizons mission to Pluto, with University at Buffalo engineering students and recent graduates. Ms. Bowman is in the center wearing the New Horizons mission patch.

AIAA NIAGARA FRONTIER SECTION HOSTED NOVEMBER LECTURE

On 19 November, the AIAA Niagara Frontier Section hosted a dinner meeting and lecture. Held in conjunction with the Aero Club of Buffalo and the Buffalo Astronomical Association, there were over 150 in attendance. Alice Bowman, Mission Operations Manager at the Johns Hopkins University Applied Physics Laboratory for the New Horizons mission to Pluto, was the speaker. Ms. Bowman discussed the challenges of the mission, including the nine years it took the spacecraft to reach Pluto, as well as its next potential goal of reaching a small Kuiper Belt object (KBO) known as 2014 MU69 that orbits nearly a billion miles beyond Pluto. Like all NASA missions that have finished their main objective but seek to do more exploration, the New Horizons team must write a proposal to the agency to fund a KBO mission. That proposal will be evaluated by an independent team of experts before NASA can decide about the go-ahead.

CALL FOR NOMINATIONS

Nominations are now being accepted for the following awards, and must be received at AIAA Headquarters no later than **1 February**.

Any AIAA member in good standing may serve as a nominator and are urged to read award guidelines to view nominee eligibility, page limits, letters of endorsement, etc. Please note that the nomination form, related materials and the three required AIAA member letters of endorsement must be submitted to AIAA by the nomination deadline. Nominators are reminded that the quality of information is most important.

AIAA members may submit nominations online after logging into www.aiaa.org with their user name and password. You will be guided step-by-step through the nomination entry. If preferred, a nominator may submit a nomination by completing the AIAA nomination form, which can be downloaded from **http://www.aiaa.org/OpenNominations/**.

Awards are presented annually, unless otherwise indicated. However AIAA accepts nomination on a daily basis and applies to the appropriate award year.

Aerospace Power Systems Award is presented for a significant contribution in the broad field of aerospace power systems, specifically as related to the application of engineering sciences and systems engineering to the production, storage, distribution, and processing of aerospace power.

Air Breathing Propulsion Award is presented for meritorious accomplishment in the science of air breathing propulsion, including turbomachinery or any other technical approach dependent on atmospheric air to develop thrust, or other aerodynamic forces for propulsion, or other purposes for aircraft or other vehicles in the atmosphere or on land or sea.

The industry-renowned **Daniel Guggenheim Medal** was established in 1929 for the purpose of honoring persons who make notable achievements in the advancement of aeronautics. AIAA, ASME, SAE, and AHS sponsor the award.

Durand Lectureship for Public Service, named in honor of William F. Durand, recognizes for notable achievements by a scientific or technical leader whose contributions have led directly to the understanding and application of the science and technology of aeronautics and astronautics for the betterment of mankind.

Energy Systems is presented for a significant contribution in the broad field of energy systems, specifically as related to the application of engineering sciences and systems engineering to the production, storage, distribution, and conservation of energy.

F. E. Newbold V/STOL Award recognizes outstanding creative contributions to the advancement and realization of powered lift flight.

George M. Low Space Transportation Award honors the achievements in space transportation by Dr. George M. Low, who played a leading role in planning and executing all of the Apollo missions, and originated the plans for the first manned lunar orbital flight, Apollo 8. (Presented even years)

Haley Space Flight Award is presented for outstanding contributions by an astronaut or flight test personnel to the advancement of the art, science, or technology of astronautics. (Presented even years)

J. Leland Atwood Award recognizes an aerospace engineering educator for outstanding contributions to the profession. AIAA and ASEE sponsor the award. ***Note***: Nominations should be submitted to ASEE (**www.asee.org**) no later than **15 January**.

Missile Systems Award — Technical Award is presented for a significant accomplishment in developing or using technology that is required for missile systems.

Missile Systems Award — Management Award is presented for a significant accomplishment in the management of missile systems programs.

Propellants and Combustion Award is presented for outstanding technical contributions to aeronautical or astronautical combustion engineering.

Space Automation and Robotics Award recognizes leadership and technical contributions by individuals and teams in the field of space automation and robotics. (Presented odd years)

Space Science Award is presented to an individual for demonstrated leadership of innovative scientific investigations associated with space science missions. (Presented even years)

Space Operations and Support Award is presented for outstanding efforts in overcoming space operations problems and assuring success, and recognizes those teams or individuals whose exceptional contributions were critical to an anomaly recovery, crew rescue, or space failure. (Presented odd years)

Space Processing Award is presented for significant contributions in space processing or in furthering the use of microgravity for space processing, (Presented odd years)

Space Systems Award recognizes outstanding achievements in the architecture, analysis, design, and implementation of space systems.

von Braun Award for Excellence in Space Program Management recognizes outstanding contributions in the management of a significant space or space-related program or project.

The **William Littlewood Memorial Lecture**, sponsored by AIAA and SAE, perpetuates the memory of William Littlewood, who was renowned for the many significant contributions he made to the design of operational requirements for civil transport aircraft. Lecture topics focus on a broad phase of civil air transportation considered of current interest and major importance.

Nominations should be submitted by **1 February** to SAE at **http://www.sae.org/news/awards/list/littlewood/**.

Wright Brothers Lectureship in Aeronautics commemorates the first powered flights made by Orville and Wilbur Wright at Kitty Hawk in 1903. The lectureship emphasizes significant advances in aeronautics by recognizing major leaders and contributors. (Presented odd years)

Wyld Propulsion Award recognizes outstanding achievement in the development or application of rocket propulsion systems.

For further information on AIAA's awards program, please contact Carol Stewart, Manager, AIAA Honors and Awards, carols@aiaa.org or 703.264.7538.

To submit articles to the *AIAA Bulletin*, contact your Section, Committee, Honors and Awards, Events, Precollege, or Student staff liaison. They will review and forward the information to the *AIAA Bulletin* Editor. See the AIAA Directory on page **B1** for contact information.

DEFENSE 2016

AIAA Defense and Security Forum
Innovating to Meet Defense Challenges

A SECRET/U.S. Only forum for classified and unclassified discussions of innovations in defense aerospace technology

8–10 March 2016
Kossiakoff Center at Johns Hopkins University Applied Physics Laboratory
Laurel, Maryland

Leaders from U.S. government, military, industry, and academia will explore this year's theme "Innovating to Meet Defense Challenges." The intersection between defense policy and technical advancements at a classified level allows for highly interactive, "no holds barred" programmatic and technical discussions. Experts will present the latest innovative technological breakthroughs that will integrate with current and next-generation defense systems, while defense leaders will provide high level discussions on current challenges and topics at the plenary sessions.

AIAA DEFENSE 2016 high-level plenary topics include:

- Defense Innovation
- Space-Based Threats
- Foreign Space Threats
- Strategic Capabilities
- Testing & Evaluation

Our technical program will present research in topic areas such as:

- Missile Defense
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2–3 January 2016

2nd AIAA Aeroelastic Prediction Workshop (Organized by the AIAA Structural Dynamics Technical Committee)
How well do modern computational aeroelastic tools predict flutter? How well do they predict unsteady aerodynamic phenomena? How do choices of spatial and temporal parameters and turbulence model affect the solution? How does the presence of separated flow influence the accuracy of the calculations? These are questions being addressed in the 2nd AIAA Aeroelastic Prediction Workshop (AePW-2). AePW-2 will focus on assessing the state of the art of computational methods for predicting unsteady flow fields and aeroelastic response.

The goals of the workshop are to:

- Provide an impartial forum to evaluate the effectiveness of existing computer codes and modeling techniques
- Identify computational and experimental areas needing additional research and development

Systems Requirements Engineering (Instructor: John C. Hsu, Ph.D.,P.E., AIAA Fellow, INCOSE ESEP)
Requirements analysis and specification development are the most important contribution at the onset of a program/project. It will set a corrective direction to guide the program/project preventing redesign and rework later on. This course will help familiarize you with an effective method for defining a set of requirements of a system. The focus is on the initial problem of space definition, defining user needs, concept of operations, systems, segment, subsystem requirements, and architecture. Gain an understanding of the following requirements of engineering activities: elicitation of requirements, system requirements analysis, requirements integration, interface requirements and control, functional analysis and architecture, requirements management, and verification and validation of requirements. Learn about the principles and characteristics of organizing well-written requirements and specifications.

Key Topics
- Requirements elicitation and analysis leading to concept of operations
- Systems requirements analysis and requirements fundamentals
- Requirements integration and management
- Specification development
- Functional analysis and architecture
- Interface requirements and control

Guidance of Unmanned Aerial Vehicles (Instructor: Dr. Rafael Yanushevsky)
This course presents a rigorous guidance theory of unmanned aerial vehicles. It can be considered as the further development and generalization of the missile guidance theory presented in the author's book, *Modern Missile Guidance* (2007). Guidance of the unmanned aerial vehicles (UAVs) differs from missile guidance. Its goal is different. Moreover, since UAVs can perform variety of functions, the goal depends on a concrete area of their application. To address a wide class of guidance problems for UAVs, a more general guidance problem is formulated and a class of guidance laws is developed. In addition, the obstacle avoidance problem for UAVs is discussed and avoidance algorithms are considered.

Key Topics
- Generalized guidance laws for UAVs
- Waypoint guidance problem
- Rendezvous problem
- Conditional rendezvous problem
- Guidance of a swarm of UAVs
- Obstacle avoidance algorithms

3 January 2016

Structural Dynamics of Rocket Engines Tutorial (Instructor: Andy Brown, Ph.D.)
Structural dynamics plays a key role in the design, test, and operation of rocket engines. This talk will discuss some of the types of analyses that are required, such as the Campbell Diagram in turbomachinery, the "side-loads" fluid/structure interaction problem in over-expanded rocket nozzles, and the necessity of a system loads model for the generation of interface design loads. The role of modal and hot-fire test for verification will also be discussed. As structural dynamics is frequently a root cause in failure investigations, we'll be able to see some spectacular video of these failures as well.

General Standards and Architecture Tutorial (Fred Slane)
Standards are a critical aspect of the space industry and provide many benefits including best practices, economies of scale, expanded trade possibilities, and increased resource flow. This tutorial is focused on increasing the understanding of the benefits of and the usability of Space Standards and Architecture Framework. The tutorial is presented by the Space Infrastructure Foundation in collaboration with AIAA.

AIAA Home Study Courses
https://www.aiaa.org/homestudy

Home study courses let you work at your own pace while still providing interface with the instructor. Students receive instructions for completing the course, along with a course notebook, problem sets, and accompanying texts. Over five months, they follow a proven curriculum of reading and homework assignments, and forward completed homework assignments to the instructor for review and comment via mail, email, or fax. The instructor will also answer questions by email or phone. The time required varies depending on the course and the student's prior knowledge, but in general, amounts to about 20 hours of work per month. Course completion certificates are awarded upon satisfactory completion of all homework assignments. These are self-paced courses.

1 February–30 June 2016

Introduction to Computational Fluid Dynamics (Instructor: Klaus A. Hoffmann)
This introductory course is the first in the three-part series of courses that will prepare you for a career in the rapidly expanding field of computational fluid dynamics. Completion of these three courses will give you the equivalent of one semester of undergraduate and two semesters of graduate work. The courses are supported extensively with textbooks, computer programs, and user manuals. You can use the computer programs to develop your own code, or you may modify the existing code for assigned applications.

Key Topics
- Classification of partial differential equations (PDEs)
- Finite-difference equations
- Parabolic equations
- Stability analysis
- Elliptic partial differential equations
- Hyperbolic partial differential equations
- Scalar representation of the Navier-Stokes equations
- Incompressible Navier-Stokes equations

Advanced Computational Fluid Dynamics (Instructor: Klaus A. Hoffmann)
This advanced course is the second in the three-part series of courses that will prepare you for a career in the rapidly expanding field of computational fluid dynamics. Completion of these three courses will give you the equivalent of one semester of undergraduate and two semesters of graduate work. The courses are supported extensively with textbooks, computer programs, and user manuals. You can use the computer programs to develop your own code, or you may modify the existing code for assigned applications.

Key Topics
- Grid-generation-structured grids
- Transformation of the equations of fluid motion from physical space to computational space
- Euler equations
- Parabolized Navier-Stokes equations
- Navier-Stokes equations
- Grid-generation-unstructured grids incompressible Navier-Stokes equations
- Finite volume schemes

Computational Fluid Turbulence (Instructor: Klaus A. Hoffmann)
This advanced course is the third in the three-part series that will prepare you for a career in the rapidly expanding field of computational fluid dynamics with emphasis in fluid turbulence. Completion of these three courses will give you the equivalent of one semester of undergraduate and two semesters of graduate work. The courses are supported extensively with textbooks, computer programs, and user manuals. You can use the computer programs to develop your own code, or you may modify the existing code for assigned applications.

Key Topics
- Introduction to turbulence and turbulent flows
- Reynolds averaged Navier-Stokes equations parabolic equations
- Turbulence models
- Compact finite difference formulations
- Boundary conditions
- Large eddy simulation
- Direct numerical simulation

Spacecraft Design and Systems Engineering (Instructor: Don Edberg)
This course presents an overview of factors that affect spacecraft design and operation. It begins with a historical review of unmanned and manned spacecraft, including current designs and future concepts. All the design drivers, including launch and on-orbit environments and their effect on the spacecraft design, are covered. Orbital mechanics is presented in a manner that provides an easy understanding of underlying principles as well as applications, such as maneuvering, transfers, rendezvous, atmospheric entry, and interplanetary transfers.

Key Topics
- History
- Design drivers
- Orbital mechanics and trajectories
- Systems engineering
- Design considerations
- Mass, power, and cost estimation