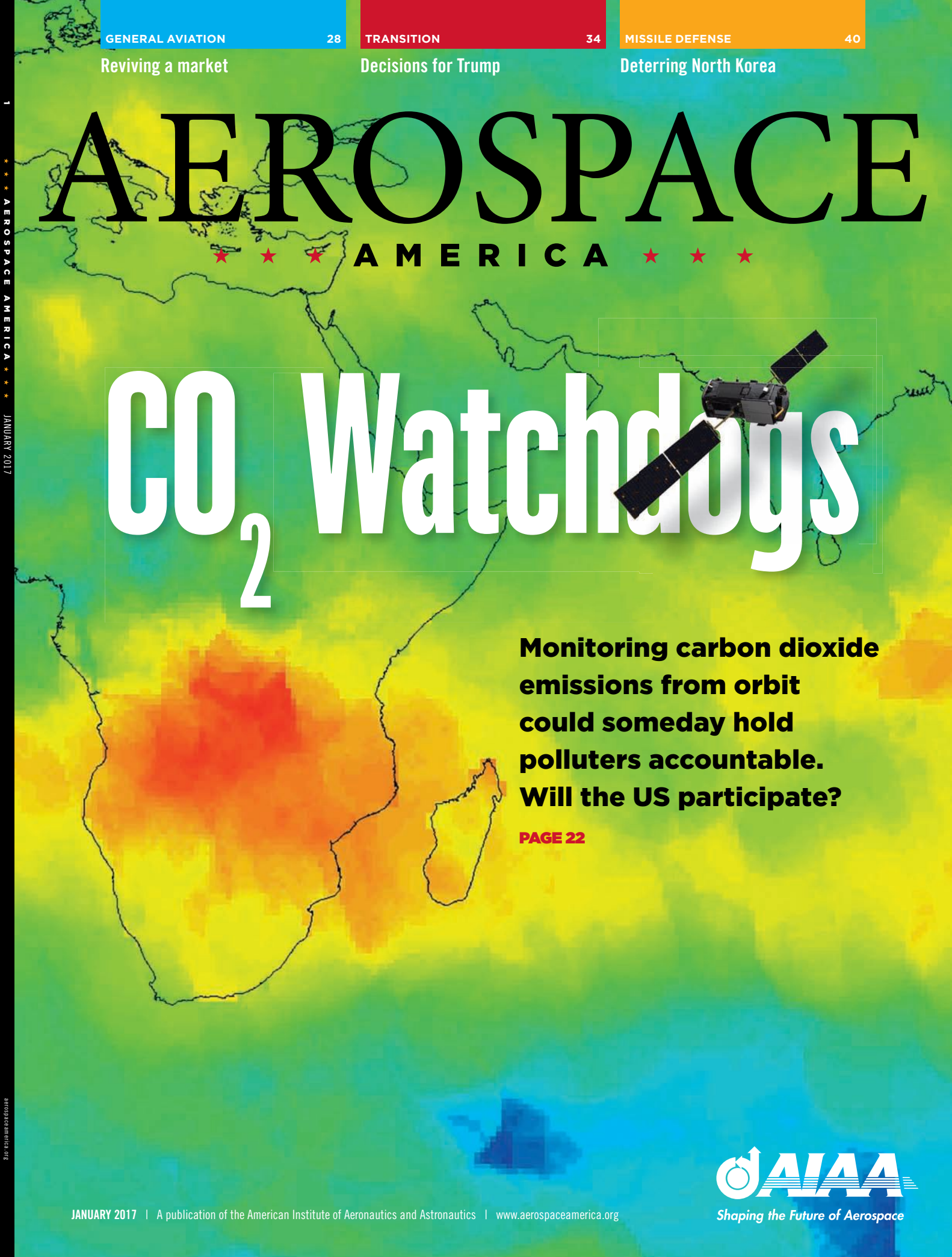
AEROSPACE AMERICA



CO_2 Watchdogs

Monitoring carbon dioxide emissions from orbit could someday hold polluters accountable. Will the US participate?

PAGE 22

JANUARY 2017 | A publication of the American Institute of Aeronautics and Astronautics | www.aerospaceamerica.org

AIAA Shaping the Future of Aerospace

SPACE FORUM

12–14 SEPTEMBER 2017 **ORLANDO, FL**

Call for Papers

AIAA SPACE Forum combines the best aspects of technical conferences with insights from respected leaders, providing a single, integrated forum for navigating the key challenges and opportunities affecting the future direction of global space policy, capabilities, planning, research and development, funding, security, environmental issues, and international markets.

Topics:

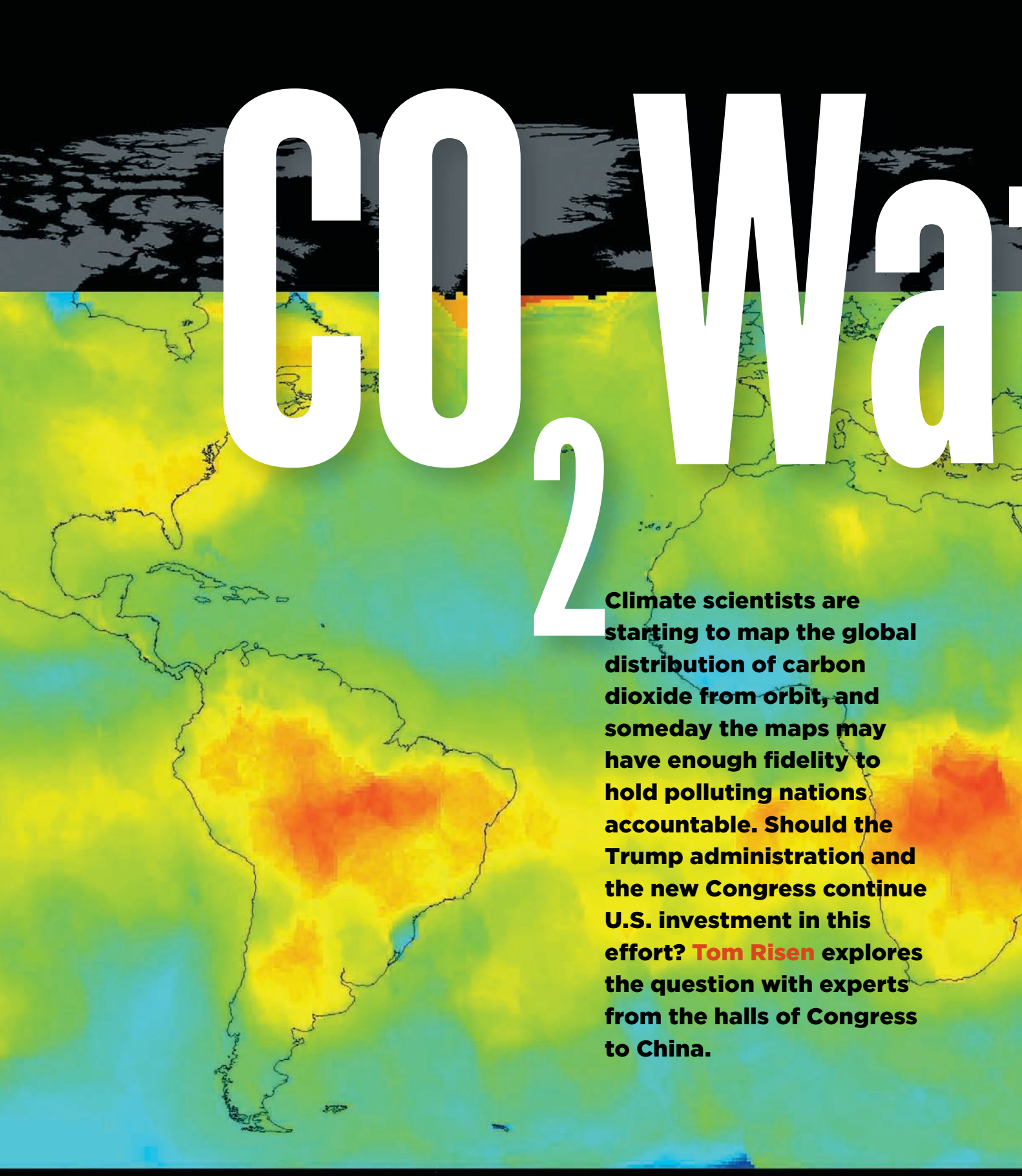
- Human Habitation and Development of Space
- Information Systems and Software
- Reinventing Space
- Small Satellites
- Space and Earth Science
- Space Exploration
- Space History, Society, and Policy
- Space Logistics and Supportability
- Space Operations
- Space Robotics and Automation
- Space Systems
- Space Systems Engineering and Space Economics
- Space Transportation and Launch Systems

LEARN MORE

www.aiaa-space.org/callforpapers

AIAA
Shaping the Future of Aerospace

17-1465



CO_2 Wa

Climate scientists are starting to map the global distribution of carbon dioxide from orbit, and someday the maps may have enough fidelity to hold polluting nations accountable. Should the Trump administration and the new Congress continue U.S. investment in this effort? Tom Risen explores the question with experts from the halls of Congress to China.

tchdogs

The tropical rainforests of South America, Africa and Indonesia glow orange on this map, indicating high emissions of carbon dioxide from burning vegetation to create farmland. The orange over China comes mainly from the burning of coal. The map was created from infrared readings gathered by NASA's Orbiting Carbon Observatory-2 between Oct. 1, 2014, and Nov. 11, 2014.

NASA/JPL-CalTech

NASA's Orbiting Carbon Observatory-2 has been circling the globe from pole to pole every 100 minutes for more than two years, gathering sunlight reflected by Earth and bouncing it across reflective surfaces covered with ridges to diffract the light into spectra. Nearly a million daily recordings are downloaded from OCO-2's three near-infrared spectrometers to show the absorption footprints of gases, including carbon dioxide and oxygen.

These recordings once seemed sure to be the next step toward an international response to climate change in which the world's worst carbon dioxide emitters would be outed, with their emissions showing up as big orange globs on a global map that would be shared among countries. So far, China and Europe plan to launch carbon-dioxide monitoring satellites; Japan has had one in orbit since 2009; and the International Space Station is even slated to carry one. These readings will be combined with those from spectrometers at ground stations around the globe to gauge the world's progress in curbing emissions of carbon from burning fossil fuels, forests and crops.

"Over time, remote-sensing data is expected to play an important role in compliance monitoring of commitments made in the Paris Agreement," says Paul Wennberg, the American scientist who chairs the Total Carbon Column Observing Network, the international scientific partnership that manages the ground sites. The Paris climate accord, supported strongly by Democratic presidential candidate Hillary Clinton, went into force several days before the U.S. presidential election, when an international ratification threshold was met. The agreement aims to reduce greenhouse gas emissions enough to keep the planet from warming more than 2 degrees Celsius over pre-industrial era levels.

Then came the surprise election of Republican Donald Trump. This outcome is raising new questions about whether the U.S. will continue funding climate change research and more satellites like OCO-2 or whether scientists from Europe, Japan and China will have to proceed without the U.S. in their plans to monitor carbon dioxide from space.

Trump's transition team did not respond to requests for comment, but he has given mixed signals about his views on climate change. In 2012, Trump tweeted that the "concept of global warming was created by and for the Chinese in order to make U.S. manufacturing non-competitive." During the heat of the Re-

Orbital ATK

▼ NASA's Orbiting Carbon Observatory-2 measures carbon dioxide levels across the world to improve understanding of the natural and human-induced sources of the gas as well as how emissions cycle through the Earth's oceans, land and atmosphere. OCO-2 underwent environmental tests in December 2013 at Orbital Sciences Corp. (now Orbital ATK) in Gilbert, Arizona.

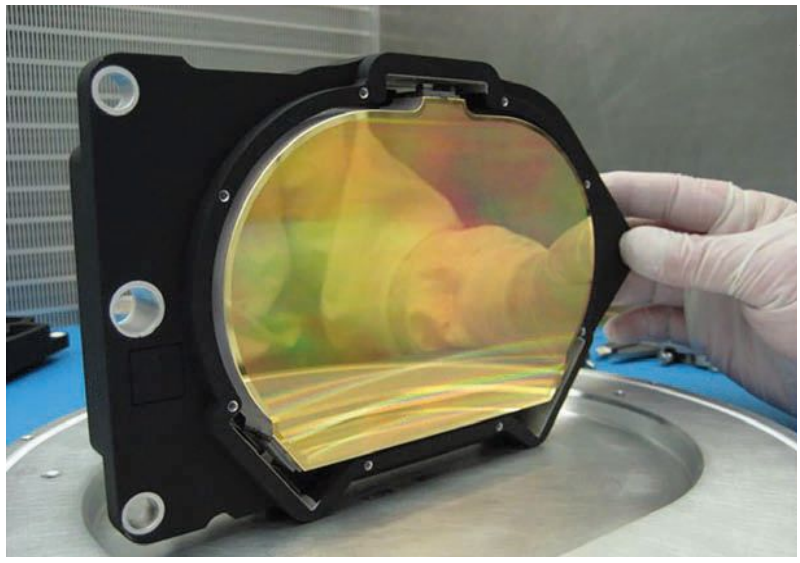
publican primary in South Carolina, he denounced global warming as a "hoax." In May, he told a North Dakota crowd that he would "cancel the Paris Agreement." Trump then seemed to reverse himself after the election, telling reporters and editors from the New York Times that "there is some connectivity" between humans and climate change, that "clean air is vitally important" and that he would keep an "open mind" on the international emissions agreement. Advocates of the multinational agreement are far from certain, however, about the incoming administration's final stance on policies to address climate change.

International effort

What is certain is that multiple satellites are needed for a more comprehensive map of carbon dioxide in the atmosphere, and that is starting to happen. China was planning to launch its TanSat last month to measure carbon dioxide with a near-infrared spectrometer, says Liu Yi, who is the team leader of the satellite project. Liu says the Chinese Academy of Sciences "plans to sign cooperation agreements soon" to share the TanSat's maps of carbon dioxide sinks and emissions with Wennberg's Total Carbon Column Observing Network. This year, scientists expect the European Commission to ask the European Space Agency to build a carbon-dioxide monitoring satellite likely to be called Sentinel-7. It would be constructed under Europe's Copernicus climate data initiative for launch in 2024 or 2025. Japan led the way on carbon-dioxide monitoring when it launched its Greenhouse Gases Observing Satellite, or GOSAT, in 2009. The Japan Aerospace Exploration Agency plans to launch GOSAT-2 between April 2018 and March 2019 to measure carbon dioxide, methane and carbon monoxide.

One satellite can't do it all. To get its high-resolution readings, OCO-2 measures a swath that is about 10 kilometers wide for each orbit, which means it covers only about 7 percent of the atmosphere each month. Only 10 percent of the nearly 1 million measurements it captures each day are free of disturbances that interfere with its data collection, including clouds that prevent sunlight from reaching the surface. More satellites like OCO-2 would close those gaps and improve the odds of collecting cloud-free data at a specific location. It would then be possible to pinpoint which factories, cities and coal mines in different countries spew the most carbon dioxide, says David Crisp, an atmospheric physicist at the NASA-funded Jet Propulsion Laboratory in California, who led the design of the OCO-2 spectrometer.

The ground spectrometers operated by Wennberg's group don't have to collect data while rapidly orbiting the planet, so they can collect more sensitive measurements than those on existing satellites. The drawback of ground-based spectrometers is that they provide soda-straw views of the atmosphere from fixed locations. Scientists want to expand this coverage by adding the view from multiple satellites like OCO-2. Even with the OCO-2 data, today's carbon dioxide maps are rudimentary.



NASA/JPL-CalTech

▲ A diffraction grating has ridges spaced a fraction of a millimeter apart to splay light into spectra. This one was destroyed when the first Orbiting Carbon Observatory crashed in 2009.

"These maps do not yet have the precision, accuracy, resolution or coverage needed by policymakers," Crisp says. "We are a long way from that goal."

Advocates say the idea can work without the U.S. but that it would be much harder.

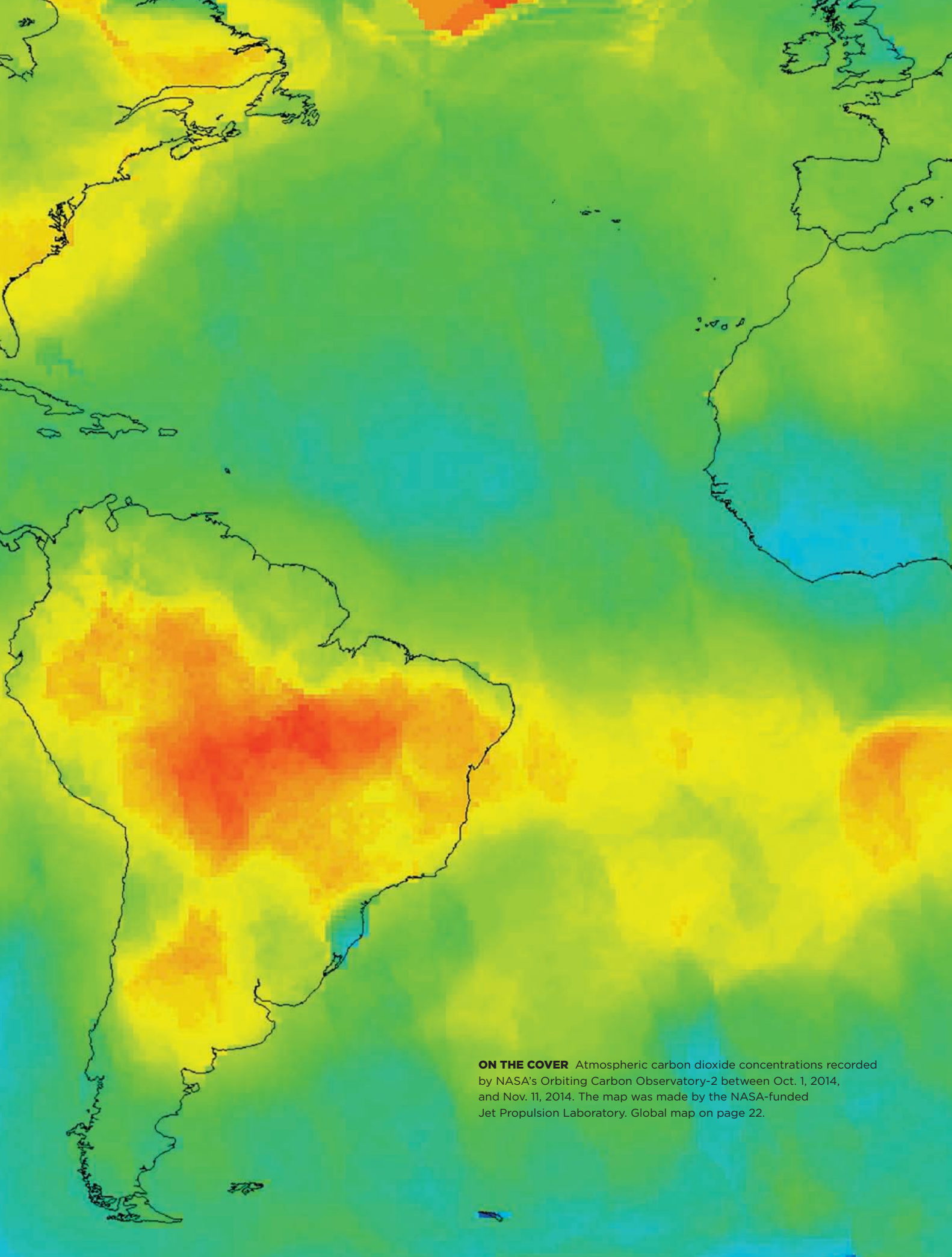
"Many hands make for lighter work," Crisp says.

Scientists want to measure carbon dioxide more frequently because the emissions dissipate from their original source or become corrupted by the presence of aerosol, water vapor or other gases.

"Monitoring is knowing. As such, it is in the interest of any modern society and [should] not be seen as a partisan issue," says Guido Levrini, the Italian program manager with ESA's Copernicus initiative. "Space is the only way to get real global coverage and a uniform, calibrated way of measuring air pollution. It will establish the facts of how much pollution is coming from different nations."

"I am not aware that the dinosaurs had any problems with industrial pollution."

Ð U.S. Rep. John Culberson, R-Texas, suggesting that natural factors may play a major role in warming the climate



ON THE COVER Atmospheric carbon dioxide concentrations recorded by NASA's Orbiting Carbon Observatory-2 between Oct. 1, 2014, and Nov. 11, 2014. The map was made by the NASA-funded Jet Propulsion Laboratory. Global map on page 22.

NASA/ESA

A year of milestones and changes in aerospace

BY P.J. BLOUNT AND CHRISTOPHER M. HEARSEY

The **Legal Aspects Technical Committee** fosters an understanding of legal areas unique to aerospace.

▲ **The crew of the** International Space Station poses in the Bigelow Expandable Activity Module, or BEAM, after it was filled with air in May.

Calendar year 2016 proved to be another eventful one for the aerospace industry. The **Commercial Space Launch Competitiveness Act,** signed by President Barack Obama in late 2015, energized and provided much-needed legal clarity for the commercial space industry. The act provides for statutory rights to obtain space resources for exploration and utilization, adds a new category, "government astronauts," for future commercial launches of NASA crew; establishes exclusive federal jurisdiction for third-party and spaceflight-participant lawsuits for injuries; and mandates a dozen reports and studies on a variety of topics in advance of future policy discussions, including space traffic management, voluntary consensus standards and the status of remote-sensing licenses.

After a difficult period in the launch sector, a SpaceX Falcon 9 launched a Dragon cargo capsule to the International Space Station in April. The mission, Commercial Resupply Services-8, was an important milestone for SpaceX, which for the first time landed a Falcon 9 first stage on a drone ship, the **Of Course I Love You** stationed off Florida, and also for Bigelow Aerospace, whose unique cargo was secured in the trunk of the Dragon. The capsule delivered the Bigelow Expandable Activity Module, or BEAM, the first privately owned, commercial expandable habitat designed for human use. On May 28, NASA astronaut Jeff Williams managed the expansion of BEAM from its original packed configuration. BEAM will stay berthed to the aft port of the Tranquility module for approximately two years, during which time NASA will collect data from internal sensors monitoring radiation, temperature and micrometeorite impacts.

In September, the **House Committee on Science, Space, and Technology** held hearings with experts to discuss the issues with NOAA's licensing of proposed remote-sensing satellites. Reports of licensing denials, unprocessed license applications and licensing changes due to national security concerns in contravention to current law and policy have frustrated the commercial remote-sensing industry. Witnesses noted the need for reduced regulatory burden, adherence to current law and reform of the interagency process that governs NOAA licensing decisions. NOAA is expected to release its mandated study on its licensing processes soon, and some type of policy or statutory reform is anticipated in the near future.

It was also an interesting year for law and policy at the international level. The **United Nations Committee on the Peaceful Uses of Outer Space**, or UNCOPUOS, took two significant steps. In June, the committee reached consensus on 12 guidelines for the long-term sustainability of space. These broad guidelines are intended to give states a framework for engaging in space activities while ensuring the space environment is protected. These initial guidelines are the first of many and are slated to be presented to the U.N. General Assembly in 2018. Then, complementing the U.S. Commercial Space Launch Competitiveness Act, the Legal Subcommittee of UNCOPUOS adopted an agenda item on space resources. This means that in 2017, discussions will begin to heat up on what the U.S. act means at the international level.

Drones remained a hot topic in aerospace law in 2016, specifically the FAA's adoption of small drone rules for non-hobbyists. This rule requires drone operators to obtain a remote pilot certificate before operating a small drone. In addition to showing aeronautical knowledge, potential drone operators must also pass a background check administered by the **Transportation Security Administration**. While these rules will lead to safer drone operations, privacy questions still swirl around drones, which were highlighted by numerous incidents where individuals shot down drones over their property or in public places. In April, the FAA issued a statement that it was a federal crime to shoot any aircraft, including drones.

In both space and aviation, the **Brexit** vote has caused lots of consternation. As the United Kingdom removes itself from the European Union, governments and private industry will need to untangle how Brexit will affect international coordination of aerospace activities. Specifically, the effects of the U.K. leaving the single EU market is likely to have ripple effects across regulatory issues and bilateral cooperation. Going into 2017, the implications of Brexit will become clearer for the aerospace industry. ★

Editor's Note:
These articles were accidentally omitted from the December Year-in-Review issue.

Testing resource utilization

BY JULIE KLEINHENZ

The **Space Resources Technical Committee** advocates affordable, sustainable human space exploration using non-terrestrial natural and discarded resources to supply propulsion, power, life-support consumables and manufacturing materials.

Growing interest in **in-situ resource utilization**, spurred activity in the space resources community in 2016. Lunar and Martian resources are of continued interest for human missions and outposts, and there is a growing focus on asteroid resources.

On the moon, the target resource is the water-ice that has been detected in permanently shadowed craters at the polar regions. Characterizing these resources is the focus of **NASA's Resource Prospector**, RP, rover mission and the European Space **Prospect drilling and sampling package** Technology development continues for these potential missions. In May, RP was put through its fourth thermal vacuum test at the NASA Glenn Research Center's Planetary Surface Simulation Facility. The drill (from Honeybee Robotics), the spectrometer (NASA's Ames Research Center), and sample crucibles (NASA's Kennedy Space Center) were tested with water-doped, frozen, lunar regolith simulant. These tests continue to refine hardware development, concepts of operations, and volatiles-detection methods. Meanwhile, the Canadian Space Agency accepted delivery of two lunar rover prototypes from contractor Ontario Drive and Gear. The larger one measures 1.6 meters X 1.6 m, has a mass of 112 kilograms, and a 1G payload of 160 kg, while the smaller 90 kg rover has a footprint of 1.2 m X 1.2 m and a 50 kg payload. Both platforms have a drivetrain that was subjected to dusty thermal vacuum testing at NASA's Glenn Research Center to achieve **Technology Readiness Level-6**.

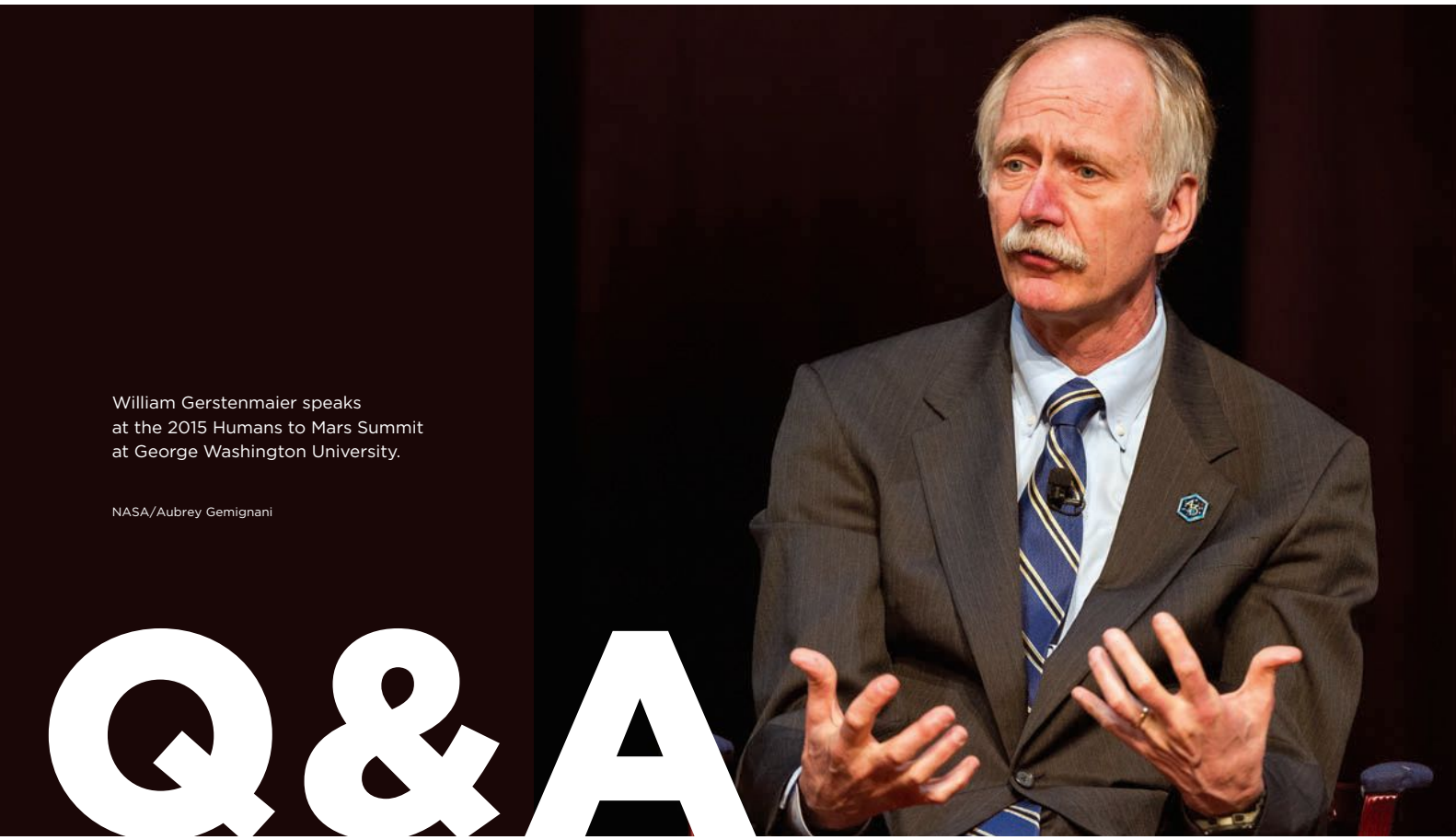
▼ **The Canadian Space** Agency's Lunar Rover Drivetrain Prototype, foreground, and Small Planetary Rover Platform were driven across the agency's Mars yard near Montreal in 2016 to simulate conditions on the moon. Ontario Drive and Gear delivered the vehicles in April.

NASA's exploration plans are increasingly including ISRU. **NASA's Human Architecture Team** conducted system level studies to examine the impact of incorporating full-scale ISRU systems into human missions (namely the Evolvable Mars Campaign) using atmospheric and ground water resources. Likewise, the **Mars Water In-Situ Resource Utilization Planning** study led by NASA's Science Mission Directorate leveraged university, NASA, and commercial partners to identify potential Mars resources and the instruments and data still needed to fully characterize them for ISRU use. The NASA Capability Leadership Team continues to assess and plan for facilities and resources needed for future ISRU efforts, and a potential ISRU technology development program is in formulation under NASA's Advanced Exploration Systems.

NASA's Mars 2020 mission will include the **Mars Oxygen ISRU Experiment**, or MOXIE, payload that will demonstrate ISRU technologies to convert Mars atmospheric carbon dioxide into oxygen. Led by MIT, MOXIE completed instrument preliminary design review in January and is now working toward delivery in May 2018. Mars 2020 is the first mission that will fly an ISRU payload.

Asteroid resources are the focus of three university-led projects under NASA Early Stage Initiative awards, now in their second year. The **Robotic In-situ Surface Exploration System** (RISES) project at the University of West Virginia is looking at robotic systems and non-destructive tests for the strength of asteroid materials. At Missouri University of Science and Technology and the Colorado School of Mines, work is focused on volatiles extraction and capture, while Stanford University is examining characterization of asteroids using impact plasma detection.

On the commercial side, several companies are pursuing asteroid resources. Planetary Resources, Inc., PRI, has shipped their **A6 satellite**, a 6-unit cubesat that will demonstrate technologies to measure resources on water-rich asteroids, to Vandenberg Air Force Base with a scheduled launch date of late 2016. PRI also announced a partnership with the government of Luxembourg to advance technologies and businesses related to exploration and utilization of asteroid resources. Honeybee Robotics and the University of Central Florida developed a concept for a 6-unit cubesat that could extract water from hydrated asteroid regolith and use it to "hop" between asteroids via steam propulsion. In 2016, the extraction hardware for this cubesat recovered water from asteroid simulants during laboratory tests under a Small Business Technology Transfer project with Kennedy Space Center. ★



William Gerstenmaier speaks at the 2015 Humans to Mars Summit at George Washington University.

NASA/Aubrey Gemignani

Q&A

Managing NASA's "special task"

More online aerospace america.org

See the extended transcript for more about NASA's space exploration plans.

It's often said that those who don't know history are doomed to repeat it. That shouldn't be a problem for those in NASA's Human Exploration and Operations Directorate, given that the man in charge has been directly involved with decades of NASA's human space flight history.

What about the space shuttle-Mir negotiations and operations in the 1990s? Gerstenmaier managed them. Construction and assembly of the International Space Station? Gerstenmaier managed much of it. The phase out of the space shuttle? Gerstenmaier directed the final 21 shuttle missions.

These days, Gerstenmaier spends much of his time planning and defending NASA's future human exploration endeavors and the hardware necessary for them. A special concern is how to wring the most value out of the International Space Station while simultaneously, it is hoped, inspiring the private sector to build and operator a successor to it.

Gerstenmaier spoke to Ben Iannotta by phone during a layover on one of his many work trips.

WILLIAM H. GERSTENMAIER

POSITION: Associate administrator for human exploration and operations

NOTABLE: Spent much of his career in Houston. Was operations manager for the space shuttle-Mir program during the 1990s. In 1998, became program integration manager for space shuttle, then managed the International Space Station program during its critical construction and assembly period in the early 2000s. Moved to Washington, D.C, in 2005 to direct the final 21 space shuttle missions as associate administration for space operations.

AGE: 62

RESIDES: Alexandria, Virginia

EDUCATION: Bachelor of science in aeronautical engineering from Purdue University; master of science in mechanical engineering from University of Toledo in 1981

Robotics versus human exploration

It's not that one is better than the other. We absolutely need both, but taking humans and actually placing them in this severe environment is, is a special task and it's a special role. It gives our population a chance to have an aspirational goal, or an inspirational goal. There's a special character that comes with human space flight. It's present in robotics, but I think it's more personal when you actually see human lives on the line and you're actually you know, launching your friends and colleagues on rockets into space.

For the U.S., perseverance and soft power

What we've done with space stations by keeping our international crews on orbit for 16 years is pretty amazing. That's through the Columbia tragedy, through all those other activities. We've been able to keep this human presence in space. Two countries have, have done that really – Russia and the U.S. – and that also sets apart kind of a leadership or soft power role for human space flight. It differentiates us from other countries that have space programs but they don't really have a human space flight program and they don't have a human space program of depth and breath. It's really important for our character as a nation.

Inspiring innovation

You hear many, many times, "If we can land on the moon we can do: Fill in the blank." The lunar landings really differentiated us as a nation, and said: There's nothing that's impossible. There's nothing that we can't do if we all work together internationally, and nationally too, to accomplish these tasks.

Team requirement: Total honesty

The thing I really like about human space flight is the fact that it's really a team effort. We can't say that it's really one individual. It takes the absolute best of all the team players. It takes everyone describing what they know and more importantly what they don't know, and being totally honest with each other and working together. If you look at the, what we're doing on space station, it is truly an international team activity.

Lifespan of International Space Station

From a pure engineering standpoint, we've done studies that show the physical hardware has a life at least until 2028. Current policy has us ramping down station operations in 2024. We're busy at looking at how we transition from this space station to other space activity.

Moving toward a privately-run space station

The station that comes after the International Space Station may not be permanently crewed. It may be smaller, it might be a permanent space station, it may be transient. We'll let the private sector determine what best meets their needs and then they're free to go acquire that and build that on their own

There's nothing that we can't do if we all work together internationally, and nationally too, to accomplish these tasks.

For ISS, "precious" final years

It's 2017 now. We have roughly seven years until this end of mission for the space station as currently planned. Those seven years are pretty precious, so we're trying to expose a broad community of terrestrial researchers to the benefits of research on board the space station or, or on board, or actually in space. Many physical properties change when they get exposed to microgravity. We see combustion in a different way. We see materials properties in a different way. We see genomics changing. We're trying to take terrestrial industry and terrestrial companies and expose them to these unique properties that occur in space and let them discover and be innovative. Trying to deal with combustion or genetics, they can look at this in the microgravity lens, which is different than the 1G lens to gain competitive advantage or a research advantage over others that are not engaging in this activity. Then hopefully they can use that knowledge to turn revenue around and actually make a profit from space activity. We're using the space station as a catalyst or an innovation engine to, to get other folks excited about what we've seen as interesting phenomena in space and then turn in over to the imagination of individual companies. Then ultimately they may want to have their own space station or facilities in the future.

Relationship with space station researchers

We're trying to expose an industry that doesn't have any exposure to space to this facility. So the fact that we help them with transportation to space station, the time from crew members and the data, I think that's really important, but we're also asking them to invest dollars in building the equipment that's going to fly on station. We don't pay for that equipment. We're asking also them to invest in putting intellectual property and imagination and creativity into these unique properties in space to figure out how they can generate revenue. That's not a trivial ask that we're asking them to go do.

Trending: commercial business in space

We're starting to see some interest from many companies Pharmaceuticals; there's a commercial 3-D printing facility aboard station that they can use to investigate the properties of 3-D printing in space. Little pieces are starting. What's encouraging to me is that this is last year I'm starting to see these flickers of interest from other companies saying, "Hey, there is something here that's special. Maybe we can use this in a new way." ★

Correcting NASA's course

Ron Dantowitz/Clay Center Observatory

While we should expect a hard look at NASA from his administration, President-elect Donald Trump should resist the temptation to overturn the agency's human exploration initiatives. Instead, he should give NASA the tools and resources it needs to open space to explorers and commerce. Former astronaut Tom Jones makes the case for continuity, acceleration and a shift toward cislunar space.

By Tom Jones
Skywalking1@gmail.com
www.AstronautTomJones.com

Come Jan. 20, the Trump administration should resist the urge to discard the human space-flight progress of the past eight years. Instead, it should look hard at NASA's priorities and give NASA a course correction, refocusing the agency on achieving concrete exploration and economic goals in cislunar space, the region between Earth and the moon.

In reviewing NASA's goals and programs, the new administration should assess whether those serve the nation's economic, scientific and national security priorities. It should avoid the mistake of starting over, which the Obama administration made seven years ago when it tossed the Bush-initiated Constellation lunar-return program

◀ **Mars passes behind the moon in an image** produced by the Clay Center Observatory during the 2003 alignment of the two bodies. Telescopic views of the event were digitally stacked to produce this image.

and bypassed the moon for an underfunded Journey to Mars preparation initiative. Instead, the president and Congress should keep the promising elements of NASA's human space-flight portfolio and use those to establish the U.S. as the leader in exploring and exploiting cislunar space. With a properly funded course correction, within two presidential terms, NASA could be poised to exploit the moon's resources, establish an ability for astronauts to visit there and build a partnership to explore Mars.

Where NASA stands

NASA is slowly moving forward on its Journey to Mars, a technology path that aims to put humans on the red planet in the 2030s. So far, progress has been limited mostly to robotic exploration of Mars. For human exploration, the Obama administration has pushed for development of the Orion Multi-Purpose Crew Vehicle and the Space Launch System rocket but has shown little interest in setting calendar milestones beyond those for testing Orion and SLS. It will be up to future administrations to fund the bulk of the technology needed to get human explorers to Mars. Orion is still fi e years from flying a crew. After an uncrewed test flight to lunar orbit in late 2018, the only future exploration on the books for Orion is the Asteroid Redirect Mission, or ARM, in which an astronaut crew will be sent to lunar orbit to examine a captured asteroid fragment. ARM faces stiff opposition in Congress and may not survive 2017.

Orion's heavy lift booster, the SLS, has yet to fly. In development as the Ares 5 when the Obama White House took charge in 2009, the SLS was first canceled, then revived by congressional direction. Its first flight is now targeted for late 2018 for the uncrewed Orion flight to and from lunar orbit. After Constellation's cancellation, the White House directed NASA's immediate focus not toward the moon or deep space, but to replacing the shuttle with commercially built transports to launch astronauts to the International Space Station. Those ships, from Boeing and SpaceX, are well behind schedule and won't fly for another two years, forcing NASA to extend its reliance on Russia's Soyuz crew transport. That arrangement, in place since 2011, is vulnerable to the whims of Vladimir Putin. The slow progress of restoring U.S. human launch capability is due at least in part to NASA's budget — $19.3 billion in 2016 — which has lost buying power since 2009.

Defining the goa

The most important element of the course correction is to clearly inform NASA of its goal: Establish this nation as the leading technical, scientific and economic power in cislunar space. Everything else — including Mars — should be secondary. In pursuing

▼ **The liquid hydrogen tank is part of the core** stage for the Space Launch System. The rocket's fir t flight is set for late 2018, but NASA would need to accelerate its launch pace to sustain astronauts in cislunar space.

NASA

NASA

▲ **The Resource Prospector prototype** searches for a buried sample tube at NASA's Johnson Space Center in Texas in 2015. Intensive robotic exploration of the moon could locate water ice and supply propellant for an astronaut return.

that goal, the administration should follow these general principles:

- Expand and repurpose existing programs; don't wastefully cancel them and start over.
- Provide technology and skills to U.S. companies to help expand their reach into cislunar space, in return contracting for essential, more affordable services.
- Enlist international and commercial partners to provide critical human space-flight elements, e.g., lunar orbit habitats, a lunar lander, propulsion, nuclear power and logistics.
- Provide NASA with the resources it needs; increase NASA's budget by 10 percent immediately and let it pace inflation thereafter.
- Use the capabilities and skills gained in cislunar space to reach Mars. We should take that exciting step when the nation and our partners are ready. Exploiting the resources of the moon and nearby asteroids will get us ready sooner.

Within the decade, NASA should do the following:

- Re-establish humans around and on the moon. Start with intensive, robotic lunar surface exploration. Put a U.S. rover down at the lunar poles by 2020, prospecting for water ice. Demonstrate small-scale extraction of oxygen, hydrogen and useful metals like iron.
- Contract for lunar landing services with private firms competing to reliably deliver robotic payloads to the moon. These commercial missions would begin commercial-scale extraction of water, oxygen and rocket propellant.
- Accelerate the Orion and SLS booster flight schedule. By the early 2020s, fly Orion astronauts to a lunar-orbiting habitat for a monthlong stay. From orbit, control a surface rover on the lunar far side.
- Carry out the Asteroid Redirect Mission, extending our astronauts' lunar orbit expertise to asteroid resource exploitation. Open the asteroid fragment to follow-up commercial prospecting and processing experiments, using the returned asteroid boulder to demonstrate extraction of water from hydrated silicate minerals.
- Extend the ISS partnership to the moon. If lunar resources prove attractive, NASA with its willing partners should develop a lunar lander, planning a return to the moon by the mid-2020s. Astronauts would help establish a propellant plant and conduct scientific exploration. The lunar partnership would build momentum toward reaching Mars together.

On course for deep space

By the mid-2020s, NASA should be poised to return astronauts to the lunar surface, for jobs beyond the skills of robots alone. The same spacecraft elements tested in lunar orbit — habitat, propulsion, energy systems and heavy lift booster — could also be combined in a piloted voyage to a near-Earth asteroid, expanding humanity's reach millions of kilometers from Earth and extending our deep-space endurance to six months or more. By 2030, NASA should contract with commercial ventures for the first return of water and rocket propellant from a near-Earth asteroid. Lunar-generated propellants and/or asteroids will be key in designing an affordable human campaign to reach Mars orbit; visit its two small moons, Phobos and Deimos; and eventually, land on Mars itself.

20 years out

Establishing humans on Mars should remain NASA's "horizon goal," but it should not be a near-term or exclusive NASA priority. Instead, the agency should focus on the technical and economic development of cislunar space. By the mid-2030s, NASA should have laid the groundwork to make the Earth-moon system a thriving economic zone, hosting everything from low Earth orbit tourism to space-based solar power stations to commercial research labs or production facilities, to commercially run propellant tank farms. These activities would help support the ongoing scientific exploration of the moon.

Confidence gained in systems tested at the moon and at near-Earth asteroids would put the U.S. in position by the late 2030s to plan an international expedition toward Mars. Even if NASA still lacked the technology by then for landing a crew on Mars, a NASA-led crew could enter Mars orbit and establish a habitat on Phobos (about 22 kilometers in diameter) or Deimos (about 12 km in diameter). From this close-in outpost, geologists could establish a scientific telepresence on the surface, guiding surface rovers with no appreciable time delay.

Under astronaut control, these robots could search for life and the best site for a human landing. Robots could also assemble the elements of that surface outpost: landing aids, habitat, propellant plant, solar or nuclear energy station, and machines for extracting subsurface ice or water. We would cross the final approximate 9,400 kilometers from Phobos to Mars when technology, budget, risk assessments and international partnerships align.

Advantages of changing course

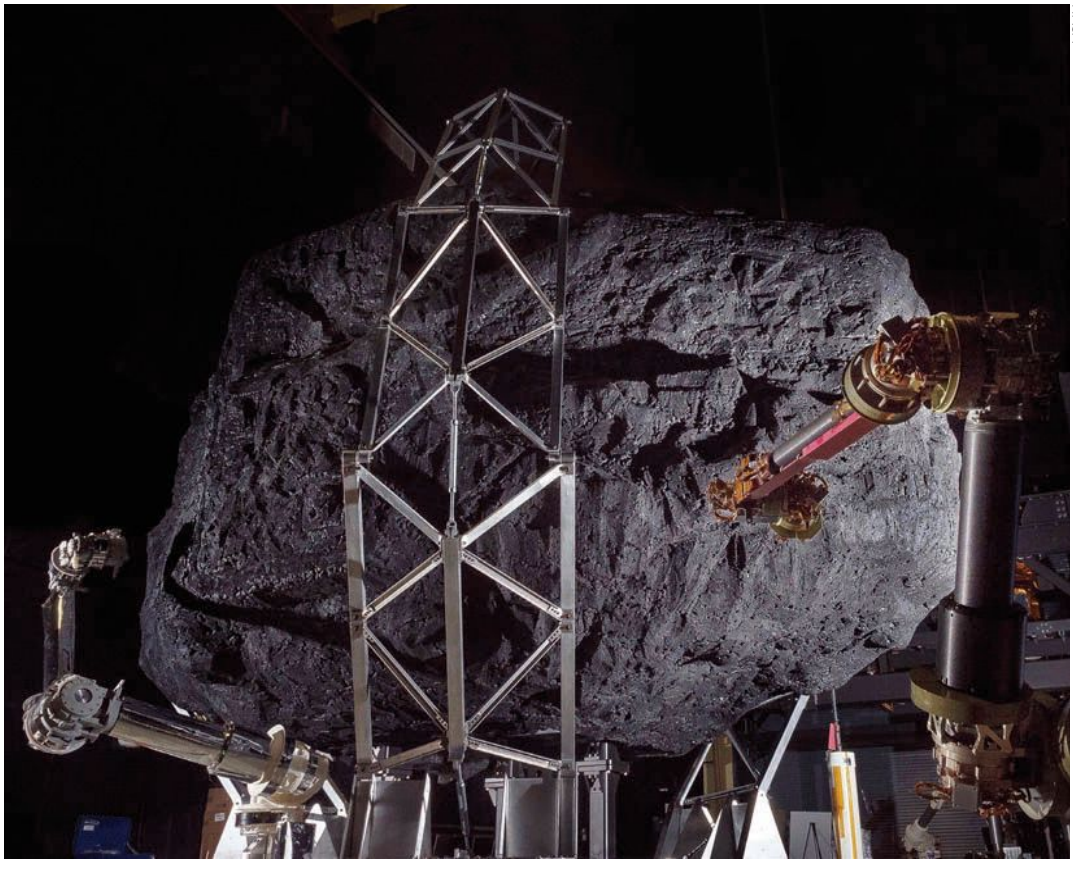
Within two presidential terms, a NASA focus on cislunar space would produce highly visible progress, namely the following:

- Commercial robots busily exploiting the moon, extracting water and metals from the lunar regolith;
- Astronauts regularly visiting a lunar orbit habitat, tele-operating robots and readying for a return to the moon's surface;
- An international lunar exploration consortium for science and resource production, an achievement readily adapted for reaching Mars;
- Private companies under NASA contract shipping supplies to the lunar orbit outpost and extracting tons of oxygen and rocket fuel from the moon;
- And astronauts training for their first deep-space encounter with a resource-rich asteroid.

By contrast, under current NASA direction and projected budgets, the U.S. couldn't achieve a human mission to the moon — even if it decided to join its ISS partners in the effort — let alone Mars. By 2025, for example, NASA astronauts will have flown Orion perhaps twice, repeating what America first accomplished on 1968's Apollo 8 mission. ARM is unlikely to make the new Congress's list of space priorities. And on our current course, by 2025, the ISS will be just a few years from a fiery re-entry into the Pacific, leaving China with the only space station in low Earth orbit. Soon after, these learners in space and up-and-comers will stamp their footprints on the moon.

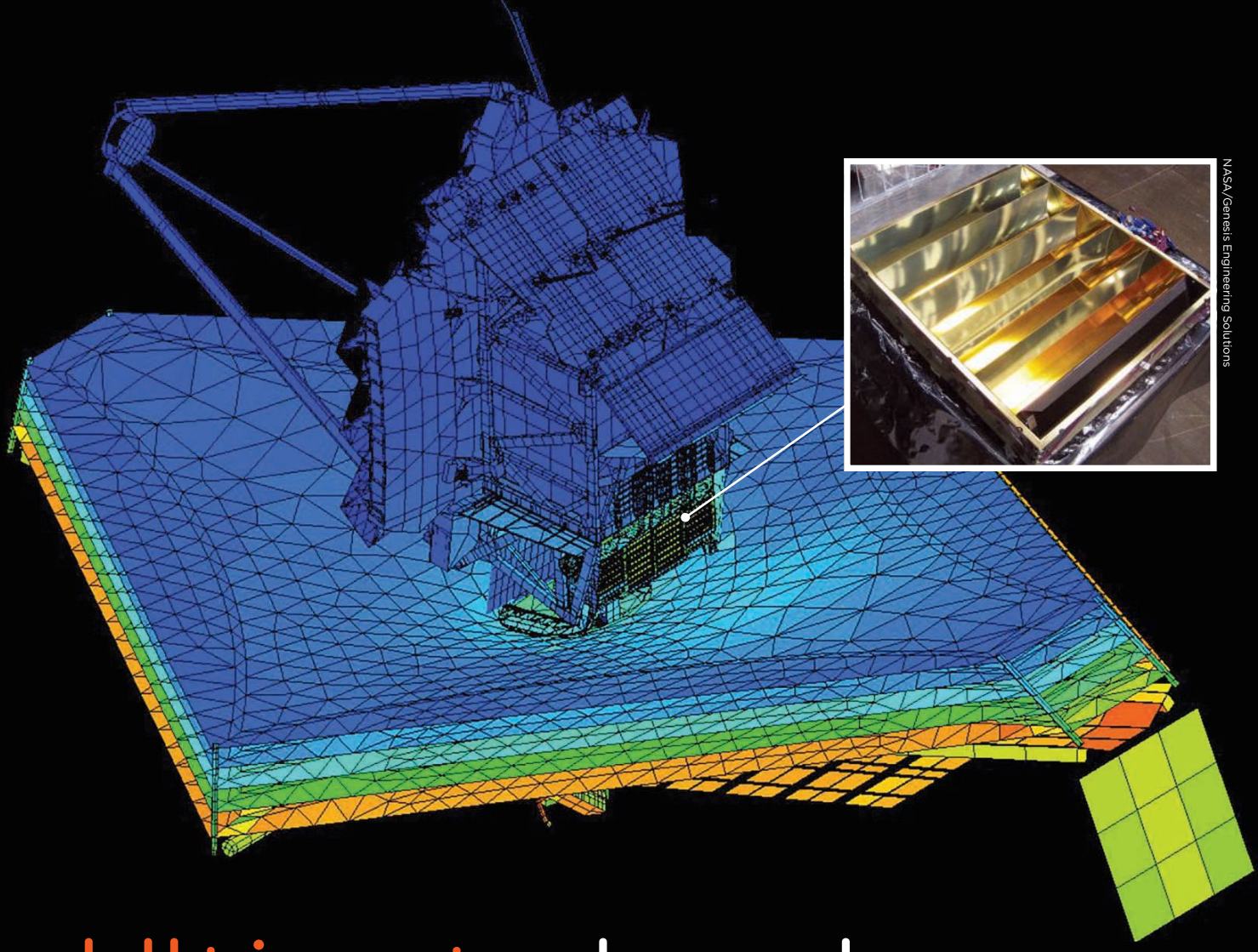
Executing this course correction — preserving and accelerating NASA's promising programs — would restore bipartisan support to the agency, so lacking for eight long years. The U.S. will use cislunar space to train for Mars while tapping the economic potential of the Earth-moon system. Near-term success would bring renewed confidence in NASA's abilities and its hopes for leading a partnership to the asteroids and Mars.

In 1801, President Thomas Jefferson delivered his first inaugural address and predicted a "rising nation, spread over a wide and fruitful land ... advancing rapidly to destinies beyond the reach of mortal eye." Today, that frontier is not the West, but space and its resources. A wise course change for NASA's exploration plans would invigorate our nation's fortunes once again. ★



NASA

An Asteroid Redirect Mission robotic prototype is tested with a mock asteroid boulder at NASA's Goddard Space Flight Center in Maryland. The robotic portion of ARM is targeted for launch in 2021, but the mission's fate is in the hands of the new Congress.



NASA/Genesis Engineering Solutions

Ultimate hands-on experience

One day in 2008, Rick Krontz, then an aircraft-structures instructor at Middle Georgia College, stopped by Neptune Precision Composites in Jacksonville, Florida. It was a routine check-in about a technical student the company hired. Krontz struck up a conversation with Frank Huber, a composites engineer at Neptune. Huber had an inspiration when he heard about the school's fabrication facility and students. He introduced Krontz to Robert Rashford, whose company Genesis Engineering Solutions was known for making flight hardware for the Hubble Space Telescope. Aerospace America invited Krontz and Rashford to describe how they assembled a team of students and professionals to make components for NASA's $8 billion James Webb Space Telescope.

In 2008, composites engineer Frank Huber suggested to us that the missions of Middle Georgia College (now Middle Georgia State University) and Genesis Engineering Solutions might mesh well. At the time, Middle Georgia trained aircraft structural technicians and Genesis made tools and parts for NASA's Hubble Space Telescope servicing missions. Huber was right.

What emerged was a partnership that helped each of our organizations grow while giving hands-on manufacturing experience to dozens of students. This was not just any experience, but experience building critical components of the James Webb Space Telescope scheduled for launch in 2018.

We realized quickly that Middle Georgia State had manufacturing resources capable of accommodating complex structures, and Genesis had experience with space structures, having helped NASA with Hubble. By teaming with Genesis, we won a contract from NASA's Goddard Space Flight Center to build the telescope's Integrated Science Instruments Module Electronics Compartment, or IEC for short, and also a backplane support fixture, the structure that holds the primary mirror. This backplane was for the second round of thermal testing, called Core 2. To orient you, the IEC is located in Region 2 of Webb's blueprint, an area on the shaded cryogenic side of the telescope's sunshield. From this side, the telescope's segmented mirror will look out to the cold of space to gather infrared radiation from the early universe, our galaxy and planets beyond our solar system. Additional mirrors will direct that radiation into the Integrated Science Instruments Module, or ISIM, which houses the four scientific instruments. Mounted to this module is the ISIM Electronics Compartment, or IEC, which our team built.

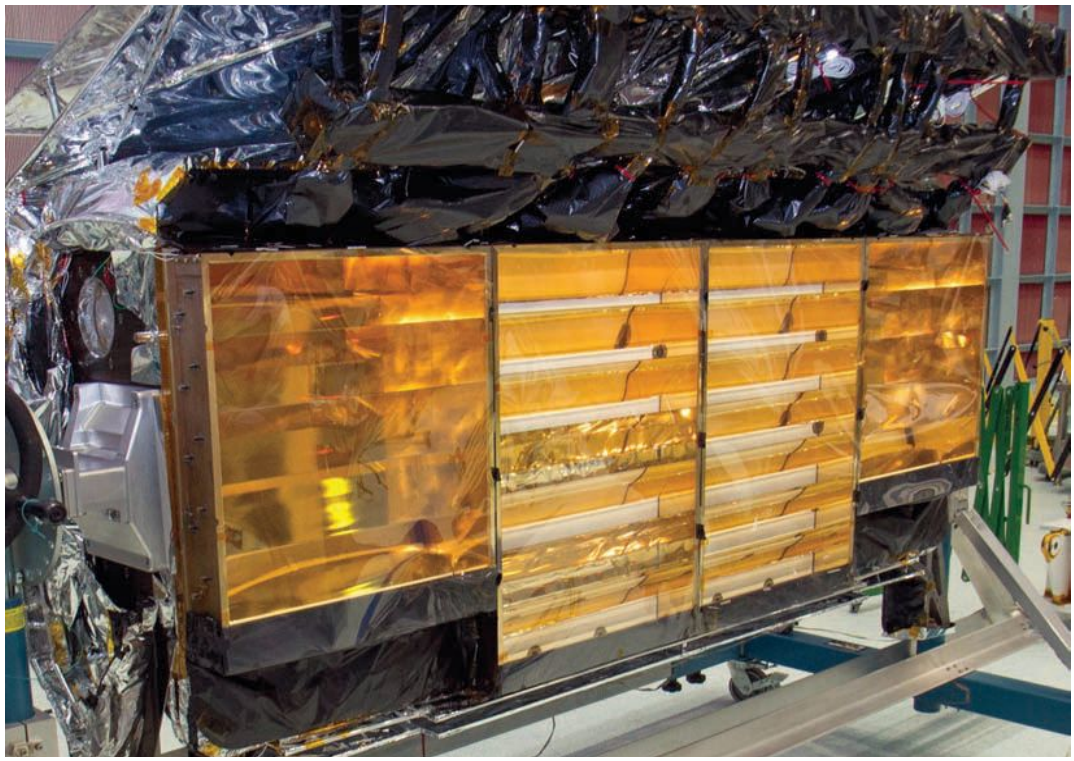
The IEC is a composite structure that houses 13 electronics boxes,including those that will control the mechanisms that must unfurl, unfold and erect the Webb telescope in space after its launch; plus the computer that will align the mirror's segments and steer the secondary mirrors to direct photons into an optical path leading to the four science instruments; and the electronics that will convert those photons into signals that will be read by computers on Earth.

The design of the IEC was complex because of the thermal challenges aboard Webb. The electronics in the IEC must be kept at 80 degrees Fahrenheit (300 kelvins) to operate properly, but the equipment outside the enclosure must stay at minus 400 degrees Fahrenheit (33 kelvins) to maximize the telescope's sensitivity to infrared radiation. The thermal task was akin to putting a freshly roasted chicken into a freezer, and keeping the chicken warm without letting it melt the surrounding ice. To do that, you would have to put the chicken, or the electronics in our case, inside a protective enclosure, but one that lets excess heat escape the freezer without reaching the ice.

◀ Student contributions: Gold-coated composite louvers in four baffles, like this one built with the aid of students, will steer heat out of the James Webb Space Telescope's electronics compartment.

▶ Student technicians work on composite tubes that will form a backplane support fixture for the Webb telescope. The backplane holds the primary mirror and compartments for Webb's instruments and electronics. This backplane was used in thermal testing.

That's the IEC. Inside, sets of electronics are attached to four composite panels whose job is to capture heat from the electronics. This heat must be steered out of the IEC and away from the instruments, so on one wall we installed four baffles consisting of graphite composite louvers covered with vapor-deposited 14-karat gold. Graphite lay-up material was chosen because of its low coefficient of thermal expansion, which means it's very stable. The gold coating has the desired thermal emissivity for removing heat quickly. Each baffle is attached to a 2.5-centimeter-thick radiator panel. Together, the radiators and baffles direct heat out to space safely.



These four louvered baffles will steer heat out of the electronics compartment of the James Webb Space Telescope. Students helped build them.

Robert Rashford is an aerospace engineer and founder of Genesis Engineering Solutions of Lanham, Maryland.

Rick Krontz retired in October as director of the Institute for Applied Aerospace Research at Middle Georgia State University's Eastman Campus. Krontz retired from the U.S. Air Force in 1998 as a master sergeant with a specialty in aircraft structures and advanced composites.

To build the IEC and the Core 2 backplane support fixture, Middle Georgia established a student internship program under which participants worked up to 20 hours a week. Other students at times participated from their classrooms. Specifically, students helped build the louvers and the primary ICE structure using computer-aided-design data and approved written work instructions and guidance from Genesis staff. The students interpreted the CAD data; created two-dimensional cut programs to trim the carbon and fiberglass materials on a computer-numerical-control, or CNC, cutting table. They also operated CNC routers and milling machines to make small molds and tooling aids. They helped create written instructions and quality control programs. Students kept track of pertinent information such as batch and lot numbers, expiration dates and quantity. They were required to work within high tolerances and an aggressive schedule. They prepared composite lay-up molds; hand-laid materials; vacuum bagged, leak checked, cured, cut and trimmed composite parts.

NASA accepted the idea of students participating in the manufacturing because of the precautions each of us took. Genesis ultimately is responsible for our contract and the hardware that gets delivered. NASA trusted Genesis, because of our record of on-time and on-budget delivery for Hubble. Our team also walked NASA's quality control and assurance expert through the process of how we were going to manufacture the components.

For Middle Georgia, the program was a great way to stay proficient and current in aerospace technologies. The work also caught the eye of Georgia's Center of Innovation for Aerospace, which helped the school forge a partnership with Area I, a drone start-up in Kennesaw. For students, the program was an invaluable opportunity to work in real-world, intense, hands-on project. Some students decided to pursue engineering degrees because of their experiences. Others decided to become entrepreneurs. All went on to be employed in some fashion in the aerospace industry, applying a multitude of skills for major aviation or space employers.

When the IEC was completed, we packed the components into an air-cushioned truck and drove the parts to our facility in Lanham, Maryland, for assembly. We delivered the IEC in 2014 on time and within budget. For that reason, NASA asked our team to build two more IECs to support system level testing. Today, we have one flight replica at NASA's Johnson Space Center in Texas and one at NASA's Goddard Space Flight Center in Maryland. They are used for quantifying the rate at which heat is radiated out of the IEC. Maintaining the right temperature is critical for the health of the electronics. Unlike Hubble, Webb will be too far from Earth for NASA to send astronauts to service it.

Today, technicians and engineers in a variety of organizations acquired critical skills because of this program. They will be watching as closely as anyone in 2018 when the telescope lifts off aboard its Ariane 5 rocket. ★

With President-elect Donald Trump promising big, but still-evolving, policy changes, we asked two leading aerospace journalists to analyze the most important decisions facing the incoming administration.

Associated Press

5 Space Decisions

Warren Ferster says Trump is arriving at a pivotal era for those involved in space, whether for exploration, business or science.

1. Should NASA operate the International Space Station beyond 2024?

ANALYSIS – This is a linchpin decision for president-elect Trump and his team. NASA has pledged to fly the orbiting lab for seven more years, and its international partners have followed suit or are expected to do so. The question is whether to extend operations even longer, to at least 2028, or whether to steer the more than 400,000-kilogram behemoth into the atmosphere, where it would break apart with surviving pieces splashing down in the Pacific Ocean.

A decision to abandon the station in 2024 would surprise many observers, given that assembly was not completed until 2011.

"I can't imagine that, in 2028, you're going to dump a $100 billion asset into the ocean," Robert Walker, a former U.S. congressman who began advising the Trump campaign in October, told the FAA's Commercial Space Transportation Advisory Committee before the election.

If the Trump administration decides to extend the station, it must weigh whether more responsibilities can be handed off to the private sector to reduce today's approximately $4 billion annual expenditure on space station operations and support. Currently, SpaceX and Orbital ATK are under contract to deliver cargo to the station, while Sierra Nevada is developing its Dream Chaser spacecraft for station logistics, too. SpaceX and Boeing have contracts for commercial crew launches, which could start in 2018.

NASA officials are looking at three broad operating schemes: limiting NASA dollars to those space station activities that further the agency's deep space exploration goals; investing in activities that support exploration and also commercialization goals; and investing NASA dollars more aggressively in commercialization

▸▸ CONTINUED ON PAGE 37

NASA

▲ **Robert Walker, a Trump administration** adviser and former U.S. congressman, sees the International Space Station continuing beyond 2024 but with operations shifted more toward the private sector.

▸▸ **AVIATION DECISIONS** Continued from page 34

To keep this competitive momentum going, many free-marketers would like Open Skies agreements with the countries that account for the remaining 30 percent of international departures. The U.S. also would need to renegotiate its Open Skies agreement with the United Kingdom, because the U.K. is leaving the European Union and will no longer be covered by the U.S.-EU agreement.

But Open Skies, like other free-trade policies, has its critics. Major U.S. passenger carriers complain that Persian Gulf carriers have used oil revenue to subsidize rapid growth in world markets under Open Skies. Then again, challenging this behavior could endanger the Open Skies approach. The Trump administration faces the challenge of preserving competition and ensuring that it is fair competition.

3. How far should the U.S. go on reducing aviation emissions?

ANALYSIS – The president-elect's team will quickly learn that advocates of cleaner flight see 2016 as a turning-point year. A committee of the International Civil Aviation Organization in February agreed on carbon dioxide emission limits for new aircraft to be applied in the early 2020s. In October, the U.S. joined 190 other nations in agreeing to an ICAO program in which carbon dioxide offsets could be applied to limit carbon emissions. An airline might, for instance, pay another entity or project outside aviation to reduce carbon dioxide emissions in order for the airline to continue emitting CO_2 at more than the level of 2000.

The U.S. signed up for a voluntary offset program, which starts in 2021. ICAO plans on mandatory offsets from 2027 to 2035. If the Trump administration and Congress accept the offsets, many implementation questions will need to be answered by 2020. Which government department will ensure U.S. compliance? How will carbon dioxide emissions be measured? Will the year 2000 base levels apply to airlines individually or as a whole? Which entities and projects will be eligible for offsets, and how will double counting of offsets be avoided?

4. How can flights of drones be expanded safely in the years ahead?

ANALYSIS – The FAA's new regulations for unmanned aircraft that went into effect in August are unlikely to be the last word on the topic of drones in the national airspace. The regulations allow flights of small drones in many areas but also limit their operating altitudes and create no-drone zones around airports. FAA is working on a system to protect descent and takeoff paths around airports. Many more decisions lie ahead if the Trump administration wants to set the conditions for this market to grow safely. When should geofencing — software that keeps drones from entering certain airspace or forces wayward drones to land — be applied? What rules can best ensure safety, and how can they be enforced? How does drone size affect safety? How should regulation of small, hobbyist drones differ from rules for larger business drones?

5. Should the Ex-Im Bank assist U.S. exports with loan guarantees?

ANALYSIS – The U.S. Export-Import Bank has financed foreign purchases of U.S. aircraft and serves as a counterweight to the export assistance given by other nations to their aerospace industries. But free-market purists in the U.S. consider Ex-Im loan guarantees to be subsidies. Opponents were successful in suspending Ex-Im programs for a while and have limited recent guarantees to $10 million. Aerospace manufacturers want the $10 million limit lifted and a regular Ex-Im appropriation bill passed, rather than another continuing resolution.★

Henry Canaday is a former energy economist who has written for Air Transport World, Aviation Week and other aviation publications for more than two decades.

▸▸ SPACE DECISIONS Continued from page 35

initiatives, even if they don't support classic exploration goals. NASA Chief of Staff Mike French described these options at the same advisory committee meeting where Walker spoke.

Walker — a longtime supporter of commercial space "before it was cool," as one industry executive put it — envisions the station as a beehive of private sector activity. Companies and an expanded set of international partners, potentially including China, would chip in for operations and upkeep.

2. Should new military satellites be [a]disaggregated[o]?

ANALYSIS – U.S. planners will surely brief the Trump team about proposals to make military satellite constellations less vulnerable to any antisatellite weapons that China or Russia might wield, either launched from the ground or maneuvering in space. The Pentagon wants to decide very soon what the replacement systems will look like for today's missile warning and nuclear command-and-control satellites. That way, work can begin toward fielding them a decade or two from now. One strategy under discussion, called disaggregation, calls for dispersing communication payloads and sensors across lots of smaller satellites, rather than concentrating them on large, vulnerable platforms.

3. Which agency should study Earth's climate, land and oceans?

ANALYSIS – It's no secret that many Republicans in Congress don't see the wisdom of NASA spending between $1.5 billion and $2 billion per year studying Earth when there is a whole solar system and beyond to explore.

The question is whether the Trump administration should try to move NASA's Earth sciences mission portfolio to NOAA, which operates weather satellites and is viewed by some lawmakers as a more appropriate home for that activity.

Moving those programs to NOAA would be complicated and messy and likely require congressional authorization. Advocates for Earth sciences worry the dollars might not be transferred with the portfolio. The move also could encounter fierce institutional resistance from NASA.

Politically, the powerful U.S. Sen. Barbara Mikulski, D-Maryland, is set to retire in January, so this could be a tempting time to try. Mikulski has been a longtime patron of NASA's Earth sciences work, much of which is performed in her state at the Goddard Space Flight Center.

4. Should the U.S. team with China on space projects?

ANALYSIS – Working with China in space has long been a political taboo for NASA and the Pentagon because of China's growing military power, antisatellite testing, military and industrial espionage, and suppression of dissident groups. But if Robert Walker, a Trump adviser and former U.S. congressman, has his druthers, the president-elect's administration would usher in a thaw in Sino-U.S. civil space relations, similar to that with Russia. He doesn't think U.S. know-how would be at risk:

"The fact is, I think we're probably in a position now where we can learn from China as much as they would potentially learn from us, and there's no doubt that they have some fairly expansive views of utilizing space," Walker said at a meeting of the FAA's Commercial Space Transportation Advisory Committee before the election.

Perhaps, but whether Capitol Hill's current denizens feel the same remains to be seen.

5. Should FAA manage space traffic?

ANALYSIS – The world's spacefaring nations have long leaned on the Pentagon as their de facto space traffic cop, but military leaders increasingly see this role as a burden and distraction. Commercial satellites are about to explode in numbers, which will make tracking them more challenging. The U.S. military would rather focus on China and Russia, which have maneuvered spacecraft in manners that suggest work toward antisatellite weapons in space. In 2007, China destroyed one of its weather satellites with an antisatellite rocket. Given that trend, the Pentagon wants the FAA to take on the job of providing standard collision avoidance warnings to government and commercial operators, since it already has a commercial space regulatory role. The FAA's Office of Commercial Space Transportation says such a transition could work. It could fall on the Trump administration to give this novel idea an official thumbs-up — or down. ★

Parrot

▼ **The FAA implemented new regulations** for unmanned aircraft in August, but questions remain on how rules for larger business drones should differ from hobbyist drones, such as Parrot's Bebop 2.

Warren Ferster is a senior analyst with the space consulting practice of The Tauri Group in Alexandria, Virginia. He was editor-in-chief of Space News, where he worked for 21 years, starting as the national affairs and policy reporter.

DETERRING NORTH KOREA

The U.S. Missile Defense Agency wants 2017 to be a turning-point year for an anti-missile system the Pentagon knowingly deployed before it was fully developed. **Michael Peck** examines the technology and history of the Ground-based Midcourse Defense system.

BY MICHAEL PECK | michael.peck1@gmail.com

Should North Korea's leaders ever consider launching a nuclear-tipped missile at the United States, there are two considerations that might give them pause: First, there is the certainty that North Korea would be committing national suicide. Second, there is the uncertainty that the missile's warheads would ever reach Honolulu or Los Angeles.

That's because the U.S. plans to body-slam any warheads headed this way with darts that would be launched atop boosters sprung from among dozens of silos in Alaska and California.

Ground-Based Interceptors like this one are deployed in Fort Greely, Alaska, and Vandenberg Air Force Base, California, to defend against missile attacks on the U.S. homeland. The Missile Defense Agency plans to raise the number deployed to 44 and improve their Exoatmospheric Kill Vehicles.

Missile Defense Agency/Defense Department

The task for the $28 billion Ground-based Midcourse Defense system, or GMD, is often compared to hitting a bullet with a bullet, but that's probably an understatement. First, the interceptor must spot the bullet in the vast expanse of space. Then it must intercept it at a combined closing velocity at least 10 times higher than that of two bullets fired at each other.

No one can credibly promise that the GMD system will work as planned in an emergency, but with North Korea exploding nuclear bombs underground and testing long-range missiles, the U.S. plans to spend hundreds of millions of dollars in 2017 to continue improving a system that was rushed into service in 2004 to meet then-U.S. President George W. Bush's deadline for deploying a missile defense system.

Intercepting a warhead arcing through space requires fast detection of the missile launch followed by the firing of an interceptor missile armed with an Exoatmospheric Kill Vehicle, plus accurately discriminating the real warhead from what's likely to be decoys and a cloud of debris left by a warhead or warheads separating from a missile.

Norm Tew, the program director for prime contractor Boeing, notes that the GMD system must link seven kinds of sensors spanning 15 time zones. The sensing needed to detect and knock down warheads comes from the Space-Based Infrared System satellites; Cobra Dane upgraded early warning radars; the Ballistic Missile Early Warning System radars in Greenland and England; Precision Acquisition Vehicle Entry Phased Array Warning System radars in the U.S.; a floating Sea-Based X-band radar; land-based mobile X-band radars; and Aegis ship-based radars. Tew, who has been working in missile defense since 1983, describes GMD as such a vast conglomeration of sensors that it is "the missile system for which you can't stand in one place and see everything required to commence an engagement."

As vast an undertaking as it is, it's clear what GMD is not: an impervious "Star Wars"-esque shield meant to eliminate the specter of total nuclear annihilation. If hundreds of Russian intercontinental ballistic missiles were to streak in over the North Pole, GMD won't stop them. GMD is strictly aimed at blocking a missile strike from a rogue nation, in particular North Korea, but the system could also defend against Iran, should the international nuclear agreement fail.

Why it's the focus

Currently, the U.S. has at the ready 30 ground-based interceptors: 26 at Fort Greely, Alaska, and four at Vandenberg Air Force Base, California. By 2017, 44 are scheduled to be primed for launch from their underground silos. In an attack, a volley of them would rise from their silos. Once in space, each booster would release a rocket-propelled metal cylinder. Each cylinder, guided by its own optical and infrared sensors plus targeting data fed from ground- and space-based sensors, would slam into an incoming warhead, the sheer kinetic impact of the collision destroying or disabling the warhead.

The goal is to destroy a warhead in the middle of its approximately 30-minute flight, when the launch vehicle has ascended through the atmosphere and

Raytheon

▼ A Ground-based Interceptor roars from Vandenberg Air Force Base last January to test a redesign of the Exoatmospheric Kill Vehicle.

NASA

into space and the engines have burned out.

To understand why the Pentagon has made such a focus of going after warheads in space, instead of only when they are conveniently closer to the ground, consider the three stages of an ICBM's trajectory: boost, midcourse and terminal. All things being equal, experts say the best time to shoot down a ballistic missile would be during the boost phase, when it is ascending slowly on a pillar of fire that makes a lovely beacon for optical and infrared sensors and weapons. In addition, the warheads and decoys are still nestled in the nose cone, so there is only one target. The trade-off is that boost phase is geographically and technically challenging. As a 2004 American Physical Society report pointed out, the boost phase only lasts two minutes for solid-fueled missiles and three minutes for liquid-fueled, which leaves little time for interception. An interceptor, or perhaps someday a laser, would need to be positioned or flown close to the enemy's launch site.

Then there is the terminal phase, when the warhead is falling through the atmosphere toward its target. Terminal interceptors would have an easier time picking out targets from decoys, because real warheads fall through the atmosphere more slowly and heat up more quickly than heavier warheads sheathed in protective materials. The downside is that the terminal phase might last only 30 seconds, and the warheads could potentially take evasive action or detonate above their targets.

▲ **In the dark:** North Korea and South Korea as photographed from the International Space Station. In 2004, then-President George W. Bush accused North Korea of "arming with missiles and weapons of mass destruction, while starving its citizens."

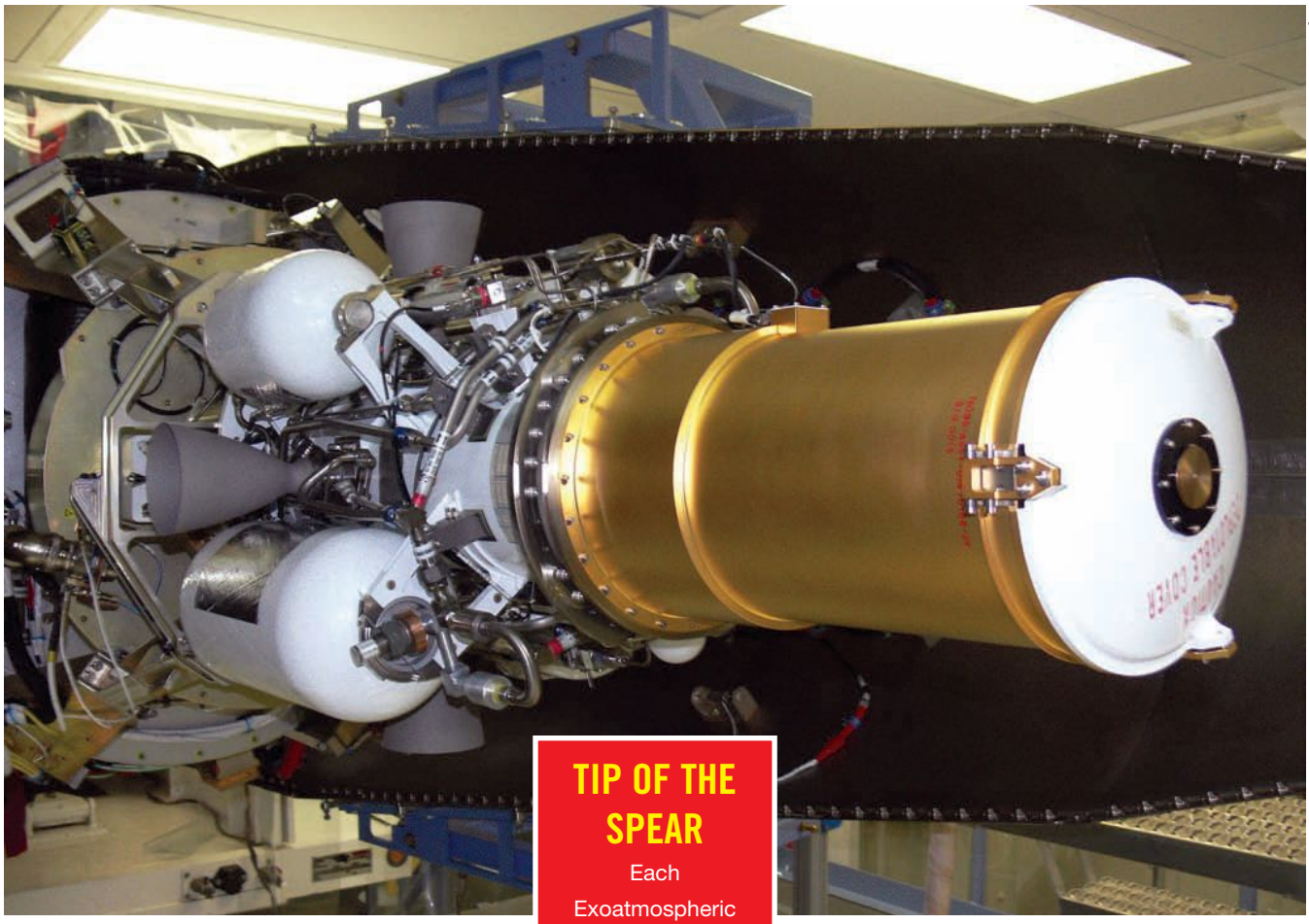
THE DREAM TEAM

For the Ground-based Midcourse Defense program, Boeing is prime contractor, with Orbital ATK building the booster, Raytheon building the kill vehicle and Northrop Grumman building the fire control and communications systems.

Experts hope that defending the homeland will never come down to a shot in the terminal phase alone, which is why the midcourse is the main focus, at least for now. In the long term, the U.S. Missile Defense Agency wants to put lasers on high-altitude, long-endurance unmanned planes and destroy missiles in the boost phase from standoff ranges. U.S. Navy Vice Adm. James Syring, head of the MDA, said in August 2016 that the agency plans to test lasers aboard MQ-9 Reaper unmanned aircraft. Last year, five prime contractors — Boeing, General Atomics Aeronautical Systems, Lockheed Martin, Northrop Grumman and Raytheon — completed MDA-funded studies to assess the feasibility of an airborne laser demonstrator. In fiscal 2017, MDA plans to award two contracts for preliminary design of a multi-kilowatt laser to be mounted on a high-altitude manned or unmanned aircraft. The goal is to flight test a prototype in 2020.

Why it's hard

Development of GMD has been technically challenging, especially the Exoatmospheric Kill Vehicle, or EKV. An MDA fact sheet on GMD lists 17 tests between 1999 and 2014, of which nine were deemed successful: Three of the eight failures were caused



Raytheon

by the kill vehicle not separating from the booster; two involved sensor issues on the kill vehicle; two involved failure to launch due to problems with launch software or silo hardware; and one was scrubbed because the target vehicle malfunctioned.

Ted Postol, a professor emeritus of science and international security at the Massachusetts Institute of Technology, argues that the basic science behind GMD is flawed.

Postol believes that while the kill vehicle's sensors can detect objects in space, they can't discern warheads from decoys until it is too late to intercept. Assume the warheads and decoys are traveling at around 7 kilometers per second, and the kill vehicle at around 8 kilometers per second, for a combined closing speed of 15 kilometers per second, Postol postulates. If the kill vehicle's sensors only register indeterminate points until the targets are about 10 kilometers away — his best guess based on likely fields of view and sensor dimensions — then once the true target is discriminated, there would be less than one second to adjust course and strike it.

Postol compares the task to a street-corner shell game: You can see the hustler whirl his three cups over the table, but you can't be sure which cup has the little ball. Picking out the warhead from among a cloud of decoys and debris can't be done quickly enough, he says. The only way to find the real warhead would be to have advance knowledge of the characteristics of the warhead, such as its shape, temperature and color.

MDA and the companies that build GMD have a hard time blunting such arguments with specifics, because they fear that disclosing technical details could enable an adversary to spoof or evade a kill vehicle.

Still, Air Force Brig. Gen. Bill Cooley, GMD program director at MDA, expresses confidence about the GMD system. "Objects have different [sensor] signatures," he tells Aerospace America. "We use all phenomenology to perform discrimination."

Tew points out that GMD uses a combination of technologies, including infrared and visible-light sensors on the EKV, plus ground- and space-based sensors that feed updated targeting information to the booster and kill vehicle in flight.

"With any one type of technology, you can figure out how to confuse" a kill vehicle, Tew adds. "So the key is you want to use all the types to make it really difficult for anything to get past it."

Even if the EKV's sensors work as designed, hitting a fast-moving warhead will require the kill vehicle to maneuver extremely rapidly. Which is where

TIP OF THE SPEAR

Each Exoatmospheric Kill Vehicle, or EKV, is a cylinder with four thrusters encircling its midsection. The kill vehicle's three sensors Ð two infrared and one that detects visible light Ð must pick out a nuclear warhead or warheads from amid a cloud of decoys and debris from its booster. Once the sensors pick out the warheads, its thrusters line it up to intercept the target.

EVEN IF THE EKV'S SENSORS WORK AS DESIGNED, HITTING A FAST-MOVING WARHEAD WILL REQUIRE THE KILL VEHICLE TO MANEUVER EXTREMELY RAPIDLY. WHICH IS WHERE THE GMD STORY GETS ESPECIALLY COMPLICATED.

the GMD story gets especially complicated. A persistent problem with GMD has been rough combustion of the EKV's thrusters. This shakes the kill vehicle's initial measurement unit, which must determine the kill vehicle's position relative to the target. In at least one test, the shaking caused the kill vehicle to miss its target.

That problem affected the first generation of the EKV fielded in 2004, called the Capability Enhanced, or CE-1. New interceptors are equipped with the CE-2 models whose inertial measurement units are cocooned against vibrations caused by rough-firing thrusters. Engineers also improved the sensors, electronics and communication components. MDA declines to specify the exact mix of CE-1s and CE-2s in the field. However, the agency says Redesigned Kill Vehicles currently under development will replace all existing CE-1s by fiscal year 2022. The CE-2 was tested Jan. 28, 2016, in what MDA called a non-intercept test. The kill vehicle wasn't supposed to hit the target but rather get close enough to show that its sensors and thrusters worked. MDA proclaimed the test a success, but in July, the Los Angeles Times reported the kill vehicle had not homed in anywhere near the target. MDA maintains that the test was not meant to be an intercept and that it was successful.

The January launch is not listed on the MDA fact sheet describing test results, and MDA says this is because the sheet lists only intercept tests. The agency provided a list of 11 non-intercept tests between June 1997 and January 2016, all of which were described as "achieving test objectives."

Early deployment

President George W. Bush in 2002 ordered the Pentagon to put a GMD defense in place by 2004. In his January State of the Union address, Bush had accused North Korea of "arming with missiles and weapons of mass destruction, while starving its citizens," and he placed its government in what he called an "axis of evil" with Iraq and Iran. For acquisition officials, Bush's decision meant that GMD had to be developed at the same time as it was being fielded. Bush's predecessor, Bill Clinton, had started the GMD program by signing the National Missile Defense Act of 1999, but Clinton had deferred a deployment decision to his successor.

Raytheon

▲ **A Raytheon engineer** conducts final inspections during assembly of an Exoatmospherc Kill Vehicle.

◀ **An Exoatmospheric** Kill Vehicle is shown in the shroud of a Ground-based Interceptor.

In subsequent years, Government Accountability Office reports criticized the Pentagon for deploying equipment before it was fully tested. As a 2012 GAO study noted, while "some concurrency is understandable, committing to product development before requirements are understood and technologies mature or committing to production and fielding before development is complete is a high-risk strategy that often results in performance shortfalls, unexpected cost increases, schedule delays and test problems."

MDA continues to work toward improving the system. The agency wants $274 million in fiscal 2017 for the Redesigned Kill Vehicle. Another $72 million would go for development of a Multi-Object Kill Vehicle. Just as ICBMs can carry multiple warheads, a single interceptor would carry multiple kill vehicles. The agency also wants an upgraded interceptor that could be launched as a two- or three-stage booster depending on the range to the target.

As program director Cooley sees it, the GMD program has reached a turning point. The focus has shifted from basic development to making the system reliable and sustainable. A CE-1 built in 2004 is now 12 years old, raising issues of obsolescence and maintaining an industrial base for spare parts. Cooley wants to see a kill vehicle "that can last for decades." ★

Lockheed Martin

▲ **Lockheed Martin's** Quiet Supersonic Transport (QueSST) concept

The other 4 percent

Here's something worth remembering during any presidential transition: The first A in NASA stands for aeronautics. Research in that area accounts for only 4 percent of NASA's budget, but those dollars have an outsized impact on the daily lives of taxpayers.

Many of us would love to fly from point A to B faster (See "Flying fast, flying quiet" on page 8), on the most efficient route possible, with fewer delays, propelled by engines that won't choke on ice and that fly with the least possible environmental impact. NASA is working with the aviation industry and in some cases the FAA to achieve all those objectives.

Some of what's been accomplished so far is visible when looking out the terminal window. Many airliners now have drag-reducing winglets. Damage-tolerant fan casings protect fuselages in the unlikely event an engine's blades fly apart. NASA's Aeronautics Research Mission Directorate has assembled a diagram depicting "decades of contributions to commercial aviation."

Depending on how one measures fuel efficiency, a Boeing 787 or Airbus A350 today is 50 to 70 percent more efficient than a Boeing 707, according to the forward to the forthcoming book, "Green Aviation: Reduction of Environmental Impact Through Aircraft Technology and Alternative Fuels."

My purpose in pointing this out is not to cry poor on behalf of aeronautics. My fear is that there is a risk of forgetting about this kind of work amid all the exhilaration that will come from peering back toward the origins of the universe with the James Webb Space Telescope; or making a space station near the moon; or mining asteroids for commerce; or walking on Mars or maybe even looking out a spacecraft's window someday and seeing Jupiter's Great Red Spot or the icy surface of Europa.

We are becoming extraterrestrials, and it is exciting. But it is also resource intensive. Forty-four percent of NASA's budget goes to Human Exploration Operations, including the International Space Station, Orion and the Space Launch System rocket; 29 percent goes to a long list of science projects, from assembly of Webb to developing the Mars 2020 rover to planning a robotic mission to Europa.

What is the right balance between aeronautics and space? Opinions will no doubt vary, but here's an argument for why today's balance might be about right. NASA maintains a separate Space Technology research category, and it makes up 4.3 percent of the budget. That's not much more than the 4 percent that goes to aeronautics research. In that sense, there is parity and perhaps one that should be maintained. ★

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

Flying fast, flying quiet

The curves and features of Lockheed Martin's supersonic X-plane model have specific purposes in the quest to show the feasibility of Mach 1-plus passenger jets. Keith Button spoke to the engineers who hope to fly this, or a similar X-plane, by 2020.

By Keith Button
buttonkeith@gmail.com

The path to the potential return of supersonic passenger flights travels through an artificial living room, specifically the Interior Effects Room at NASA's Langley Research Center in Virginia, better known as the boom room. It's furnished like a typical suburban American living room, with bookshelves, a flat screen TV and stereo, curtains, paintings on the wall, a coffee table, and a chair and couch. Here, starting in 2011, NASA engineers sat down test subjects to listen to and rate their annoyance from recorded and simulated airplane noise. Speakers pointed at the walls from the outside emitted a range of sounds based on recordings of supersonic F/A-18s, from muted thumps to sonic booms that rattled the fake windows.

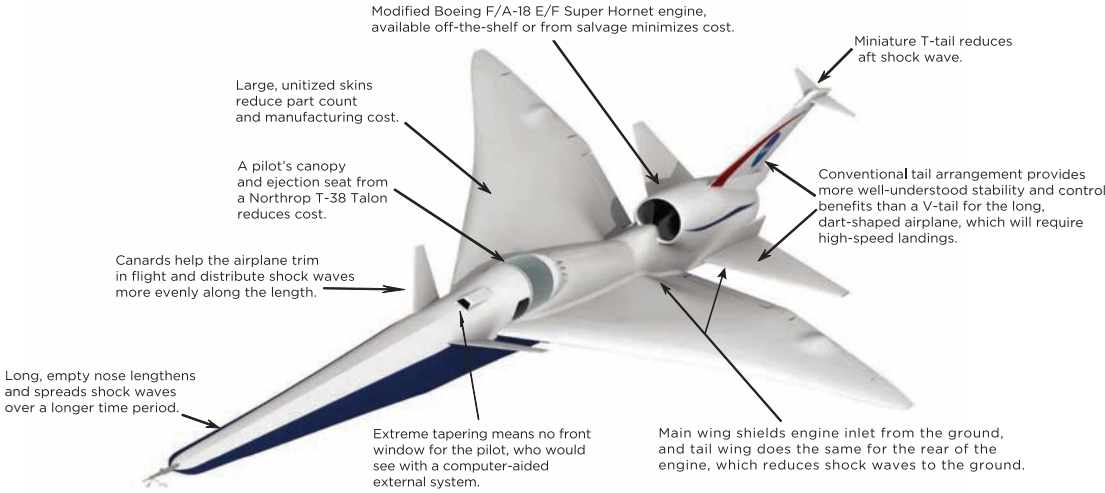
This testing and other experiments dating to the 1980s helped engineers from NASA's Commercial Supersonic Technology Program decide just how quiet a future supersonic jet would probably need to fly to be accepted by the public and the FAA.

The FAA banned supersonic flights over land even before the supersonic Concordes began

Lockheed Martin

▲ **Lockheed Martin's Quiet Supersonic Transport (QueSST)** concept seeks to produce a distant supersonic thump rather than a disruptive boom.

DAMPENING SHOCK WAVES



Innovations are evident from tip to tail in Lockheed Martin's wind tunnel model for a proposed X-plane to demonstrate quieter supersonic flight.

(Not shown: Landing gear from an F-16 to reduce cost)

their trans-Atlantic flights to the U.S. in the 1970s. The planes were not permitted to fly supersonically over the U.S. Most other countries also prohibit commercial supersonic flight over their territories. What's changed is that modern computational fluid dynamics and computing are providing confidence that engineers can shape an aircraft to deliver a vastly softer supersonic footprint. To prove it, NASA plans to hire a contractor to build a supersonic X-plane for a series of flights starting in 2020.

Wind tunnel tests are slated in February on a preliminary design crafted by Lockheed Martin Skunk Works, called QueSST, for Quiet Supersonic Transport. Engineers will install a 9-percent-scale model in a high-speed wind tunnel at NASA's Glenn Research Center in Ohio to see if the shape delivers the desired result. A preliminary design review will follow in June, and in August Lockheed Martin will deliver a flight simulator and additional QueSST models to NASA. After that, NASA plans to share the design and test data with the industry and hold a competition in 2018 for the right to build the single-pilot X-plane. It would be one of five X-planes NASA wants to fund under its New Aviation Horizons initiative.

The hope is that the flight tests will provide justification for lifting the ban on supersonic commercial flights over land, if the Trump administration has not already done so, as the transition team was reportedly considering. Airplane makers might then choose to make passenger jets that would cut current flight times in half. The first of the new class would be corporate jets or 100-passenger versions, but large airliners could follow if additional innovations are made.

Noise reduction

Supersonic airplanes typically produce a double-cracking noise of at least 95 A-weighted decibels, or dBA — a measure of loudness in the frequency range detected by the human ear. On the dBA scale, a pin dropping would be 10 dbA; whispering 25 to 30 dBA; normal human speech 60 to 70 dBA; a lawnmower 90 to 100 dBA; and a jackhammer 110 dBA.

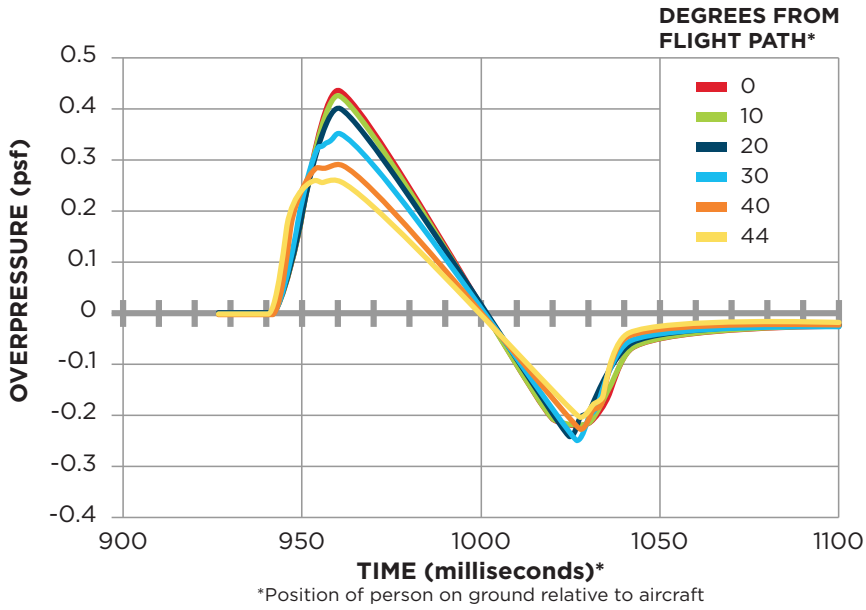
The audible portion of the X-plane shock wave would sound about like riding in a luxury car on a highway. The sound would not be noticeable above the noise of people conversing or a stereo at a low volume, engineers say.

"You get a thump, equivalent to if you get out of your car and your neighbor a few doors down gets out of his car and slams the door, you hear a thump. But it's not really a disturbing sound," says Peter Coen, who manages the Commercial Supersonic Technology Program at NASA Langle.

Lockheed Martin Skunk Works finished building the wind-tunnel scale model of its QueSST concept in December and planned to ship it to NASA Glenn. The Skunk Works designers in Palmdale, California, ran 9,000 potential solutions on the design to optimize it, says the company's Peter Iosifidis, program manager for the QueSST aircraft preliminary design.

Computer simulations show that the X-plane

SONIC HEARTBEAT



*Position of person on ground relative to aircraft

When air pressure beyond normal ambient is charted over time for Lockheed Martin's proposed supersonic X-plane, the result is a sine curve rather than the sharp N expected from a war plane. For someone on the ground, that means hearing a distant thump rather than a loud boom, engineers say.

would be a "low boom" aircraft peaking at far less than the 95 dBA sonic booms produced by the Concorde jets that stopped flying in 2003.

Lockheed Martin engineers demonstrated in 2011 that they could accurately predict the acoustic signature of a supersonic airplane, as designed on paper and proven by the actual noise produced by a different 9-percent model in a high-speed wind tunnel. That demonstration opened the door to computational fluid dynamics designing and optimizing without having to wind-tunnel test each iteration.

It's all in the shape

Any disturbance in the air flowing over a supersonic airplane creates a shockwave. Typically the nose, canopy, antennas, wings, tail and other protuberances create mini-shockwaves at different strengths moving at different speeds, and these small shockwaves pile up as they travel to the ground, combining into two large shockwaves, from the front and rear of the aircraft.

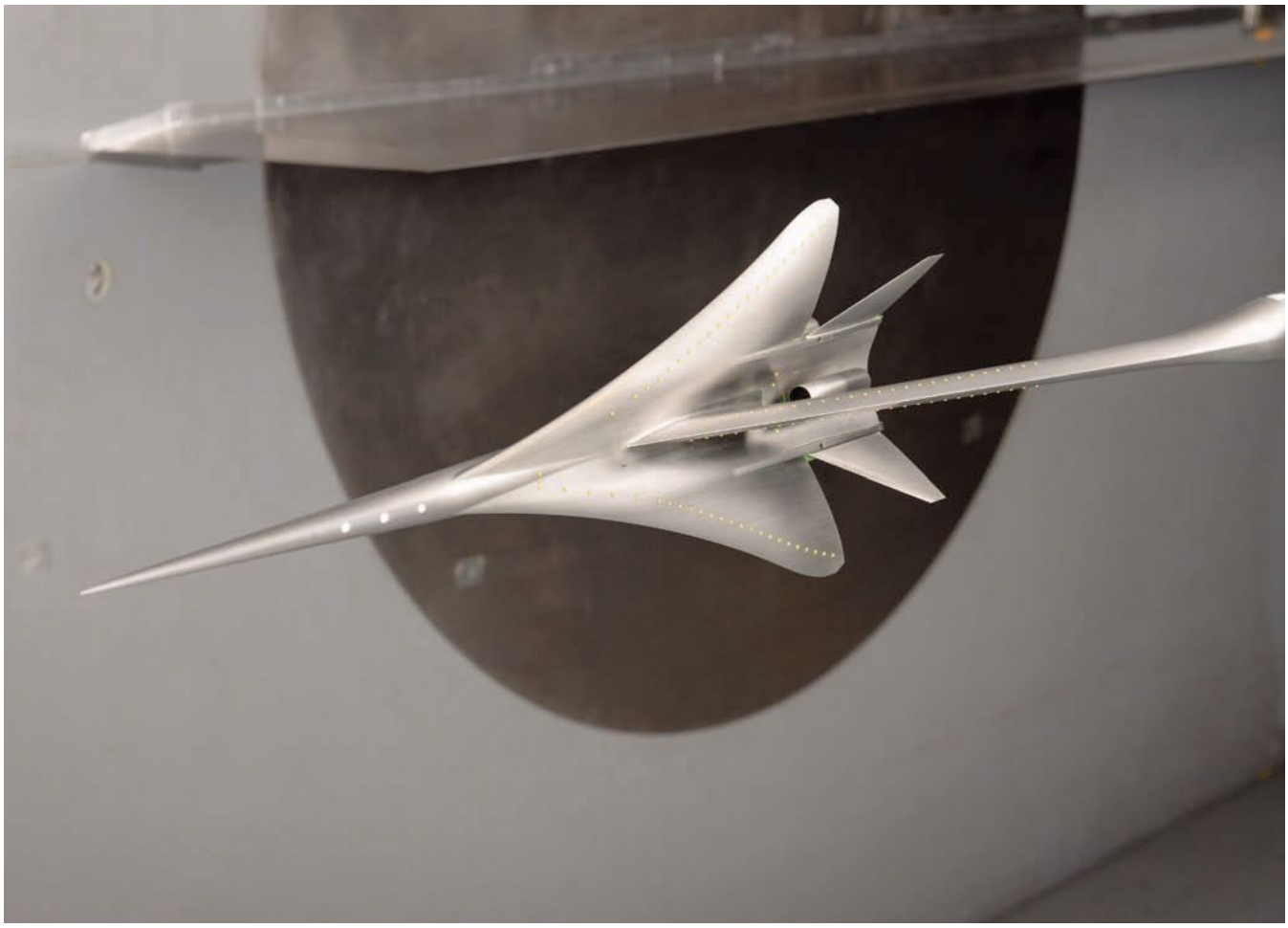
By shaping a plane to control the strength and position of the many small shock waves emanating from the body of a supersonic plane, designers can create shock waves that are relatively evenly spaced and equal in strength, so the waves don't coalesce and are more easily dispersed by the atmosphere as they travel to the ground, says NASA's Coen. Instead of the two sharp increases in air pressure and sound that mark a typical sonic boom for a listener on the ground, an airplane designed to control its sonic boom will create more gradual changes in air pressure that are less noticeable and therefore less annoying.

If one were to chart the pressure changes over time as heard on the ground beneath a conventional supersonic jet, the line would be shaped like an N. It would start at ambient level and rise sharply, then decrease to below ambient, followed by another sharp increase. The line for a controlled sonic boom would look more like an irregularly shaped sine wave than an "N," rising and falling more gradually. It would peak at 65 dBA or less, Coen says.

Lockheed Martin's designers drew up a plan for a plane whose noise signature, if charted, would be an irregular sine wave. The air pressure of individual supersonic shock waves weakens, and the waves spread over time. The plane's long pointy nose creates a weak bow shock, or initial shock. Lengthening the fuselage spreads the acoustic signature. The dart-like shape of the airplane and its extreme fuselage tapering eliminates the forward-facing window for the pilot, who views the front-facing scene through a computer-aided external vision system.

Small canards, or tiny wings, project from the fuselage in front of the main wings to help the airplane trim during flight. They also distribute shock waves more evenly along the length of the plane. The main wing shields the jet engine's inlet from the ground, reducing the shock wave emanating to people on the ground. A horizontal tail wing shields the exhaust end of engine for the same purpose. The airplane has a conventional tail wing arrangement, but also has a small T-wing that designers added not for airplane control, but to reduce the aft shock wave.

The 28.7-meter-long, 10,886-kilogram QueSST



NASA

would fly at Mach 1.4 at up to 55,000 feet. Future designers would draw on data from the computational modeling backed by wind-tunnel testing of the design. This data establishes how each feature of the design contributes to the plane's shock waves, Iosifidis says. Those designers could apply the same methods to design larger aircraft with the same noise level as QueSST, but the QueSST design won't simply scale up to a commercial passenger plane.

Beyond the shaping in the design, every component of the Lockheed Martin would be commercially available off-the-shelf or from salvage, Iosifidis says — a T-38 pilot's canopy and ejection seat; a modified Boeing F/A-18E/F Super Hornet jet engine; and the landing gear from an F-16. "There's no other technology, other than shaping, to actually achieve the noise signature."

Coen says that airplane designers could design, with shaping and currently available technology, a low-noise supersonic corporate business jet, or even a 100-passenger, 136,000-kilogram airplane.

For a 200-passenger supersonic plane, shaping might not be enough. The weight of an airplane is an important component of its supersonic shock wave, because the larger the airplane, the larger the lifting surfaces, and the stronger the shock waves and the more difficult they are to manage. NASA's vision is that airplane makers will innovate once the supersonic market is re-opened, with the X plane as the starting point for technology that will evolve into supersonic airliners.

"If you solve the sonic boom problem, the market will open for supersonic business aircraft, some companies will enter that market," Coen says. "That will help further prove the technology and also open a market and develop an appetite for supersonic flight."

If airplane designers are to create a low-boom supersonic airliner capable of carrying 200-plus passengers, perhaps in 25 years, today's researchers will have to develop new ideas for modifying air flows around supersonic planes, Coen says.

"Could [shaping techniques] improve in 20 years? Maybe. But from my perspective, if we're eventually going to have an airliner, we need all of the technology," Coen says. Flow modification, along with other developing technologies, "needs to be explored at the fundamental level now, so 25 years from now it's ready for application in a practical product." ★

▲ **NASA windtunnel tests on a Lockheed Martin** model in 2011 gave confidence in the accuracy of noise predictions from computational fluid dynamics. The yellow dots on the model protrude from the surface slightly to produce turbulent flow when desired.