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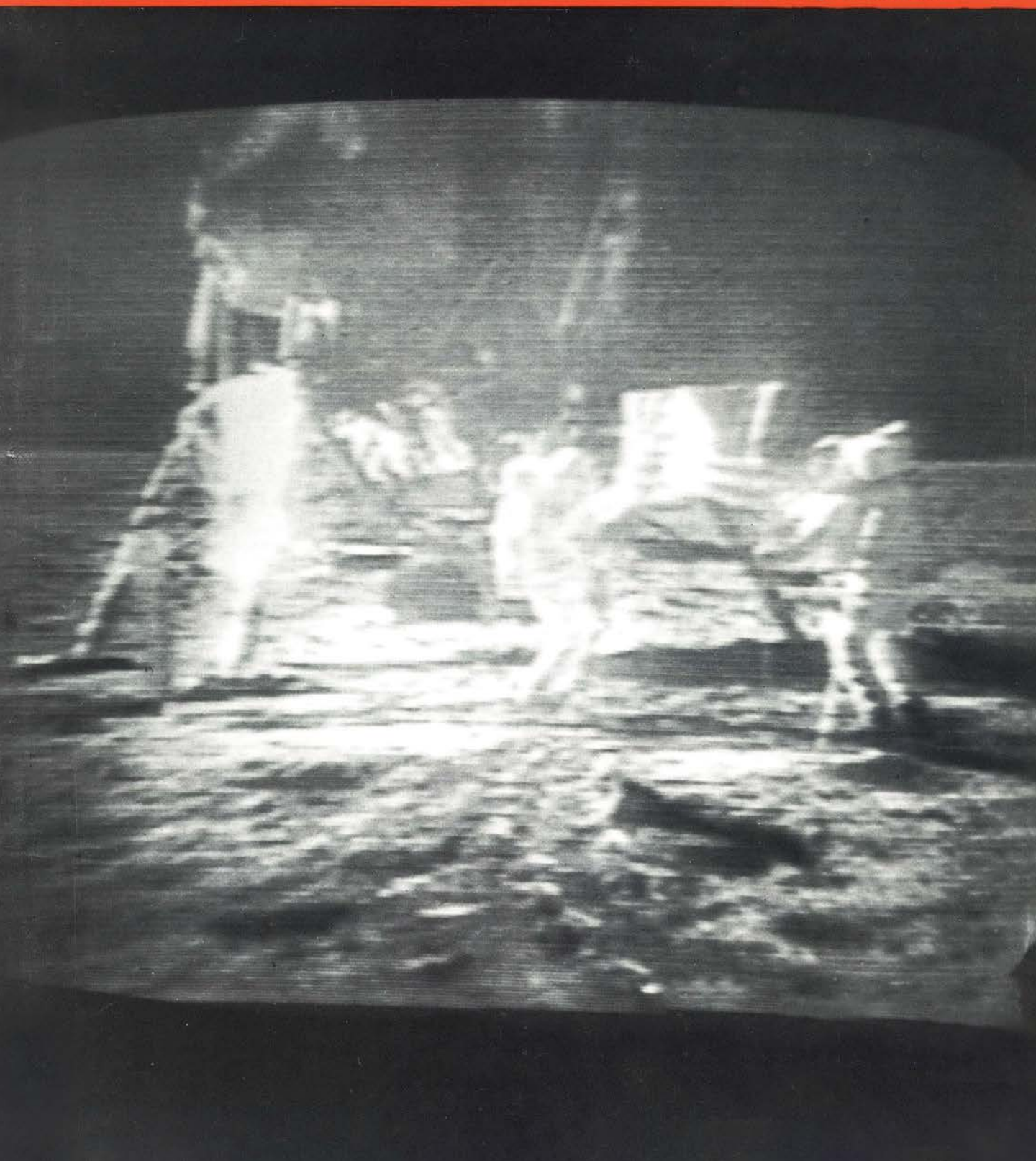
Special Report:

Apollo 11 Landing On Moon

See contents, page 15

Apollo 11 astronauts plant U. S. flag on lunar surface



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AVIATIONWEEK
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July 15-28, 2019 · Volume 181 · Number 14

NASA

"HERE MEN FROM THE PLANET EARTH
FIRST SET FOOT UPON THE MOON JULY 1969 A.D.
WE CAME IN PEACE FOR ALL MANKIND"

The words on a plaque left on the Moon by Neil Armstrong and Buzz Aldrin

APOLLO 11 AT 50 | Next Steps

APOLLO 11 AT 50 | Viewpoints

70 | *Blue Origin's concept of the Blue Moon lunar lander with a crew/ascent module.*

APOLLO 11 AT 50 | Interviews

FEATURES

DEPARTMENTS

ON THE COVER

Fifty years after Apollo 11 commander Neil Armstrong snapped what has become an iconic photograph of his crewmate Buzz Aldrin on the surface of the Moon, NASA is developing a new lunar exploration blueprint that includes commercial services and international partners, with the goal of a sustained human presence beyond low Earth orbit, as pictured in this composite illustration. Aldrin image: Neil Armstrong/NASA; Moon base: European Space Agency concept; Earth image: Mopic/Shutterstock

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FIRST TAKE

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NASA

SPACE

Early data indicate a successful flight test of NASA's Space Launch System/Orion crew capsule launch abort system on July 2 from Cape Canaveral. The 3-min. test should set the stage for the Artemis 1 uncrewed Orion flight around the Moon in late 2020/early 2021 (page 48).

NASA has awarded SpaceX a $50 million contract to launch an X-ray observatory using a previously flown Falcon 9 from Kennedy Space Center, Florida. IXPE is designed to measure polarized light from black holes, neutron stars and other high-energy astrophysical objects.

NASA chief Jim Bridenstine on July 10 shuffled the top management of the agency's human exploration and operations division, sidelining Associate Administrator Bill Gerstenmaier and his deputy, Bill Hill. Gerstenmaier was replaced by former astronaut Ken Bowersox. Gerstenmaier was reassigned as a special advisor to Bridenstine's deputy, Jim Morhard. Hill becomes a special advisor to Associate Administrator Steve Jurczyk.

The 15th mission of Arianespace's Vega light launcher failed, tarnishing the thus far impeccable track record of the Italian-designed vehicle and destroying the United Arab Emirates' FalconEye 1 Earth-observation satellite.

Startup small-satellite launch company Virgin Orbit completed what it expects to be the final unpowered flight test of its two-stage, liquid-fueled LauncherOne expendable rocket, clearing the way for a trial run to space, possibly by late summer.

DEFENSE

Boeing has restarted T-X trainer flight testing after the two company-funded prototypes were modified with changes, including Collins Aerospace ACES ejection seats, planned for the engineering and manufacturing development aircraft.

The first of 16 modified Airbus C295 airlifters for Canada's Fixed-Wing Search-and-Rescue program flew on July 5 in Spain. The aircraft, designated CC-295 in service, will be fitted with search radar, electro-optical/infrared sensor and aerodynamic improvements to extend time on station.

AIRBUS

Guatemala is the first export customer for Argentina's upgraded Fabrica Argentina de Aviones IA-63 Pampa III jet trainer, with a $28 million contract for two aircraft for training and border control.

KAI

Korea Aerospace Industries (KAI) flew the first prototype LAH battlefield helicopter on July 4 at Sacheon, South Korea. The LAH is an armed version of KAI's LCH, a development of the Airbus H155, which flew in France in July 2018.

The future of the European EuroMALE unmanned aircraft system is hazy after French officials described it as "obese" because of German requirements for twin engines to operate safely over cities.

Karem Aircraft has teamed with airframe manufacturer Northrop Grumman and system architect Raytheon to bid for the U.S. Army's Future Attack Reconnaissance Aircraft Competitive Prototype program.

Lockheed Martin is designing a longer-range version of the urgently de-

50 YEARS AGO IN AVIATION WEEK

Neil Armstrong became the first person to set foot on the Moon on July 20, 1969. And a panoramic image on Aviation Week's July 21 cover featured . . . four Lockheed C-5A Galaxy cargo transports parked next to three Lockheed C-141s on a flight line in Georgia. But what might appear to be a case of colossally bad editorial judgment is really an example of life before the internet. The weekly edition of the magazine had gone to print before the world knew whether Armstrong and Edwin E. "Buzz" Aldrin would successfully land on the lunar surface. In fact, the July 21 edition made almost no mention of Apollo 11, save for a scant news brief about the mission's launch on July 16. Aviation Week made up for it, however. Apollo 11 appeared on our cover of July 28 (reproduced on page 3 of this issue)—and for the next four weeks after that.

Subscribers can access Aviation Week's original coverage of the Apollo 11 mission at: **archive.aviationweek.com**

RECOGNIZING THE PAST EXPLORING THE FUTURE

Boeing is proud to have been part of America's first steps into space and the "giant leap" made on the Moon 50 years ago with Apollo. But just as the past is merely prelude to the incredible future we are building today, *Aviation Week*'s brilliant coverage of more than 100 years of flight is just the beginning of the amazing true stories they will tell in the decades to come. With over 500,000 pages, their digital archive highlights the most significant achievements in aerospace, including the historic Apollo 11 Moon landing.

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AVIATIONWEEK & SPACE TECHNOLOGY

BOEING

FIRST TAKE

veloped AGM-158C Long-Range Anti-Ship Missile just eight months after the stealthy weapon entered service.

Germany has become the first Airbus A400M operator to deploy the airlifter overseas in an aerial refueling role, sending an aircraft to Jordan to support coalition aircraft operating over Iraq and Syria.

COMMERCIAL AVIATION

Saudi Arabian low-cost carrier Flyadeal has ordered 30 Airbus A320neos, plus 20 options, reversing a December 2018 commitment with Boeing for 737 MAX 8s. Flyadeal is the first airline to publicly drop the MAX since its grounding (page 18).

Boeing delivered just 90 aircraft in the second quarter and 239 for the first half of 2019, as the 737 MAX grounding and related delivery suspension cut into the manufacturer's totals. Commercial 737 deliveries totaled 113 in the first half, a 58% drop from a year earlier (page 16).

French accident investigator BEA says the fan hub from the engine of an Air France Airbus A380 has been recovered from under the ice in Greenland, almost two years after the uncontained failure of the Engine Alliance GP7000.

France plans to introduce an "eco-tax" on flights departing from French airports starting in 2020, Transport Minister Elisabeth Borne said July 9, sparking criticism from Air France and the French airport industry.

Israel has blamed Russia for GPS spoofing that affected flights into Tel Aviv's Ben Gurion Airport for weeks and forced changes in approach procedures.

Space-based surveillance provider Aireon has activated its Aircraft Locating and Emergency Response Tracking service to provide on request the last known position of any transponder-equipped aircraft in distress.

Airbus has teamed with the operators of Paris' airports and public transport system to study the feasibility of an urban mobility demonstration during the 2024 Olympic Games, which Paris will host.

GENERAL AVIATION

Bombardier Aircraft has launched the Learjet 75 Liberty light business jet, a revamped Learjet 70/75 with more legroom, additional range and a lower price. First deliveries are expected in 2020.

Turkish Aerospace flew the first complete prototype of its T625 Gokbey medium-twin utility helicopter on June 29 at its Akinci Air Base facility outside Ankara.

TURKISH AEROSPACE

Gulfstream Aerospace's long-range G600 has earned its type and production certificates from the FAA, clearing the way for first deliveries to customers.

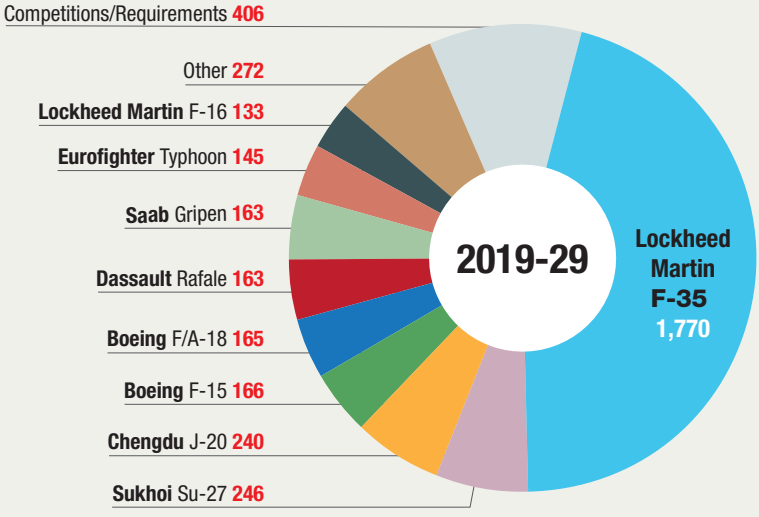
Gyroplane developer Skyworks Global has struck a deal with Serbia to produce the five-seat, runway-independent Hawk 5 autogyro. Skyworks has also partnered with Scaled Composites to build a demonstrator for its Vertijet high-speed gyrodyne.

SKYWORKS GLOBAL

OBITUARY

Norris Krone, considered the father of the Grumman X-29 forward-swept-wing fighter demonstrator, died on June 27 in McLean, Virginia, aged 87. Krone's Ph.D. thesis proved that proper layering of the composite structure could eliminate the aeroelastic instability of forward sweep and enable the aerodynamic benefits. As a U.S. Air Force colonel, and then air vehicle research Director at DARPA, his vision was realized by the X-29. As president of the University Research Foundation's Maryland Advanced Development Laboratory until his death, Krone led work on certification of enhanced vision systems and validation of FAA automatic dependent surveillance-broadcast (ADS-B) ground stations.

The F-35's Fighter Domination Looks Unstoppable



As Boeing and Eurofighter threaten to pull out of Canada's fighter competition, arguing that the contest is unfairly tilted toward the Lockheed Martin F-35, Aviation Week's Fleet Data Services projects the stealthy F-35 will make up more than half of the new-build fighters delivered over the next decade.

For more information about Aviation Week Fleet Data, go to **pgs.aviationweek.com/FleetDataServices**

Source: Michael Tint/Aviation Week Intelligence Network

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Bill Carey WASHINGTON

- FAA DELAYS RELEASE OF REMOTE ID DRAFT RULE
- AGENCY CALLS FOR VOLUNTARY INDUSTRY ADOPTION
- ASTM READIES REMOTE IDENTIFICATION STANDARD

FAA allowances to fly drones over people and beyond visual line of sight of their operators are considered key for commercial applications of small unmanned aircraft systems (UAS), as is the development of a UAS Traffic Management (UTM) system for multiple drones. But none of this is possible, the agency says, until government and industry devise a method of identifying drones from the ground.

In a succession of presentations in June, FAA senior executives reinforced the message that "Remote ID" is a prerequisite for enabling more complex drone operations the agency now disallows except by waiver. The FAA also believes that remotely identifying drones will be key to determining an errant operator's intent, and whether a craft is being maliciously flown near an airport or other sensitive sites.

As of June, according to the FAA, more than 1 million people in the U.S. had registered to fly drones for recreation. There were 380,794 small UAS registered as commercial aircraft, and 140,311 remote pilot certificates issued under the agency's Part 107 regulation governing commercial operations.

Drafting a rule to require that drones be capable of remote identification is the FAA's top UAS regulatory priority.

Remote ID is "the fundamental and next service that needs to be put in place to ensure UTM," Jay Merkle, executive director of the FAA's UAS Integration Office, told the 1,200 people who attended the agency's fourth annual UAS Symposium in Baltimore in early June.

Days later, at a meeting of the high-level Drone Advisory Committee (DAC) in Arlington, Virginia, Merkle called on members to drive voluntary industry compliance with standards for drone identification while the FAA drafts an enforcing regulation. The agency has delayed its plan to release a notice of proposed rulemaking (NPRM) for Remote ID to September from July, citing its complexity.

Coming after a comment-and-review process, the release of a final regulation is "likely up to 24 months away," according to a presentation Merkle delivered June 6 to the committee of senior industry, association and government executives.

"We would like to propose that the DAC set up a task group focused on driving industry-led voluntary compliance with Remote ID ahead of the rulemaking," Merkle told the committee. "We would like the DAC to provide a set of recommendations outlining the process and framework for driving voluntary industry compliance, and our recommendation is that you get that to us in 90 days."

The FAA in June 2017 formed a UAS Identification and Tracking Aviation Rulemaking Committee (ARC) to provide recommendations on available and emerging technologies and a means of implementing remote tracking and identification of drones.

The ARC produced a final report in September 2017 that recommended direct broadcast and network methods for drones to transmit ID and position data. It "did not reach consensus on an applicability threshold" for the types of drones that should squawk their identity, with members disagreeing over capabilities-based and weight-based approaches.

During a June 18 hearing on drone security threats, U.S. senators asked Angela Stubblefield, FAA deputy associate administrator for security and hazardous materials safety, why the agency is taking so long to produce a Remote ID rule. In the FAA Extension, Safety and Security Act of 2016, Congress directed the agency to develop standards for remotely identifying drone operators and their aircraft within two years of the law's enactment in July 2016.

An ASTM standard will describe local broadcast and network methods for a drone to transmit its identification.

"A final rule is nowhere in sight, notwithstanding the congressional mandate," said Sen. Ed Markey (D-Mass.), noting the FAA has pushed back release of the NPRM. "Please explain what is causing the FAA delay on this critical rulemaking."

No requirement exists that a drone "have any kind of 'black box' or flight recorder that would give any evidence of its operation, its control, its flightpath—any of the details that we expect now in many commercial planes," noted Sen. Richard Blumenthal (D-Conn.).

Stubblefield replied that before passage of the FAA Reauthorization Act of 2018, Congress prevented the agency from regulating drones flown for recreational purposes. Section 349 of the legislation President Donald Trump signed into law in October extends remote tracking and ID requirements to hobby drones.

"The challenge has been that prior to October, we did not have the authority over recreational users to be able to craft a rule that would establish this [Remote ID] requirement across the board," she explained.

"Remote identification is the top UAS rulemaking priority in the FAA right now. We are putting all due resources to move that as expeditiously as possible," Stubblefield said. "It's a very complex rule and there are a number of stakeholders to be taken into consideration. It's critical that we get this right because it is foundational not only from the security perspective but the safety perspective as well."

In his presentation to the DAC, Merkle called on drone manufacturers and operators to adopt Remote ID standards developed by the Consumer Technology Association (CTA) and the ASTM International Committee F38 on Unmanned Aircraft Systems.

The CTA's Portable Handheld and In-Vehicle Electronics Committee in April 2017 published guidance for manufacturers on creating physical serial numbers and optional electronic serial numbers to identify individual drones.

Representatives of Committee F38 say they expect to publish a new standard for UAS Remote ID and Tracking with the numeric designation 65041 by late this summer. The ASTM standard covers local broadcast and network mechanisms for transmitting a drone's unique identification, as well as location and vector (speed and direction) information at a regular interval at low altitudes.

Work started in May 2018 as a result of discussions held during the Association of Unmanned Vehicle Systems International Xponential conference in Denver. ASTM and CTA have collaborated to include the latter organization's physical serial number guidance.

"We've already gone through a preliminary ballot [review] at the working group level and will do a ballot to take in the whole committee," says Committee F38 Chairman Philip Kenul. "We plan on having [the standard] finished this summer. We accelerated the development effort because we knew this was so important to the regulators and the industry."

Gabriel Cox, an Intel Corp. drone system architect who leads the ASTM committee's Remote ID work group, says the 65041 standard builds on a solution Intel developed and made public for the local broadcast mechanism. More broadly, the standard takes direction from the FAA's UAS Identification and Tracking ARC.

Intel's Open Drone ID Project to develop a low-cost "beacon" capability for drones produced a specification based on wireless Bluetooth legacy data packets—known as advertisements—and new Bluetooth 5 long-range advertising extensions. Development of the ASTM standard adds a Wi-Fi broadcast as an option.

Keeping the broadcast function compatible with handheld devices such as smartphones and tablets was a "narrowing characteristic" that led the work group to choose Bluetooth and Wi-Fi as the transmission protocols, says Cox. The beacon capability resembles automatic dependent surveillance-broadcast (ADS-B) position reporting by traditional aircraft, but at a much lower power, he adds.

"There's no cell phone connecting to an SSID (service set identifier for networks within range of a device) or anything like that—it just broadcasts out. In that way, it's similar to ADS-B," he says.

The standard sets minimum broadcast intervals of once per second for dynamic positional data, including the drone's latitude, longitude, speed and altitude, and every 3 sec. for static data such as its serial number or registration number and the base operator's location. Disseminating data over a series of messages economizes bandwidth, Cox explains.

A Bluetooth radio or Wi-Fi transmitter, connected by serial port to the drone's flight-control computer, would transmit aggregated positional data via an omnidirectional antenna that radiates a toroid (doughnut-shaped) pattern. Many drones already are Wi-Fi-enabled, so fitting them for Remote ID broadcasts might involve just a firmware update with no additional components. Cox estimates that integrating a Bluetooth radio and antenna on a drone could cost less than $10.

Depending on the receiving device, Bluetooth 4.0 has a range of about 300-400 m (984-1,312 ft.) in an area with little radio congestion, which is within the visual-line-of-sight range for a small drone, Cox says.

As part of the UAS Integration Pilot Program effort led by the Choctaw Nation in southeast Oklahoma, Intel in August 2018 demonstrated an Open Drone ID application that works with Apple and Android operating systems running on smartphones to track a Falcon 8+ octocopter with a Bluetooth 4.2 radio installed. The app displays a map of where a drone is operating, marks its position and provides identifying information.

"When we were working through the standard, one of the really important [considerations] was that we didn't come up with some academic requirement that doesn't match what's available in the market," says Cox. "We know the cost needs to be really low for this. We don't want to prescribe a $1,000 solution on a $100 drone."

The standard generally envisions cellular LTE as the network provider, with a transmitter integrated in the drone. Another possibility would be to use a smartphone that connects to the drone's base station as a bridge to feed data to the network.

Defining network intercommunication protocols involving multiple service providers in a federated system is the last piece to be completed of the 65041 standard. Cox notes that the ability of service providers to propagate drone position and identification data over a network makes possible other applications for flight planning and deconfliction, bringing industry closer to the UTM vision.

NASA

Europe Sets UAM High Safety Bar With eVTOL Certification Rules

> INDUSTRY IS DEVELOPING STANDARDS FOR COMPLIANCE WITH NEW EASA REGULATION

> OPERATING RULES, FAA HARMONIZATION ARE KEY STEPS STILL AHEAD

Graham Warwick Washington

Electrical vertical-takeoff-and-landing (eVTOL) vehicles do not fit existing airworthiness categories, and the need for new certification regulations is often cited as a major barrier to enabling urban air mobility (UAM). So industry is welcoming Europe's publication of the first certification rules for this new class of aircraft. But more remains to be accomplished before air taxis can begin flying above cities.

German eVTOL developer Lilium wants to begin its own commercial air taxi service in 2025.

LILIUM

The European Aviation Safety Agency (EASA) released its final Special Condition for VTOL aircraft (SC-VTOL) on July 2. The certification rules apply to aircraft seating up to nine passengers, weighing up to 3,175 kg (7,000 lb.) and with distributed propulsion, defined as having two or more lift/thrust units.

The regulation establishes two categories of aircraft, Basic and Enhanced, with safety requirements proportional to the intended type of operation. Basic is for personal and rural use; Enhanced is for commercial air transport and flight over urban areas and sets higher safety levels. Enhanced requires the same 10^{-9} probability of catastrophic failure as commercial aircraft.

"The publication of the SC-VTOL by EASA is a big step for the urban air mobility industry, and explicitly enables us to certify our aircraft for urban air taxi operations. The requirements regarding safety are among the highest in the industry and rightfully so," says Jan-Hendrik Boelens, chief technology officer of German eVTOL developer Volocopter.

"Since current airworthiness standards may not address all the aspects of eVTOL vehicles that need to be considered, this special condition from EASA is a step forward in certifying eVTOL systems in Europe," says U.S. manufacturer Bell.

The Special Condition was finalized after consultation with industry. Changes from the draft include increasing the gross weight limit from 2,000 kg to give manufacturers room for growth and align with the break point between existing certification regulations for small (CS-27) and large (CS-29) rotorcraft.

The next step is to develop industry standards that eVTOL manufacturers will use to show they comply with the certification requirements. Two further steps will be critical: harmonization with the FAA and development of operating rules for eVTOLs.

"We did not get our way with everything, but we are highly appreciative of the effort to produce one coherent set of rules for eVTOL," says Kyle Martin, director of European regulatory affairs for the General Aviation Manufacturers Association (GAMA). "The primary need, particularly for European companies, is a basis for the design and certification of the vehicles. If they do not know the regulations, it will be a long process."

EASA has tasked European standards organization Eurocae to work with industry to develop consensus standards for means of compliance. GAMA estimates 70% of industry standards developed for Part 23/CS-23 aircraft can be read across, but EASA wants the first unique vehicle-defining standards for SC-VTOL to be agreed on by year-end. "With a tailwind and goodwill, we can do it," Martin says.

"One concern is we have not yet seen the FAA's equivalent," he says. So far, the FAA is taking a bespoke approach to eVTOL certification that is different for each applicant, issuing special conditions to cover the "delta" beyond existing Part 23 fixed-wing and Part 27 rotary-wing certification regulations. "That has its merits, but there is no one coherent rulebook. We hope that will be resolved," he says.

"EASA's safety requirements are ambitious. They have put a stiff requirement on industry to come up with safe designs," Martin says. "They are looking at the long-term future and saying if there will be hundreds of vehicles over an urban environment, they have to have a very high safety level. We might have preferred to start with a lower safety requirement and build up over time."

EASA was able to develop SC-VTOL in a year because a special condition does not require rulemaking. Still to be resolved are the rules governing how eVTOLs can be used and those covering crew licensing, vehicle operations and maintenance. "These rules are all based on fixed- or rotary-wing aircraft, but SC-VTOL creates an in-between category that is neither," says Martin.

"Implementing such regulations involves EU 'hard law' and could be a five-year process, although they could do derogation or exemption on a member-state basis," he explains. A working group for new air operations has just been established to start development of the regulations. "We hope they will try to expedite the rulemaking process," Martin says.

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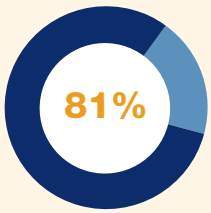
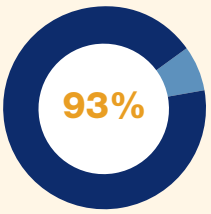


First time Delegates report they would "likely" or "very likely" attend another Conference.



Delegates report they would recommend a Conference to a colleague or peer.

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Latest 737 MAX Issue Seen Delaying Future-Year Production Increases

> PRODUCTION EXPECTATIONS ARE BEING LOWERED AND DELAYED

> BOEING WILL LIKELY TAKE THE BRUNT OF THE LATEST MANUFACTURING IMPACT RATHER THAN SUPPLIERS

BOEING

Michael Bruno Washington

Boeing is not expected to raise its monthly production of 737 aircraft until next summer, commercial aerospace experts now say in the wake of the latest MAX program setback, and the chances of a further rate cut have grown significantly.

In late June, Aviation Week and other media learned that FAA test pilots had flagged a new MAX flight-control system issue that must be addressed as part of changes underway to get the aircraft back into service (*AW&ST* July 1-14, p. 26). If necessary, a solution that requires changing computer chips could delay its return to service (RTS) further, as it likely would require new chip architecture as well as swapping out chips on nearly 500 MAXs in airline fleets or awaiting delivery.

As a result, financial analysts and industry consultants are prolonging their RTS outlook for the MAX as well as when Boeing can resume deliveries. Many do not see passenger service resuming until at least late 2019, and potentially not until 2020. Previous estimates were based on an RTS by early fall and certainly in time for traditional Western year-end holiday travel.

"We are only three and half months into the MAX crisis, but it may have twice as long again to run," say analysts at Agency Partners.

What is more, many experts now believe Boeing may not raise its own monthly production rate to 52 new aircraft until the summer of 2020, and it might put off Rate 57 until late 2020 or even 2021. Currently, Boeing is building 737s at a rate of 42 a month—two of which are P-8s for the U.S. Navy—down from 52 before the MAX crisis erupted. The OEM had planned to be building 57 per month by now.

Boeing had not commented on production plans since before the latest issue emerged June 26. Leading 737 fuselage provider Spirit AeroSystems of Wichita deferred questions to Boeing and regulatory agencies. "We remain ready to support our customer," a spokesperson says.

But analysts and consultants tell Aviation Week and their own investor clients that timelines have been extended by around three months on average. Between the latest microchip development and the belief that regulators are becoming more united globally on the RTS—meaning a longer, more thorough review until they lift groundings—it is likely that MAX deliveries will not resume this year.

"News that Boeing is having to do additional work on the Maneuvering Characteristics Augmentation System (MCAS) software, while the FAA is looking increasingly likely to move with other regulators (versus independently), means that correcting the issues on the aircraft are going to take longer than hoped," Vertical Research Partners told its investor clients July 2.

Kevin Michaels, managing director of Aerodynamic Advisory, says his consultancy is scaling back its monthly rate milestones, expecting Rate 47 for the first half of 2020, 52 in the second half and 57 in late 2021 or even 2022.

However, Sanford C. Bernstein analysts say they do not expect Boeing to reduce its rate from 42, or tell Spirit and other suppliers to cut, unless certification is delayed for much longer than three more months.

Analysts and consultants say timelines for the Boeing 737 MAX's return to service have been extended by around three months.

Nevertheless, Jefferies analysts on July 2 lowered their stock rating of Spirit, the supplier responsible for the vast majority of the 737 airframe, to "hold" from "buy." About half of Spirit's annual revenue derives from the 737 program. The company had staffed up in 2018 to address supply issues and in preparation for going to Rate 57 by now, but it since has been paying to maintain the increased production capacity at an ongoing rate of 52.

"If we assume the grounding stretches on for six months [April to October], 60 [additionally stored] fuselages will take about a year to burn off, with Spirit not fully destocked until late 2020," explain Sheila Kahyaoglu and Greg Konrad of Jefferies. "This will push out Spirit's rise to 57/month to 2021 and likely inhibit growth opportunities in addition to the potential to drive volume leverage."

For Boeing, Bernstein analyst Doug Harned estimates that an additional one-month delay in the MAX's return—beyond the previous September-October expected timeframe—would shift roughly $1 billion in revenue from 2019-20 and cut total cash in those years by $100 million per month. "An extended delay could add costs such as fixed-cost coverage, progress payment recovery, airline compensation and airplane storage," he said June 28.

Boeing has not given much guidance for MAX costs to date beyond adding

a perfunctory $1 billion to its program cost accounting. But experts see the figures only growing. "While I don't think additional recertification delays beyond the fourth quarter are terribly likely, just getting through the rest of the year will be expensive in terms of inventory," Teal Group's Richard Aboulafia tells Aviation Week.

Still, Moody's Investor Service analysts Jonathan Root and Russell Solomon note that Boeing has "considerable" financial ability to manage a grounding longer than an additional four months. "Our estimate of pre-grounding free cash flow of about $10 billion for 2019, coupled with the cessation of share repurchases and more than $6 billion of revolving credit facilities, collectively provide a substantial buffer, even if the grounding unexpectedly extends beyond six months," they said June 28.

Vertical Research Partners analyst Rob Stallard and his team surmise Boeing could take out as much as $7 billion in new debt to cover MAX costs and then pay it off next year.

Boeing 737 MAX Supply Chain Revenue Impact

	Shipset (U.S. $ millions)	Revenues (U.S. $ millions)	Percent of total
Astronics	$0.1	$9	1%
Crane Co.	0.2	15	0
Ducommun	0.2	8	1
Hexcel	0.4	18	1
Spirit Aerosystems	5.5	248	3
TransDigm Group	1.0	75	1
Triumph Group	0.8	34	1

Source: Company reports, Canaccord Genuity estimates

Still, many analysts see Boeing taking the brunt of the latest delay over the MAX, while the supply chain is likely to take it more in stride. "We believe the most recent delay in the Boeing 737 MAX RTS is not as negative for the supply chain as it could be," Canaccord Genuity analyst Ken Herbert says. "The impact of the most recent delay will be different depending on the supplier."

For suppliers that have been running closer to the 52-per-month production rate such as Spirit, Herbert does not expect this most recent delay to change planned 2019 deliveries.

For smaller suppliers running closer to Boeing's own rate of 42, such as seatback-power and connectivity provider Astronics, the second-half 2019 shortfall is likely larger than the initially expected $5-7 million total impact.

But Herbert stresses the latest additional delay will affect second-half 2019 financial results, which will not be known fully until early next year. There also could be greater pressure on 2020 results, depending on how fast Boeing can work down its inventory once the MAX has returned to service.

Europe's Airlines May Face Unwanted MAX Capacity Influx Next Year

> MANY DOUBT A PREDICTED WAVE OF CANCELLATIONS WILL MATERIALIZE

> IT COULD TAKE UNTIL EARLY 2020 FOR THE MAX TO COME BACK

European airlines could face overcapacity when parked 737 MAXs are delivered in 2020.

Jens Flottau Frankfurt

Saudi Arabia-based Flyadeal's July 7 decision to switch its preliminary commitment for up to 50 Boeing 737 MAXs to Airbus A320neos made industry-watchers take notice and wonder: Would this be the first of an increasing number of cancellations now that the global MAX grounding will continue for much longer than initially anticipated? Garuda and Lion Air said earlier they would like to back away from larger orders, and Somon Air (Tajikistan) now says it prefers to change its lease for one 737-8 to an -800.

In fact, the predicted wave of order cancellations has not materialized, and many doubt it will. It looks as if some airlines may try to use the opportunity to cancel orders because of changes in business circumstances unrelated to the MAX. From Boeing's perspective, there are far greater MAX issues of concern than losing up to 50 of 4,937 firm orders, 1% of the backlog, placed by a little-known startup airline.

The airframer will try to negotiate less favorable terms rather than agree to outright order terminations. From an airline perspective, in some regions it could be argued that given where the market is headed, more deals should be canceled or deferred.

That is mainly the case for Europe, where Bernstein Research warns that eventual late deliveries of MAXs to European airlines will make an already unbalanced supply-and-demand equation worse for those carriers. There, Boeing could be facing many requests for delivery-schedule changes as airlines try to decide the best way and time to accept aircraft they expected in the previous year. One major MAX operator told Aviation Week it will not take any new aircraft this summer, postponing deliveries to the slow seasons when the organization has spare management capacity to deal with integrating a new fleet. There is often flexibility in contracts to allow airlines to delay aircraft acceptance further when the manufacturer has been unable to deliver at the agreed time.

"The flood of planes is in full swing in Europe as narrowbody deliveries are set to reach record highs in 2020," analyst Daniel Roeska writes in a recent report. European airlines are scheduled to take delivery of around 300 narrowbody aircraft this year, rising to 400 in 2020. These figures do not include any MAXs yet; those deliveries are on hold because of the global grounding. However, Bernstein expects all of the 146 MAX aircraft that were due by the end of 2019 to be delivered by next summer. Including further aircraft that are to be phased in according to their normal schedules, European airlines could receive almost twice as many new narrowbodies than planned for this year.

The forecast makes the assumption that the MAX grounding will end relatively soon. Current optimistic scenarios foresee October as the earliest time for a slow return to flight to begin. Many observers now believe it could take until early 2020 for the aircraft to come back. The European Aviation Safety Agency (EASA) and other regulatory authorities could take longer than the FAA to clear the aircraft.

The expected influx of MAXs in early 2020 will coincide with a significant deterioration in travel demand, Roeska warns. As leisure demand has been softer in 2019 than in the two previous record-setting years, recent weeks' developments now also point toward the risk of a weakening environment for European corporate demand, notes Roeska. Such trends could "spill over into other traffic segments." Companies could decide first to cut back on short-haul business travel and later reduce spending for long-haul flying, too. Employees, becoming concerned


JOE WALKER

about the economic environment, could decide to spend less on their own travel, "further depressing leisure demand."

Intra-European capacity growth slowed to 4% this year from 6% in 2018, but Roeska sees a serious risk that this trend cannot be sustained due to slowing demand. "Airlines will likely seek to deploy this capacity with the aim of generating at least some cash contribution to partially offset depreciation," he writes.

Orders for narrowbodies are at 60% of the in-service fleet, a historical high, indicating that no quick capacity abatement can be expected beyond 2020.

Furthermore, European airlines already are operating relatively young fleets; the average age of short-haul aircraft is 11 years. Fleet age has come down over several years as low-cost carriers grew fast, but it has stabilized for now. However, with so many new aircraft expected, the average age could drop further as there is limited opportunity to retire aging aircraft.

In theory, bankruptcies also could limit capacity growth. While several smaller airlines such as WOW Air, Primera Air and Germania have failed in recent months, the last large bankruptcy was Air Berlin in late 2017.

Roeska names Thomas Cook and Norwegian as two potential bankruptcy cases that could affect the industry as a whole. Norwegian accounts for 3.4% of European capacity, while Thomas Cook controls 1.2%. SAS Scandinavian Airlines would benefit the most from the demise of Norwegian, as SAS could pick up the former's 30% of Scandinavia-based short-haul capacity. Large parts of Thomas Cook's capacity would remain, as tour operators would seek alternatives for their guests. TUI Group would see the most upside from a possible Thomas Cook bankruptcy, Roeska writes.

He believes Norwegian is increasingly likely to default on its outstanding bonds without an additional rights issue in the coming 12 months. Bernstein Research predicts a 2.3 billion kroner, ($266 million) loss for 2019, worse than the 1.8 billion kroner deficit recorded in 2018. "While the company will get through the summer, as we move into 2019Q4 and 2020Q1, we expect losses to push book equity well below the 1.5 billion kroner coven—or covenant level that would force [Norwegian] into a rights issue—or bankruptcy if shareholders are unwilling to provide additional capital." A rights issue is "the most likely outcome," Roeska writes.

Financially embattled Thomas Cook put its airline division up for sale earlier this year to raise money. Lufthansa, among others, made a non-binding bid, although its chief financial officer, Ulrik Svensson, said last month a takeover is now unlikely. At the same time, Fosun International, a Chinese conglomerate, said it is interested in buying Thomas Cook's tour operator business. Fosun already holds 18% of its shares. It is unclear whether the company would also consider buying the airline division. EU ownership and control limitations would make that a tricky, though not impossible, undertaking.


BAE SYSTEMS

UK lawmakers want to broaden combat air strategy to include platforms like jet trainers to potentially make Tempest more attractive for exports.

British Lawmakers Call for Broader Military Aerospace Vision

> BRITAIN HAS SOLD MORE THAN 1,000 HAWKS SINCE THE LATE 1970S

> UPDATE ON COMBAT AIR STRATEGY EXPECTED AT ROYAL INTERNATIONAL AIR TATTOO

Tony Osborne London

It has been a year since the British government revealed its goal of taking the first steps toward developing a next-generation combat aircraft.

The £2 billion ($2.5 billion) Future Combat Air System Technology Initiative (FCAS TI)—the Combat Air Strategy and joint government-industry initiative called Team Tempest—is seen as a potential major victory for UK industry at a time when buying off the shelf, often from the U.S., has become the fashion.

But now some British members of Parliament have called for a widening of that strategy—beyond simply producing a future fighter—to consider Britain's defense aerospace needs as well as those of export customers.

"We do not want a strategy that sounds good in practice but ends up leaving sufficient space for a far less ambitious position which does not provide the Royal Air Force with the capability it needs or protect the sovereign industry," said Robert Courts, member of Parliament for Witney, England, speaking in a Parliamentary committee debate in London about the Combat Air Strategy on June 27. "We will need to consider whether the offer of an airframe alone will be enough to make a success of this strategy, or whether it will need further expansion . . . so that we can include other capability and diplomacy."

Lawmakers point out the recent success of the UK's contract with Qatar that not only includes the provision of Eurofighter Typhoons but also nine BAE Systems Hawk jet trainers and a training partnership that will see Qatari and British personnel flying in a joint squadron. Courts noted that Saab also has proposed supplying two GlobalEye airborne-early-warning aircraft in its bid for the Finnish fighter contest, in which the Typhoon is being offered as well.

"We ought to consider similar ideas as part of the Combat Air Strategy as well," said Courts, suggesting the UK could supply an air combat cloud, intelligence-gathering capabilities plus training packages and aircraft.

"It would be not [just] a crying shame but criminal if the replacement for Hawk were something that we bought off the shelf, even if from our closest allies," said Mark Menzies, member of Parliament for Fylde, England. "We can, and must, do better than that."

TONY OSBORNE/AW&ST

While the modern Hawk T2 is the backbone of the UK fast-jet training fleet, earlier models like the T1 (pictured) are still used in the aggressor role and as a mount for the Red Arrows aerobatic team.

The Hawk has done phenomenally well for British industry for an initial government outlay of £900 million. Sales of the Hawk have generated another £15.8 billion for the treasury, with sales of 1,000 aircraft including the T-45 Goshawk to the U.S. Hawks also

are being assembled in Saudi Arabia in support of its Vision 2030.

Few nations are able to sell both fighters and trainers in a package.

Compare that to the £15.2 billion outlay from the government for the Typhoon, which brought in £28.2 billion to the treasury over the lifetime of the program, with exports to Oman and Saudi Arabia. Yet those returns on the Typhoon have justified the creation of the Tempest program, but for now there is no push to reinforce it with a new-generation jet trainer. Certainly an already crowded jet trainer market may make it a challenge to bring a new platform to market, particularly with the arrival of Boeing's T-X as well as new technology that is making synthetic training more realistic.

BAE has undertaken initial studies into a future advanced trainer particularly as part of its work with Northrop Grumman, with which it was partnered on the T-X program. BAE also has completed research flights with its Advanced Hawk program to examine what else can be done with the existing airframe, but much of that work has been shelved, as the primary envisaged customer, India, has taken a different approach to upgrading its jet trainers. Britain, meanwhile, is operating the T2 version of the Hawk, which was delivered in the early 2000s, but T1s from the late 1970s and early 1980s are still in service. They provide aggressor training for fighter units and are the mount for the UK's Red Arrows aerobatic team, with no replacement in sight.

Other companies such as Leonardo have asked for clarity about Britain's plans for military rotary-wing capability. It currently builds both the AW159 Wildcat maritime helicopter and the AW101 three-engine heavy-lift helicopter in Yeovil, England, but has expressed concerns about how it will retain the facility's design and development expertise without future programs. A small order from Poland has buoyed AW101 production, but the Wildcat's order backlog has run dry for now. With Britain taking more of an interest in U.S. programs such as Future Vertical Lift, and with long-expected development work on rotary-wing UAVs still to emerge, Leonardo management has said it could be difficult to make further investments in the UK facility.

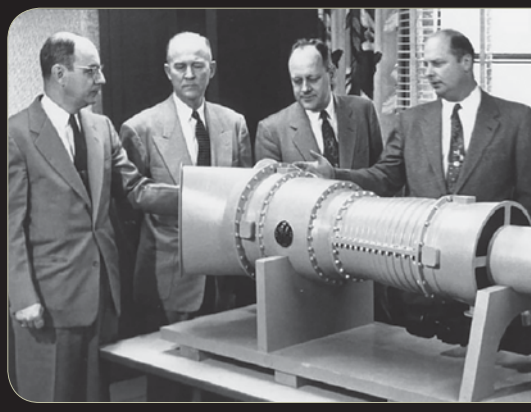
The status of Brexit has added to the uncertainty, despite several sweeteners including the Aerospace Sector Deal in December that provided government financial support to companies investing in more environmentally conscious flight such as electric and hybrid-electric propulsion and less so to those working in the military sector.

Ministers are expected to provide a major update to progress on the Combat Air Strategy at the Royal International Air Tattoo on July 19, where some international air chiefs last year were given a privileged sneak peek at the Tempest concept before it was revealed to the world. At the Tattoo, an announcement is expected on what could be the first international partner, likely to be Sweden.

POWER HOUSE


GE AVIATION

Sanford Moss led the demonstration of GE's turbo-supercharger technology at Pikes Peak, Colorado, in 1918, paving the way for initial high-altitude flights in 1919 and the development of high-altitude fighters, bombers and transports in the following decades. GE's early involvement in advanced supercharging led directly to its selection as developer of the U.S.'s first jet engine.



Guy Norris Los Angeles

FROM HUMBLE BEGINNINGS testing turbo-superchargers in the rarified mountain air of Colorado to setting world power records for turbofans in the 21st century, the past 100 years have seen GE Aviation grow into a global leader in aerospace propulsion. As the company focuses on the next generation of turbine and electric power, Aviation Week highlights just a few of General Electric's milestone engines and people from its first century.

Leading GE Aviation since 2008, company veteran David Joyce has overseen more than a decade of unprecedented growth in its commercial aviation business, including the launch of the Leap family with CFM International and the GE9X for the Boeing 777X. During the period Joyce also has steered the company's aggressive adoption of advanced materials and manufacturing processes including 3D printing and ceramic matrix composites (CMC), as well as investing in research and development for electrification, next-generation turboshafts and combat engines.

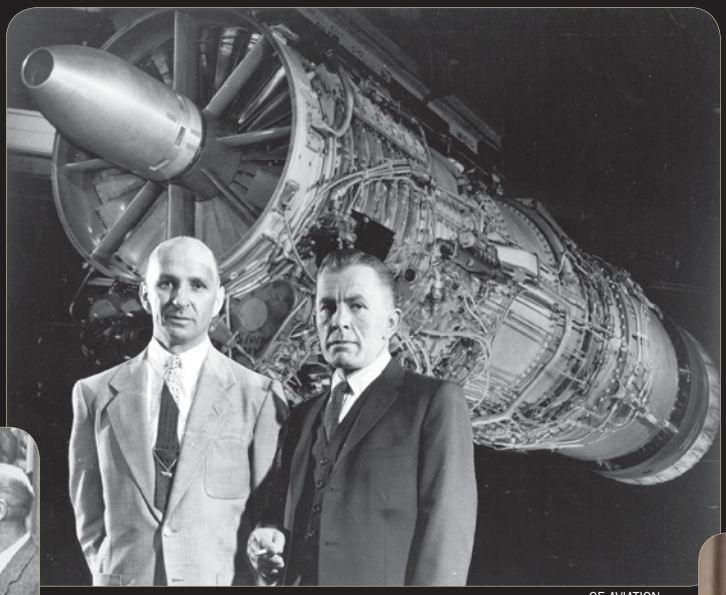

AW&ST ARCHIVES

Based on GE's experience with impellers, turbines, turbo-superchargers and compressors, the U.S. government selected the company to develop America's first turbojet based on a design developed by British jet inventor Frank Whittle. Led by Donald "Truly" Warner, the development team at GE's Lynn-based turbo-supercharger department ran the GE 1-A, an improved version of Whittle's W.2B design, in April 1941. Two 1-A engines powered the Bell XP-59A for its first flight at Muroc Dry Lake, California, on Oct. 1, 1942.

AW&ST ARCHIVES

In 1965, the U.S. Air Force selected GE's TF39, the world's first high-bypass turbofan, for Lockheed's C-5A, the winning entry in the CX-HLS (experimental cargo/heavy logistics system) contest. With an 8:1 bypass ratio, the 41,000-lb.-thrust TF39 incorporated core technology from the company's GE1/6 demonstrator, the lift fan developed for Ryan's XV-5A experimental vertical- and-short-takeoff-and-landing aircraft and the J79/J85 engines among others. GE's win set the stage for the start of decades of competition in the commercial big fan market with archrivals Pratt & Whitney and Rolls-Royce.

AW&ST ARCHIVES



GE AVIATION

GE AVIATION

Jack Parker (third from right) headed GE's influential Committee for Aviation Strategy in the 1950s, which pivoted the company toward pursuit of civil and military turbojet applications, development of a Mach 2 engine, and establishment of the Small Aircraft Engine Division at Lynn, Massachusetts, to introduce turboshafts for helicopters.

Digital Extra *See more milestones in GE Aviation's century of development:* **AviatonWeek.com/GE100**

Influential GE Aviation jet development leader and variable stator innovator Gerhard Neumann (left) and creative propulsion engineer Neil Burgess won a prized National Aeronautic Association Collier Trophy in 1958 for developing the J79, a high-performance turbojet that powered the B-58 and F-104 Starfighter, among others. Neumann also helped secure the formation of CFM International with Snecma (now Safran) in 1974.

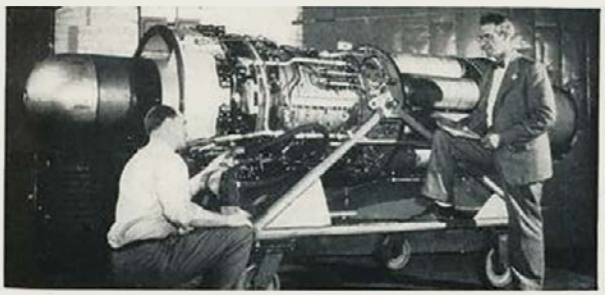
AW&ST ARCHIVES

As head of GE Aviation for 14 years, British-born Brian Rowe oversaw the launch of several key programs including the CF34, CF6-80C2 and, most memorably, the GE90 family.

Bell's Jet-Propelled P-59A Airacomet

re are first photos of Bell craft's GE-jet-powered P-59A hter . . . Comparative illustra- ns show striking similarity be- een earlier AVIATION con- ption (Feb. 1944 issue) and tual ship . . . British show ir Gloucester jetplane.

AW&ST ARCHIVES



AW&ST ARCHIVES

GE Shows -27 Version of J47 Jet

In 1946, GE began design of the J47, an axial-flow turbojet incorporating the initial anti-icing system and first electronically controlled afterburner. Targeted at 5,000-lb.-thrust, the engine was developed into more powerful variants and went on to become the mainstay of U.S. military aviation power for the next decade.

In 1974, following years of negotiations between GE and French engine maker Snecma over joint development of a 10-metric-ton (22,000-lb.-thrust) engine for single-aisle aircraft, the new partner company CFM International officially was formed. The first CFM56 engine, which was built on the F101 core with low-pressure elements provided by Snecma, made its first run in Evendale, Ohio. By mid-2019, around 33,500 CFM56 and follow-on Leap 1 engines had been delivered.

GUY NORRIS/AW&ST

In 2013, Boeing selected the GE9X as sole-source engine for the long-haul, higher-capacity 777X twinjet. The largest engine ever developed, the 134-in.-dia. fan has been designed to have 10% better fuel efficiency than that of the GE90-115 and is rated at 105,000 lb. thrust. In tests, the engine has produced 134,000 lb. of thrust, establishing a world power record for turbofans. Building on the GEnx and Leap programs, the engine incorporates an all-new core, fourth-generation composite blades and a composite fan case, as well as advanced materials such as CMCs. The first full GE9X engine began tests in 2016 and is due to power the 777-9, the first 777X version, later in 2019.

After Apollo

> NASA TRIES AGAIN FOR MOON LANDING

> PRIVATE SPACE INVESTMENTS RISE

Irene Klotz Cape Canaveral

Fifty years and one day after Neil Armstrong and Buzz Aldrin stepped foot on the Moon,

the U.S. space community will note a more somber milestone—the eighth anniversary of the final space shuttle mission, which kicked off a suspension, still ongoing, in the country's ability to launch astronauts into orbit.

With financial and technical support from NASA, Boeing and SpaceX are working to bring commercial U.S. space taxis into service and end the gap. But consider this: The time between President John F. Kennedy's May 1961 address to Congress calling for NASA to land astronauts on the Moon and Apollo 11's touchdown was eight years and two months. The dry spell in U.S. orbital human space launch reaches that milestone in September.

Optimists, however, will note the word "orbital" and point to the robust flight-test programs of emerging suborbital ride providers Virgin Galactic and Blue Origin, which both appear to be within a year of starting commercial passenger flights. In the interim, NASA has kept its astronauts flying to the International Space Station (ISS), thanks to a strong and enduring partnership with Russia—a relationship isolated from the political, military, economic and cultural issues that divide the countries today.

Considering the birth and early years of the space age, the partnership with Russia is both ironic and poetic. "The U.S. and the Soviet Union were in a great-power competition, and when it started, we were behind. . . . Landing [on the Moon] was a goal so far on the horizon that it gave us the opportunity to get ahead," says NASA Administrator Jim Bridenstine (see page 28).

"The last time we had somebody walk on the Moon was 1972. And in 1983, President Ronald Reagan announced the Strategic Defense Initiative—Star Wars—which was met with a whole lot of skepticism on Capitol Hill. They said it was too expensive, not technologically achievable and would never happen. And to some extent, those critics were right. But what's important is that the Soviet Union at the time believed it was achievable because they saw us walk on the Moon six times," Bridenstine tells Aviation Week. "Because of the credibility built by Apollo, the Soviet Union had to make big investments into how to mitigate against the Strategic Defense Initiative."

Apollo 11 astronauts captured an image of a partly illuminated Earth rising over the Moon's Smyth's Sea.

Without funding or political sup-

NASA

port to maintain an Apollo-like effort—NASA back then was allotted 4-5% of the U.S. budget, compared to the 0.5% it receives today. The space agency retooled for sustainability, first with the 30-year space shuttle program and then with the ISS, which has been staffed by rotating crews of astronauts and cosmonauts since November 2000.

NASA hoped to follow Apollo to the Moon with President George H.W. Bush's 1990s Space Exploration Initiative, and then a decade later with President George W. Bush's Constellation program, but both efforts faltered due to a lack of funding and political support. The agency is about to try again under the Trump administration's Artemis program, with the specific goal of sending a man and woman to the lunar south pole in 2024 (see page 48).

NASA is not in the habit of selecting crews by gender, but Vice President Mike Pence's March 26 Moon landing challenge was very specific on that point. Bridenstine has since adopted and personalized the theme, speaking often about how a woman on the Moon would be an inspiration to his young daughter as well as the rest of what he calls the "Artemis Generation."

During Apollo, NASA did not have the goals or cultural support to focus on the space program's impact beyond the hard work of rocket science. That changed dramatically after Armstrong and Aldrin landed on the Moon. "Right after the flight, Neil, Buzz and I got to take a trip around the world," Apollo 11 command module pilot Michael Collins tells Aviation Week (see page 40).

"I thought people would say, 'Well you Americans finally did it.' Instead, everywhere we went, people said, 'We did it.' We—humankind—have left this dinky little planet, and we have gone elsewhere," Collins says. "I don't know of any accomplishment, any human accomplishment before or after, that's had that kind of an effect of bringing nations everywhere together."

During the shuttle program, NASA diversified its astronaut corps, experimented with guest flight services and forged partnerships with other countries interested in the exploration and development of space. The agency also involved students with the shuttle-hosted Getaway Special small-payloads flight program, providing the seeds for the cubesat revolution decades later. (Small satellite pioneer Gilbert Moore personally purchased the first Getaway Special ride on STS-4 in 1982 for a Utah State University payload.)

NASA expanded the partnerships with the ISS, ultimately developing enough trust to rely exclusively on Russia for crew ferry flights after the shuttles were retired in 2011. The space agency also supported fledgling space transportation development efforts by SpaceX and other companies. Those services now are essential for space station logistics as well as future missions in low Earth orbit and deep space, including Artemis.

NASA

STS-135 astronauts (from left, pictured in front of the Astrovan before heading out to the launchpad) Rex Walheim, Sandy Magnus, Doug Hurley and commander Chris Ferguson lifted off aboard space shuttle Atlantis on July 8, 2011, becoming the last NASA crew to launch from the U.S. Ferguson, now with Boeing, is training for the first flight of Boeing's commercial CST-100 Starliner.

RISING STARS

CALTECH/LANCE HAYASHIDA

BETHANY **EHLMANN**

California Institute of Technology

"Apollo forever changed how we see the Earth. By stepping foot on another world, we inaugurated a new frontier in exploration and also realized how rare and special habitable worlds like our own are."

APOLLO'S SISTER

NASA chose the name "Artemis" for its revamped Moon exploration initiative not only as a nod to women but also because Artemis in Greek mythology was the twin sister of Apollo and goddess of the Moon. But there is a cautionary tale in the tea leaves. According to Greek myth, Artemis kills the hunter Orion—the namesake of NASA's 10-year program to develop a crew capsule for travel to and from deep space.

The first operational Orion crew vehicle is being prepared for an uncrewed trial run around the Moon in 2020-21, followed by a crewed flight test in 2022-23. By then, the program will have consumed about $12 billion on top of the nearly $5 billion NASA invested during the predecessor Constellation program, a June 2019 Government Accountability Office (GAO) audit shows.

NASA also is on track to spend an additional $14 billion developing the

Space Launch System (SLS) heavy-lift rocket and related ground systems, the GAO found. That figure does not include SLS booster production beyond the two flight tests or landing systems to support a 2024 crewed touchdown on the Moon, four years earlier than previously planned. Bridenstine estimates NASA will need an extra $20-30 billion, perhaps less, over the next five years to expedite the Moon landing.

"It's possible that the U.S. will not have a government program of human deep-space exploration if this initiative fails," says John Logsdon, professor emeritus of political science and international affairs at George Washington University and founder of the school's Space Policy Institute. "Can we continue to operate the space station for another nine years and have the resources to do what people are talking about? It doesn't seem quite believable to me."

The problem is that NASA's human spaceflight initiative remains a "vendor-driven program that is not being rationally directed," says engineer Robert Zubrin, a longtime advocate of Mars exploration. "If you were to look back at the past 30 years, ever since George [H.W.] Bush announced his attempt to go back to the Moon and on to Mars, this time to stay, what we've seen is no or very little accomplishment in the human spaceflight program, but tremendous accomplishments in the science programs," Zubrin says.

The only exception, he adds, were the five space shuttle missions to launch and service the Hubble Space Telescope. "That showed what humans in space can do with a well-conceived program that has clear and important objectives—a program that was worth risking life and treasure for—which delivered the goods."

BIG BUSINESS

Globally, government spending accounted for $82.5 billion of a worldwide space economy worth $360 billion in 2018, according to Bryce Space and Technology's annual report for the Satellite Industry Association.

In a related assessment, Bryce—a space and satellite analytics/engineering firm—notes that since 2000, startup space ventures have attracted nearly $22 billion in capital investment. That total includes an annual record of $3.2 billion in 2018. Over the last six years, an average of 21 new companies have been funded each year. The influx of private investment has sparked predictions of a global space economy worth $1 trillion in the 2040s, possibly sooner.

So far, 2019 is shaping up to be another record year for private investment in space companies. On July 8, Virgin Galactic, backed by Virgin Group's Richard Branson, announced plans to merge with a publicly traded, special-purpose acquisition group called Social Capital Hedosophia Holdings Corp., which would make an $800 million investment in exchange for 49% of the venture.

That followed a filing in June by Elon Musk's privately held SpaceX seeking to raise another $314 million, which would value the company at more than $30 billion. SpaceX's newest development effort is a Mars-class, reusable passenger space transportation system called the Starship, which if successful, could render NASA's Orion and the SLS obsolete.

"I think the next 50 years are going to be different," says Zubrin. "I was a skeptic of this entrepreneurial space stuff for some time . . . but since then NASA has so radically underperformed and SpaceX has so brilliantly overperformed that it's quite apparent that at this point the entrepreneurial space revolution is real and that it is the way forward.

"Sooner or later, the choice for the human spaceflight program is going to be, 'Do we want to go to the Moon using Orion, or do we want to go to the Moon?'" Zubrin says. "SpaceX is developing what we need to send people to Mars. It's going to be in hand by mid-decade, at which point the game changes."

If the private sector invests the money and creates the capabilities to start traveling to distant destinations, then there is no need for a government program, adds Logsdon. "I don't think that's going to happen. I think that at least the next round of exploration is going to be government-led, with the participation of the private sector in a very different way than was the case during Apollo.

"An alternate scenario, which is possible but not probable, is that this new initiative fizzles, and with it the support for government activity in human exploration dissipates. If that happens, it's entirely possible that we're dead in the water for the time being," Logsdon says.

"One of the things that makes me a bit melancholy now, at the 50th anniversary of Apollo [11], is that the people who did this are not going to be around that much longer," he adds. "The passing of the Apollo generation will be a milestone of sorts, and whether their absence lessens the urge to return to the Moon is not clear to me. It could be that Apollo was a remarkable historical accident."

VIRGIN GALACTIC

Virgin Galactic's SpaceShipTwo made its second suborbital spaceflight in February as flight tests continue in advance of the start of commercial passenger service.

What It **Cost** To Get to the **Moon**

(U.S. $ billions)

Fiscal 1960-73		Adjusted for 2019
0.9	Robotic Lunar Program	10.3
1.3	Project Gemini	14.1
3.1	Development, Support and Operations	28.7
5.2	Construction of Facilities, Salaries, Overhead	54.8
8.1	Spacecraft	81.3
9.4	Saturn Launch Vehicles	99.0
25.8	Total Spending on Apollo	263.8
$28.0	Total Lunar Effort	$288.1

Source: Casey Dreier, senior space policy advisor at The Planetary Society, reconstructed Apollo cost history, June 2019

'We Have To Think Differently'

NASA Administrator **Jim Bridenstine** met with Aviation Week editors at the agency's headquarters in Washington to discuss the meaning of Apollo 11's 50th anniversary and the path forward for human spaceflight.

AW&ST: **How do you see the impact of Apollo 50 years later?** The U.S. and the Soviet Union were in a great-power competition, and when it started, we were behind. Sputnik kicked off the space race [in 1957], and they had the first person in space, the first to orbit Earth and the first lunar landers. Then [in 1961], President John F. Kennedy made one of the most impressive declarative statements in history, which was: By the end of the decade, we're going to put a man on the Moon and bring him safely back to Earth. He declared that about two weeks after Alan Shepard went above the Karman line and straight back down. We were going from about 100 mi. to 240,000 mi. and landing on another world. Kennedy sold it, and the nation bought in. And it was a goal so far on the horizon that he gave us the opportunity to get ahead. It wasn't going to happen in the next year or two, and everybody understood that.

The last time we had somebody walk on the Moon was 1972. And in 1983, President Ronald Reagan announced the Strategic Defense Initiative—Star Wars—which was met with a whole lot of skepticism on Capitol Hill. They said it was too expensive, not technologically achievable and would never happen. And to some extent those critics were right. But what's important is that the Soviet Union at the time believed it was achievable, because they saw us walk on the Moon six times. Because of the credibility built by Apollo, the Soviet Union had to make big investments into how to mitigate against the Strategic Defense Initiative.

What does that mean for us today? Kennedy didn't say, "Go to the Moon and keep going." The problem was that Apollo was sold as a Moon program. And once that destination was reached, people said, "OK, we've done that." Today, the destination is Mars. Why are we so keen on Mars? It has liquid water and methane cycles that are commensurate with the seasons. And, unlike the Moon, Mars has complex organic compounds. The probability of finding life has gone up significantly in just the last year. Spirit and Opportunity showed us that Mars had an ocean in its northern hemisphere, a thick atmosphere and a magnetosphere that protected it from the radiation of deep space. In other words, Mars was at one time habitable. So the goal is to use the Moon as a proving ground to learn how to live and work together on another world using [its] resources, so we can eventually go to Mars for long durations.

You need $20-30 billion over the next five years for the mission to put humans on the Moon by 2024. How do you sell that? The science is critically important. The lunar regolith has so much history of the early Solar System. The Moon doesn't have an active geology, hydrosphere or atmosphere. It is a repository of billions of years of history. We can discover from the lunar regolith what the early Solar System was like, what the Sun was like. We can make amazing discoveries. The other value is that it's so quiet on the far side of the Moon that we can capture extremely long wavelengths from the cosmic dawn—the first light in the Universe—and even the dark ages before the cosmic dawn. We can improve the models of the early Universe that we currently have.

You think Congress would buy a $30 billion science program? Absolutely. We're talking about $20-30 billion spread over five years, a down payment on the development of a program that, when complete, will be sustainable at current budget levels. We're working every day to even reduce it from there, and it could actually be less than $20 billion.

NASA is asking Congress for an extra $1.6 billion in funding in fiscal 2020 to help accelerate a new Moon landing by four years, to 2024. If you don't get that, could you go back to the original 2028 landing without more money? We would need budget increases commensurate with [inflation], but with that, 2028 would be the year. The reason we want to accelerate [to 2024] is that administrations and priorities change. Go back to President George W. Bush's vision for space exploration and the Space Exploration Initiative of President George H.W. Bush. We've tried this before, and it hasn't worked, because the timescales are so long. By accelerating the timeline, we are reducing the political risks. My biggest concern is that at the end of the fiscal year [Sept.

NASA

30] we could end up with a continuing resolution [extending congressional appropriations at this year's levels]. That would guarantee we're not going to land in 2024.

Do you think NASA is doing enough of the basic research that's going to be needed to get humans to Mars? Yes. The research is being done on the International Space Station. The biggest challenge is you lose 1-3% of your bone mass per month, your muscles atrophy, your immune system gets significantly degraded and cranial pressure results in all kinds of medical problems for eyesight. The exposure to radiation changes your physiology. All of these things have to be dealt with. We don't want to send people to Mars for the first time, and when they get there, they're a marshmallow. We're going to need bigger investments for the Mars mission down the road, but the basic research is coming along just fine.

NASA's Space Launch System (SLS) is very expensive, not reusable and may be eclipsed by the SpaceX Starship or something other space entrepreneurs are cooking up. If you're moving into a new era and want to bring more players in, what's the value of sticking with heritage contractors and programs that consume $40 billion and are still two years away from flying? Those are great points, but SLS and Orion are the only vehicles that can carry humans to the Moon at this point in any way, shape or form. Nothing else exists that can do that. We have SLS, Orion and the European Service Module almost ready to go. We're very close on these projects that have been in development a long time. When you look at [lunar] Gateway, we turned to Maxar, a commercial company. They're going to deliver the power and propulsion element on orbit—we're not even going to take possession of it. So we are transforming how we do things, but we can't throw out the only capability that currently exists to get humans to the vicinity of the Moon.

One of the most compelling things about Apollo is that everybody watched it on TV. When SpaceX had a Crew Dragon capsule accident in April, NASA referred questions to SpaceX, and there's been little information. We're fixing that. When an event like this happens, we're going to do a press conference within hours. We'll be sharing information immediately, because as long as it's an American taxpayer investment, we need to be as transparent as possible. What we know at this point is there was a catastrophic loss of the vehicle, and when we have a final conclusion, we will make sure everybody is aware of what happened. It will delay [the program]. We're going to announce a date in the next month or so.

Do you still think U.S. astronauts will launch from U.S. soil in 2019? Yes. The important thing about Commercial Crew is redundancy: If one company has a setback, the other one moves forward. If you lose one capsule, there's another one in development, so it doesn't set us back as long. I believe we will have at least one and maybe two Commercial Crew launches this year.

Will you guarantee that NASA aeronautics research will not be made a bill-payer for human spaceflight, as it has in the past? Yes. We're talking about an annual aeronautics budget of $600-700 million. We could cannibalize that to go to the Moon, but we would be completely unsuccessful because there's just not enough money there. The investments we make in aeronautics are critically important. You hear the president talk a lot about the trade deficit, but the one area where there's not a deficit is aviation and aeronautics. Our ability to manufacture aircraft and engines offsets the trade deficit we run with other countries. That exists because of investments made by NASA.

Should NASA take the lead in the electrification of aviation? Absolutely. If we get complacent, we will fall behind, like we have with propeller aircraft. We know that an all-electric airliner is not realistic in the near term, but we can create a more integrated electric architecture with fewer mechanical components, streamline the aerodynamics and create more efficient engines. I think the hybrid solution works with regional jets or business aircraft. The next level down is the all-electric aircraft. I think there's a large market for personal airplanes, which is why NASA is investing in the [all-electric] X-57.

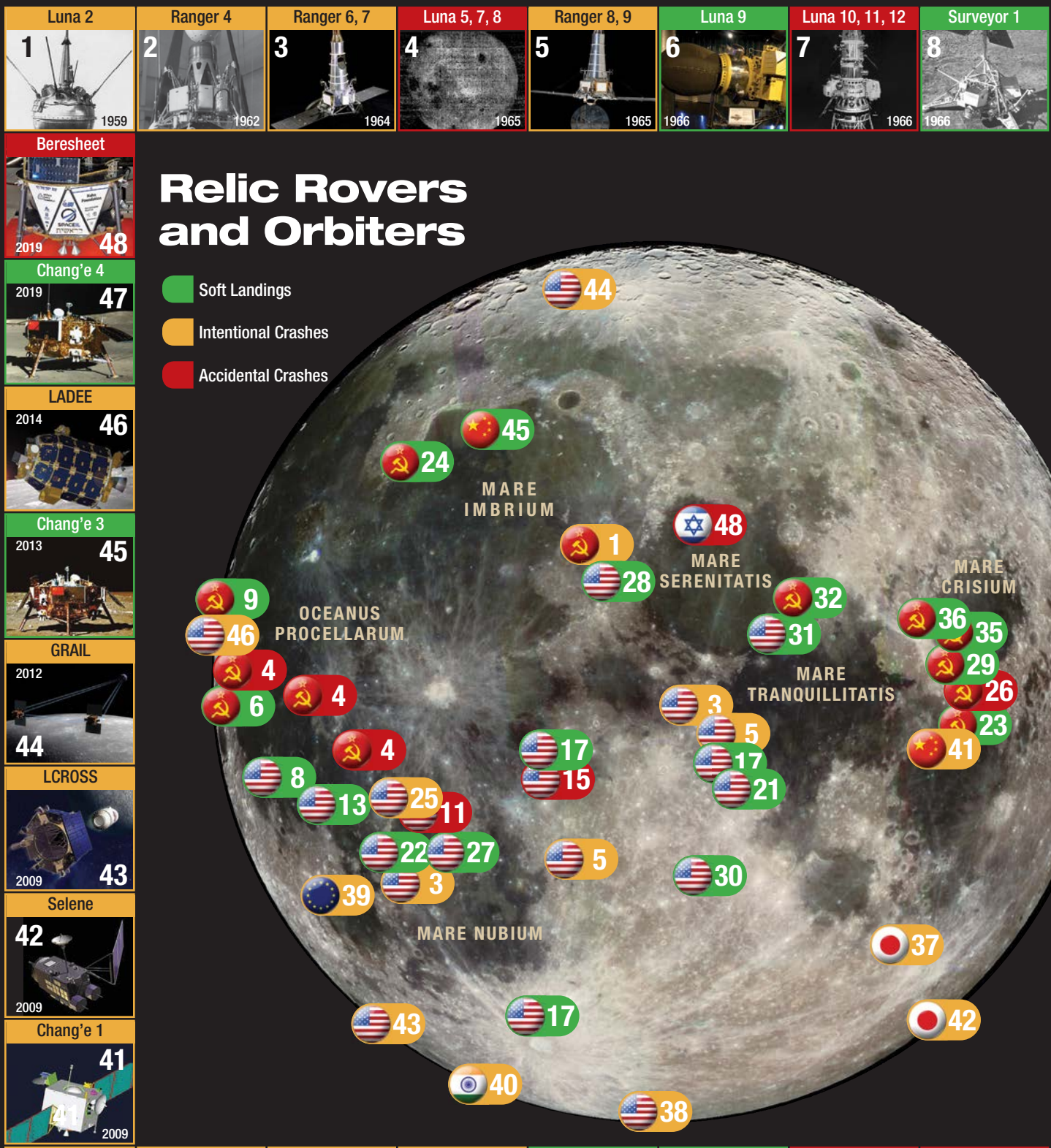
You were just at the Paris Air Show, where a lot of environmental concerns were voiced. If aviation is going to continue to be an export leader for the U.S., then we have to be able to achieve these efficiencies to be in compliance with the regulatory environments in Europe. I don't think a lot of people in the U.S. think that way, but if we want the balance of payments in aviation to be a surplus, we cannot dismiss the regulatory environments in other countries. We have to think differently than maybe some people are currently thinking.

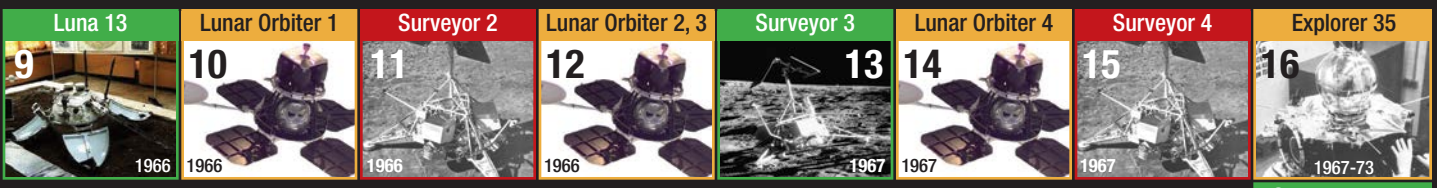
Relic Rovers and Orbiters

Soft Landings

Intentional Crashes

Accidental Crashes





Current and Future Missions

(mission **launch date** country/company)

Lunar Reconnaissance Orbiter **2009 (operational)** NASA

Chandraayan-2, orbiter, lander, rover **July 2019** India

Chang'e 5 sample-return **December 2019** China

Z-01 lander, commercial and NASA payloads **September 2020** Orbit Beyond

Chang'e 6 lunar south pole sample-return **2020** China

Lunar Flashlight cubesat to study volatiles in permanently shadowed craters **2020** NASA

Artemis-1 (formerly Exploration Mission-1) uncrewed SLS/Orion flight test around the Moon **2020-21** NASA

Korea Pathfinder Lunar Orbiter technology testbed **December 2020** South Korea

Peregrine lander, commercial and NASA payloads **June 2021** Astrobotic Technology

Nova-C lander, commercial and NASA payloads **July 2021** Intuitive Machines

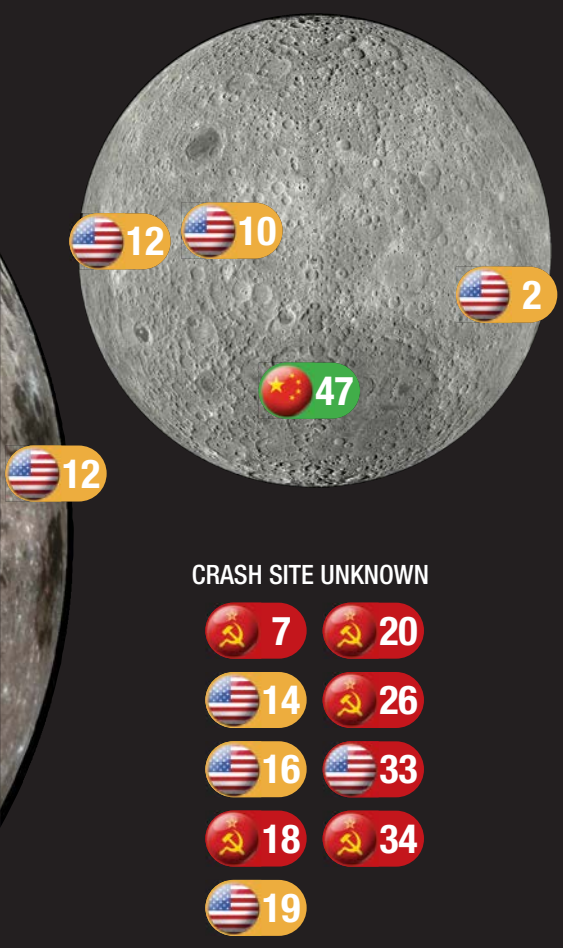
Chang'e 7 survey south polar region **2021** China

Gateway Power and Propulsion Element first module for small lunar-orbiting station **Late 2022** Maxar/NASA

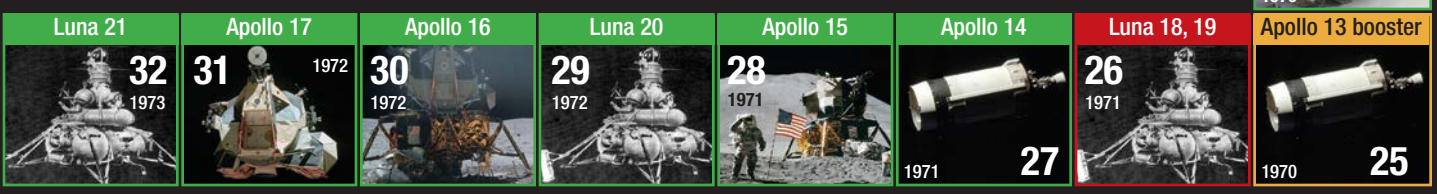
Starship private lunar flyby charter flight **2023** SpaceX

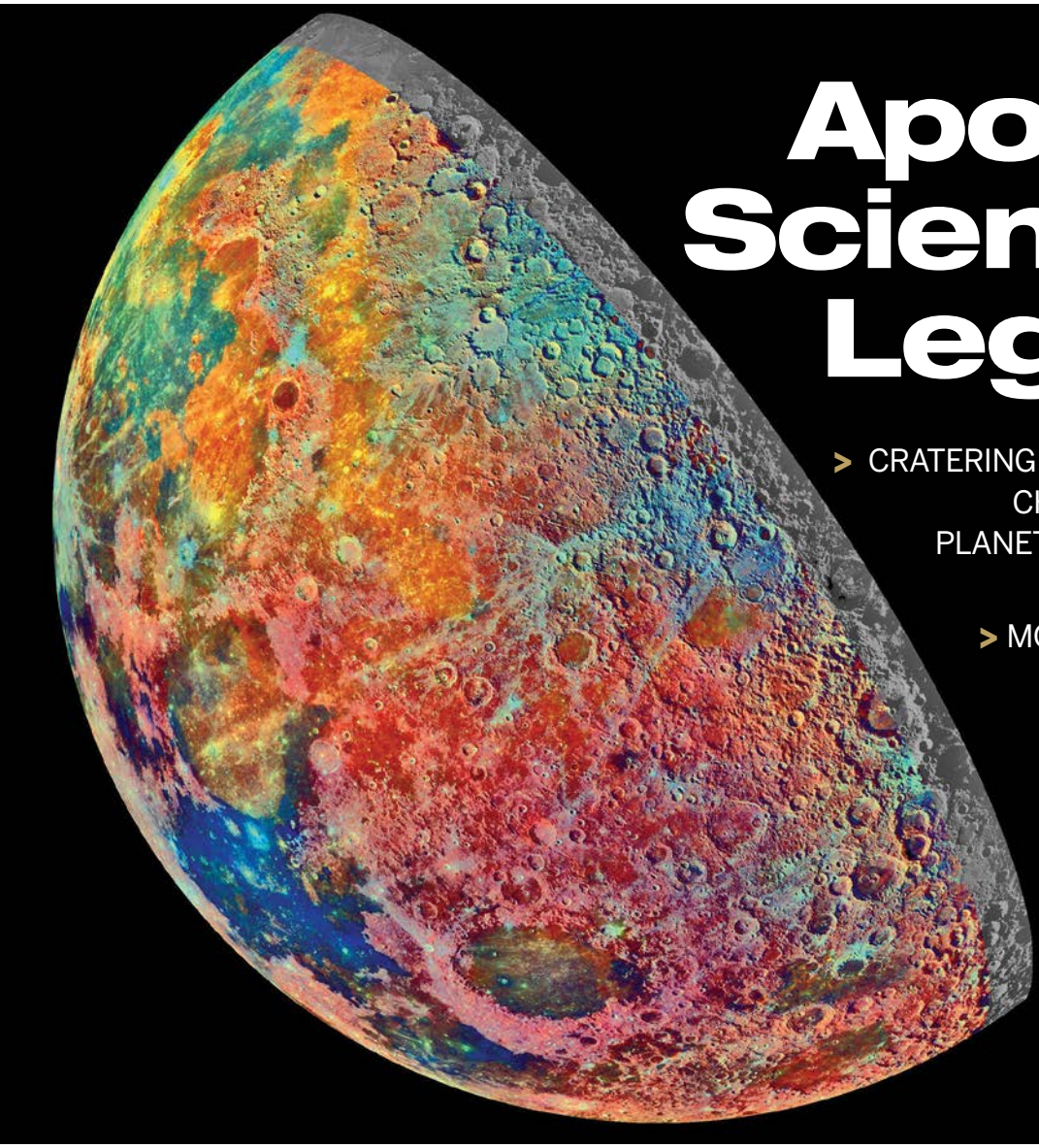
Artemis-2 SLS/Orion crewed flight test **2023** NASA

Artemis-3 SLS/Orion crewed flight for lunar landing **2024** NASA



Digital Extra *Take an interactive look at more about lunar missions past, present and future:* **AviationWeek.com/MoonMap**





Apollo's Scientific Legacy

> CRATERING RECORD BECOMES CHRONOMETER FOR PLANETARY EXPLORATION

> MOON IS NOT SO DRY AFTER ALL

Irene Klotz Cape Canaveral

Before Apollo 11 Commander Neil Armstrong stepped off the lunar module ladder to plant a boot on the Moon, he leaned down and looked at the lander's footpads to see how far they had settled into the powder-like ground at Tranquility Base.

Besides assuaging a lingering operational concern that the regolith at the landing spot would be too thick to walk through, Armstrong's observation that the legs sank only an inch or two into the dust marked the start of Apollo's lunar surface science, an initiative that continues today.

Armstrong and lunar module pilot Buzz Aldrin were sent to the Moon to fulfill a political and foreign policy agenda, but upon arrival they became ambassadors of science. They studied the lunar soil and collected rocks and core samples. They deployed a 4.6 X 1-ft. aluminum foil sheet on a pole and faced it toward the Sun to catch solar wind particles for analysis. They set up a seismometer to measure moonquakes so scientists could better understand the lunar interior structure.

"Science was along for the ride at the beginning stages of Apollo, but then by the end of Apollo it was dictating where the astronauts went, what kind of experiments were brought and what kind of samples were collected," says Noah Petro, project scientist with NASA's ongoing Lunar Reconnaissance Orbiter (LRO) mission.

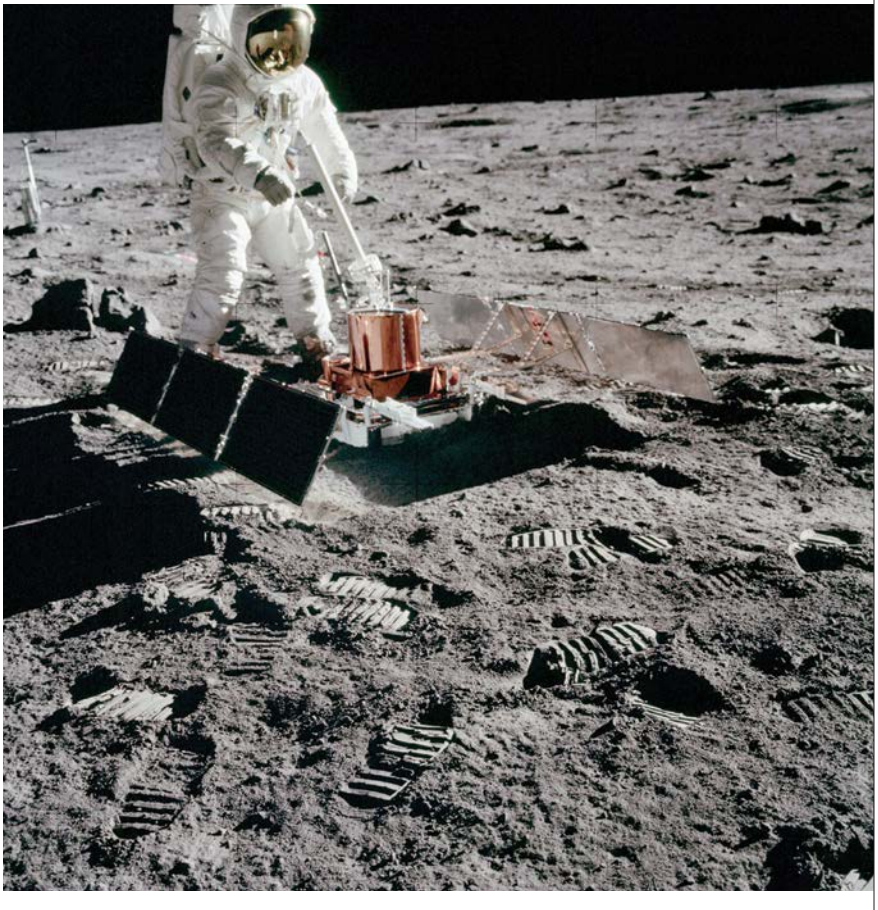
"The types of questions asked at the beginning of Apollo were about fundamental geology. By the end of Apollo, it was getting very specific: 'How old is

This color mosaic of the Moon's northern hemisphere, compiled by images taken by NASA's Galileo spacecraft en route to Jupiter, shows compositional variations. Bright pinkish areas are highlands materials such as the lava-filled Crisium impact basin, pictured on the bottom. Blue-to-orange shades indicate volcanic lava flows. Left of Crisium, dark blue Mare Tranquillitatis is richer in titanium than the green and orange maria above it.

NASA/JPL

this particular geologic feature in relation to what we've sampled before?' and 'Let's go explore this type of volcanism and get this type of material,'" he says. "The maturity of the questions evolved rapidly."

One Apollo 11 experiment is still in use today: a retroreflector to precisely measure the Moon's distance from Earth. Data obtained by bouncing laser light off reflectors placed by the Apollo 11, 14 and 15 crews show the Moon is moving away from Earth at a rate of about 1.5 in. (4 cm) per year. "You actually have to factor that in when you talk about how the Moon was created," says Jim Green, NASA's planetary science division director.



NASA

Apollo 11 astronaut Buzz Aldrin sets up the first seismometer placed on the Moon's surface. It detected lunar "moonquakes" and provided information about the Moon's internal structure.

The recession is believed to result from gravitational or tidal interaction between the Earth and Moon, the same process that also causes Earth's rotation to slow down.

The Apollo program's most valuable science contribution comes from analysis of the rocks, core samples, pebbles, sand and dust brought back to Earth by six crews that landed on the Moon between July 1969 and December 1972. About 70% of the combined 842-lb. haul remains in tightly controlled storage vaults, primarily at NASA's Lunar Sample Laboratory Facility at the Johnson Space Center in Houston.

"What was absolutely essential was the rocks," says David Kring, senior staff scientist with the Lunar and Planetary Institute in Houston. "One can design computer models, simulate things endlessly, but rock samples are geologic reality, and they provide facts that have to be addressed. That was the case with Apollo. We've had 50 years of absolutely stunning science generated by those samples."

NASA's strategy to save samples for analysis by future, more advanced equipment and techniques has paid off. For example, in 2008 scientists reanalyzed pyroclastic glass beads in Apollo 17 sample 74220—the so-called "orange soil" sample—and found water. Initial results had indicated the Moon was completely dry.

By May 2014, scientists had discovered that not only is water widespread on the Moon but rocks from different locations have different amounts of water sealed inside, suggesting that some parts of the Moon are wetter than others. Interestingly, the chemical composition of the water differs depending on the rock.

The most widely accepted theory for how the Moon formed begins with the crash of a Mars-size object named Theia into a very young Earth some 4.5 billion years ago. Debris from the impact formed a ring around Earth, which then accreted into the Moon.

The origin of the Moon's water remains a hotly debated topic. It could have come from the Earth, from impacts with water-bearing comets and asteroids, from the chemical interaction of hydrogen and other light elements in the solar wind with the lunar soil, or from multiple processes. Some of the water in the Apollo volcanic glass samples are similar to magma samples from Earth's mantle, while other Moon rocks were drier, suggesting the formation of the Moon may have

ROCKET LAB

PETER **BECK**
Rocket Lab

"I'd always felt like I'd missed the heyday of space exploration, but now I feel differently. Who ever thought that a kid growing up on a farm in New Zealand could one day own a rocket company?"

comprised a complex series of events.

It was from the Apollo samples that scientists were able to determine the Moon's age, which was older than expected, given that the oldest rocks on Earth date back to about 3.8 billion years, a billion years younger than Moon samples. Earth's plate tectonics, oceans and biosphere, it turns out, destroyed more ancient rock record, though scientists say pieces of early Earth, lofted during meteorite strikes, may have settled on the Moon. And while conditions on the Moon are not hospitable for life, ancient Earth rock preserved on the Moon may hold evidence that pushes back the timeline for life on Earth, research that has implications in the search for life on Mars and elsewhere in the Solar System.

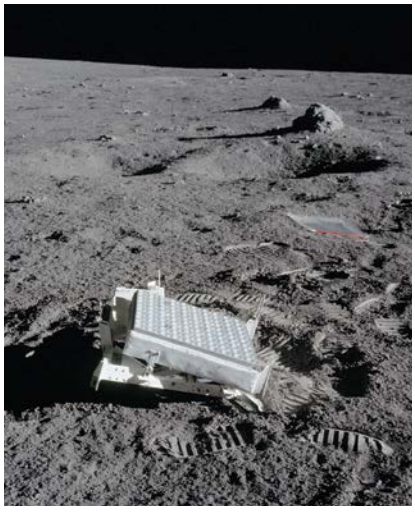
The Apollo program also gave scientists a tool for determining the age of other planetary bodies by literally counting craters. Before Apollo, scientists did not know if the Moon's rugged surface was dotted with volcanic caldera—the collapsed mouths of volcanoes after eruptions—or craters due to impacts. Though the Moon was once a sea of molten rock, indicating volcanic activity, analysis showed most of the craters and basins were formed by impacts. "While volcanism did occur, it was limited in extent and also in time . . . from about 4 billion years ago to about 1 billion years ago, and the Apollo samples reflected that," Petro says.

Scientists were able to correlate the age of the Moon rocks with the amount of cratering in the region where the rocks were found. The more impacts, the older the rock. "That tells us about planetary processes," says Green. "We've used this chronometer all over the Solar System."

"Because we learned ages of surfaces from the Moon, we were able then to look at other planets and other objects in the Solar System and understand, 'Wow, that surface on Pluto is really smooth and has very few impact craters. It must be young,' and we can take a stab at how young we think it is because we have samples from the Moon," adds Petro.

Studying the Apollo samples not only led to a new theory for the Moon's formation but also to a deeper understanding of the conditions that existed on early Earth, as the giant impact that is believed to have formed the Moon was far from an isolated event. "There is the lunar-impact-cataclysm hypothesis, this idea that during the first billion years of Solar System history, the Earth and the Moon were severely bombarded, with a particularly intense spike about 4 billion years ago," says Kring.

The bombardment was coincident with the earliest emergence of life on Earth, leading to a new hypoth-



NASA PHOTOS

A retroreflector was left on the lunar surface by Apollo 14 crew.

Selected Mission Highlights

July 16, 9:32 a.m.
Saturn V lifts off from Kennedy Space Center Launch Complex 39A.

9:43 a.m.
Apollo spacecraft reaches low Earth orbit. After 1.5 orbits, thrusters fire and astronauts Neil Armstrong, Buzz Aldrin and Michael Collins begin their journey to the Moon.

July 20, 4:17 p.m.
The Apollo 11 astronauts arrive at the Moon.

4:18 p.m.
"Houston, Tranquility Base here. The Eagle has landed."

10:56 p.m.
"One small step for man, one giant leap for mankind." Neil Armstrong becomes the first human to set foot on the Moon.

11:15 p.m.
Aldrin joins Armstrong on the surface of the Moon.

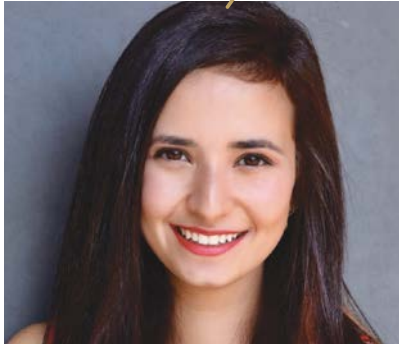
July 21, 1: 54 p.m.
Liftoff from the Moon.

5:35 p.m.
The lunar module rendezvouses with the command module, solo-piloted by Collins.

July 24, 12:50 p.m.
The Columbia splashes down about 934 mi. southwest of Hawaii.

Note : All times EDT.

RISING STARS



VIVIAN NAZZARO

SOPHIA **PORTER**
Blue Origin

"The crux of space exploration is that it unites people. I hope to watch the first multinational handshake on the Moon—or Mars."

esis that those same impact events that were devastating the Moon also were striking Earth, vaporizing the seas and "making conditions untenable for life at the surface, but simultaneously producing vast subsurface hydrothermal systems that were perfect crucibles for the early evolution of life on our planet," Kring notes.

Lunar exploration, which had paused after the Apollo program, resumed in the 1990s with robotic probes owned and operated not only by the U.S. but also Japan, Europe, India and China. Just one, NASA's LRO, remains operational today, though dozens more are due to launch over the next several years.

LRO data has revealed enormous height variations on the Moon, from a low point in the south pole-Aitken Basin—the largest known impact crater in the Solar System—to about 9 mi. higher in the lunar highlands on the far side of the Moon. On Earth, the range from Mount Everest, the planet's high point, to the Marianas Trench, the deepest part of the world's oceans, is less than 7 mi. Another mission that measured the Moon's gravity field found the lunar crust is much thicker on the far side than on the side permanently facing Earth.

Data from another U.S. mission, GRAIL, also found variations in the thickness of the Moon's crust. One theory to explain the difference is that the Moon was struck, Theia-style, by another object, building up the far-side crust. "By going back to the Moon and looking at samples and determining [their] ages, we can tease that apart," notes Green.

Another idea is that Earth is heating the near side of the Moon, causing material to flow toward and possibly accumulate on the far side, a phenomenon first observed on exoplanets in close orbits around their parent stars.

In 1972, geologists Don Morrison (left), William Muehlberger and Fred Horz gazed at an Apollo 16 sample, "Big Muley," a large breccia that is the single largest rock of any of the Apollo program's 2,200 separate samples.

Questions about how the Moon formed have been somewhat eclipsed by the discovery of water inside lunar craters that are never exposed to sunlight. More recently, data from NASA's LADEE spacecraft show water mist repeatedly forms above the Moon. The emissions are tied to micrometeorite impacts that trigger shockwaves as deep as about 10 ft., liberating the water from beneath the desiccated surface. The mist could be the source of water in the cold traps in the permanently shadowed craters.

"We've learned from recent missions that there is water or volatiles at the poles in varying concentrations, as well as water broadly distributed across the rest of the Moon in the form of a very light dew," Petro says. "It's not clear if the water is moving around on the Moon because of interaction with the solar wind, or if it's all water put into the Moon 4.5 billion years ago, when it formed, that has erupted on the surface through volcanoes and then was distributed around the poles of the Moon and across the surface."

Determining the quantity and composition of the lunar volatiles is among the key science goals of a renewed U.S. lunar exploration initiative known as Artemis (see pages 48 and 70), which, like Apollo, will begin with robotic precursor missions and lead up to a series of human expeditions, with the first visit targeted for 2024.

"The science rationale for landing astronauts on the Moon is easy: If you want to understand the origin and evolution of the Solar System, there is no better place to do that than the lunar surface," says Kring. "You can't do it well on the Earth because of all the geologic activity that has erased the record. For similar reasons, you can't do it on Venus or Mars. There is just no better library of information about the last 4.5 billion years of evolution in the Solar System than the Moon."

LEONARDO BODMER

KARINA
PEREZ MOLINA
Aerospace Industries Association

"We went to the Moon, looked back and saw the beautiful spaceship we all travel in—we truly saw Earth for the first time."

Apollo Astronauts, Then and Now

Between October 1968 and December 1972, NASA launched 11 crews as part of the Apollo flight test and lunar landing program, with astronauts Eugene Cernan, Jim Lovell, David Scott and John Young flying twice. Of the 29 astronauts who flew in the Apollo program, 15, including four of 12 moonwalkers, were still alive as the 50th anniversary of the first Moon landing approached. The youngest, Ken Mattingly, is 83. Here is a look at the Apollo flight crews.

NASA

Apollo 1 Crew

Astronauts **Virgil "Gus" Grissom** (left), **Edward White II** (center) and **Roger Chaffee**, who were to crew the first manned Apollo mission, were killed in a fire aboard their command module during a prelaunch test on Jan. 27, 1967. It took more than 18 months to implement safety upgrades including a new hatch design, removal of flammable materials and changing the all-oxygen environment to a mix of oxygen and nitrogen.

Digital Extra *See more about the Apollo astronauts:* **AviationWeek.com/ApolloAstros**

Buzz Aldrin

Colonel, U.S. Air Force, retired

Born: Jan. 20, 1930, in Montclair, New Jersey

Education: B.S. in mechanical engineering, U.S. Military Academy; Ph.D. in astronautics, Massachusetts Institute of Technology

Spaceflights: Pilot, Gemini 12; lunar module pilot, Apollo 11

Alan LaVerne Bean

Commander, U.S. Navy, retired

Born: March 15, 1932, in Wheeler, Texas

Died: May 26, 2018 at age 86, after the onset of sudden illness

Education: B.S. in aeronautical engineering, University of Texas

Spaceflights: Lunar module pilot, Apollo 12; commander, Skylab 3

Michael Collins

Major General, U.S. Air Force, retired

Born: Oct. 31, 1930, in Rome, Italy

Education: B.S. U.S. Military Academy; Harvard Business School Advanced Management Program

Spaceflights: Pilot, Gemini 10; command module pilot, Apollo 11

Charles Moss Duke, Jr.

Brigadier General, U.S. Air Force, retired

Born: Oct. 3, 1935, in Charlotte, North Carolina

Education: B.S. in naval sciences, U.S. Naval Academy; M.S. in aeronautics, Massachusetts Institute of Technology

Spaceflights: Lunar module pilot, Apollo 16

Donn F. Eisele

Colonel, U.S. Air Force, retired

Born: June 23, 1930, in Columbus, Ohio

Died: Dec. 2, 1987, at age 57, of a heart attack

Education: B.S. U.S. Naval Academy; M.S. in astronautics, Air Force Institute of Technology, Wright-Patterson AFB, Ohio

Spaceflights: Command module pilot, Apollo 7; first manned flight test of third-generation U.S. spacecraft

William Anders

Major General, U.S. Air Force Reserve, retired

Born: Oct. 17, 1933, in Hong Kong

Education: B.S., U.S. Naval Academy; M.S. in nuclear engineering, Air Force Institute of Technology at Wright-Patterson AFB, Ohio; Harvard Business School Advanced Management Program

Spaceflights: Lunar module pilot, Apollo 8

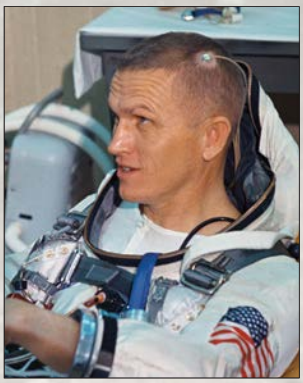
Neil A. Armstrong

Born: Aug. 5, 1930, in Wapakoneta, Ohio

Died: Aug. 25, 2012, at age 82, due to complications from blocked coronary arteries

Education: B.S. in aeronautical engineering, Purdue University; M.S. in aerospace engineering, University of Southern California

Spaceflights: Command pilot, Gemini 8; commander, Apollo 11



Frank Frederick Borman II

Colonel, U.S. Air Force, retired

Born: Aug. 14, 1928, in Gary, Indiana

Education: B.S., U.S. Military Academy; M.S. aeronautical engineering, California Institute of Technology; Harvard Business School Advanced Management Program

Spaceflights: Command pilot, Gemini 7; commander, Apollo 8

Eugene Andrew Cernan

Commander, U.S. Navy, retired

Born: March 14, 1934, in Chicago

Died: Jan. 16, 2017, in Houston at age 82, after ongoing health issues

Education: B.S. in electrical engineering, Purdue University; M.S. in aeronautical engineering, U.S. Naval Postgraduate School

Spaceflights: Pilot, Gemini 9; lunar module pilot, Apollo 10; commander, Apollo 17

Charles "Pete" Conrad, Jr.

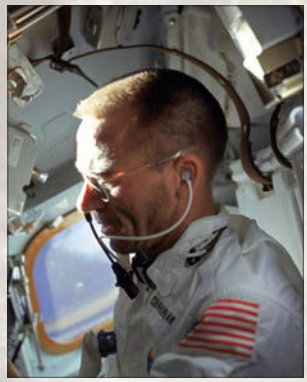
Commander, U.S Navy, retired

Born: June 2, 1930, in Philadelphia

Died: July 8, 1999, in Ojai, California, at age 69 from injuries sustained in a motorcycle accident

Education: B.S. in aeronautical engineering, Princeton University

Spaceflights: Pilot, Gemini 5; command pilot, Gemini 11; commander, Apollo 12; commander, Skylab 2



Walter Cunningham

Colonel, U.S. Marine Corps, retired

Born: March 16, 1932, in Creston, Iowa

Education: B.A. and M.A. in physics and completed work on doctorate in physics, all at the University of California at Los Angeles; Harvard Business School Advanced Management Program

Spaceflight: Pilot, Apollo 7

Ronald Ellwin Evans

Commander, U.S. Navy, retired

Born: Nov. 10, 1933, in St. Francis, Kansas

Died: April 6, 1990, in Scottsdale, Arizona, at age 56, of a heart attack

Education: B.S. in electrical engineering, University of Kansas; M.S. in aeronautical engineering, U.S. Naval Postgraduate School

Spaceflights: Command module pilot, Apollo 17

Richard Francis Gordon, Jr.

Captain, U.S. Navy, retired

Born: Oct. 5, 1929, in Seattle

Died: Nov. 6, 2017, in San Marcos, California, at age 88

Education: B.S. in chemistry, University of Washington

Spaceflights: Pilot, Gemini 11; command module pilot, Apollo 12

Fred Wallace Haise

Born: Nov. 14, 1933, in Biloxi, Mississippi

Education: A.A., Perkinston Junior College; B.S. in aeronautical engineering, University of Oklahoma; Harvard Business School Advanced Management Program

Spaceflights: Lunar module pilot, Apollo 13

James B. Irwin

Colonel, U.S. Air Force, retired

Born: March 17, 1930, in Pittsburgh, Pennsylvania

Died: Aug. 8, 1991, in Glenwood Springs, Colorado, at age 61, of a heart attack

Education: B.S. U.S. Naval Academy; M.S. in aeronautical engineering and instrumentation engineering, University of Michigan

Spaceflight: Lunar module pilot, Apollo 15

James A. McDivitt

General, U.S. Air Force, retired

Born: June 10, 1929, in Chicago

Education: Attended Jackson Junior College, Jackson, Michigan; B.S. in aeronautical engineering, University of Michigan

Spaceflights: Command pilot, Gemini 4; commander, Apollo 9

Edgar Dean Mitchell

Captain, U.S. Navy, retired

Born: Sept. 17, 1930, in Hereford, Texas

Died: Feb. 4, 2016, at age 85

Education: B.S. in industrial management, Carnegie Institute of Technology; B.S. in aeronautical engineering, U.S. Naval Post-graduate School; Ph.D. in aeronautics and astronautics, MIT

Spaceflights: Lunar module pilot, Apollo 14

Harrison Hagen "Jack" Schmitt

Born: July 3, 1935, in Santa Rita, New Mexico

Education: B.S. in science, California Institute of Technology; attended University of Oslo; Ph.D in geology, Harvard University

Spaceflights: Lunar module pilot, Apollo 17

Russell Louis "Rusty" Schweickart

Born: Oct. 25, 1935, in Neptune, New Jersey

Education: B.S. and M.S., Massachusetts Institute of Technology

Spaceflights: Lunar module pilot, Apollo 9

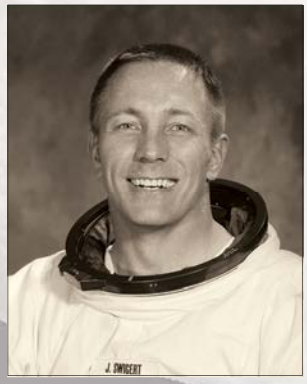
Thomas Patten Stafford

Brigadier General, U.S. Air Force, retired

Born: Sept. 17, 1930, in Weatherford, Oklahoma

Education: B.S., U.S. Naval Academy,

Spaceflights: Pilot, Gemini 6A; pilot, Gemini 9; commander, Apollo 10; commander, Apollo-Soyuz Test Project



John Leonard "Jack" Swigert, Jr.

Born: Aug. 30, 1931, in Denver

Died: Dec. 27, 1982, at age 51, of bone cancer

Education: B.S. in mechanical engineering, University of Colorado; M.S. in aerospace science, Rensselaer Polytechnic Institute; MBA, University of Hartford

Spaceflight: Command module pilot, Apollo 13

BACKGROUND IMAGE: NAS/JPL/USGS

JULY 2019

InsideMRO™

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MAINTENANCE CHECK

The Backstory

How many times have you heard that you need the right part at the right time in the right place? Getting that formula right is crucial to achieving on-time performance.

That philosophy is analogous to Embraer's approach to its new E-Jet E2 aircraft and the launch of its IKON big data platform, which are inextricably linked. It wanted to have "a mature airplane as of the first year of operation, with a 99.0% scheduled reliability," says Johann Bordais, president and CEO of Embraer Services & Support. Predictive maintenance was a key piece of this.

Here's the backstory.

In 2013, Embraer held workshops with its customers to collect feedback on the E2 concept. It identified about 200 connectivity and health-monitoring requirements. This led Embraer to conceive the E2 with the idea of enhanced connectivity from the beginning.

However, Bordais says their processes at the time lacked the needed agility, and "our bottleneck was data storage, data access and data analysis." While Embraer was doing some good predictive monitoring based on what it had at the time, in the case of the EMB145 it was extracting some information from Excel spreadsheets.

For the E2, Embraer knew it needed a big improvement in the process of storing data, analyzing it and making maintenance recommendations. This is where IKON comes in. IKON, based on the Amazon Web Services platform, is a cloud-based system that makes storing and analyzing data less expensive and faster because the data can be delivered decoded, based on established algorithms, so engineers and data-reliability specialists can assess performance more efficiently, says Bordais.

The importance of connectivity obviously influenced E2 supplier selection. In designing the aircraft, "critical components and systems with higher impact on airline operations were carefully studied prior to suppliers selection," with specific conditions contracted, says a company representative. "One of these agreements establishes, for instance, the conditions for removing parts that have not yet failed [and to have them] tested at suppliers' shops according to the results of IKON's preventive maintenance algorithms," says the representative.

"We needed the right tool, the right platform, to analyze all this data."

It also focused on certain parameters computed inside the controllers of aircraft systems that would be needed for post-flight analysis. For example, "while the aircraft's deacceleration parameters in the moment it touches the ground are important for having a smooth autopilot landing, it would typically not be required by any other system—and such information would be typically kept inside flight-control systems controllers," says the source.

The E-Jet E2 generates six times more directly accessible parameters than the E1 and 100 GB of data per aircraft per year, versus 5 MB for the E1.

While Embraer officially launched IKON at the recent Paris Air Show, it actually went live on April 24, 2018—the day of the first E2 revenue flight (by a Wideroe E190-E2), says Bordais. Since then, it has been using the system regularly to prove concepts.

"We needed the right tool, the right platform, to analyze all this data," says Bordais.

In the first year of the E2's operation, it achieved reliability of 98.94%, partly due to the IKON platform.

—Lee Ann Shay

Keep up with Shay at **MRO-Network.com** *and on Twitter* **@AvWeekLeeAnn**

Highlights

Hutchinson Launches Aftermarket Business

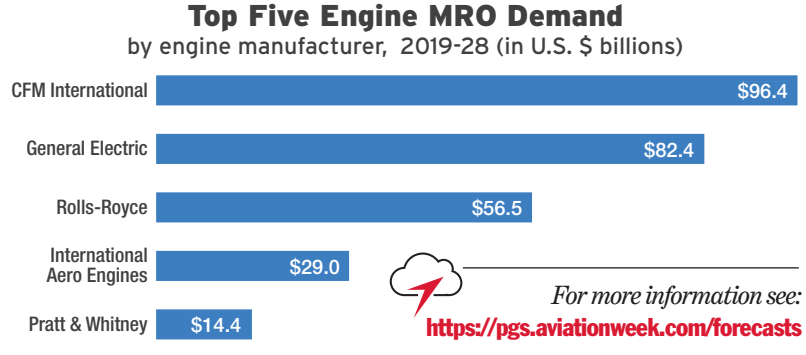
Hutchinson Aerospace & Industry is looking to enter the ever-growing aerospace aftermarket with the launch of its newest business unit, Hutchinson Aerospace Services. The company will target OEM and airline customers by providing a range of aftermarket services through Hutchinson Aerospace's existing global network of service centers, located in Europe, Asia and the U.S.

"The aerospace aftermarket is worth billions per year for the next 20 years. In 2028, there will be almost 40,000 aircraft flying, and they need maintenance. They need aftermarket services," explains Norbert Langlois, executive vice president of Hutchinson Aerospace Services. "We want to be part of this business, and the beauty of it is that the market is so big that if you do things with added value—if you bring something to the market—you'll get the business."

Langlois believes Hutchinson Aerospace Services will draw in customers through its existing technical expertise, backed by parent company Hutchinson's strength within industrial markets such as aerospace, automotive and defense. The new company plans to focus on three main segments: engines, airframes and cabins, all of which will benefit from existing Hutchinson Group expertise.

Top Five Engine MRO Demand by OEM, 2019-28

Over the next decade, Aviation Week's Commercial Fleet & MRO Forecast projects total 10-year engine MRO demand at $298.5 billion. CFM International is expected to hold 32% of the engine MRO demand share, followed by General Electric and Rolls-Royce, with 28% and 19%, respectively.



Source: Aviation Week 2019 Commercial Fleet & MRO Forecast.

Rolls-Royce Buys Siemens' Electric-Propulsion

Rolls-Royce's decision to acquire the electric aircraft-propulsion activities of Siemens, announced at the Paris Air Show, builds on several years of cooperation between the companies. The deal is expected to close by late this year.

In 2017, Airbus, Rolls-Royce and Siemens began collaborating to fly a hybrid-electric engine on a BAe 146 test aircraft in 2020.

Rolls-Royce was responsible for the turboshaft engine, two-megawatt generator and power electronics, while Siemens covered the two-megawatt electric motors and their power electronic control unit, as well as the inverter, DC/DC converter and power distribution system.

"We are at the dawn of the third era of aviation, which will bring a new class of quieter and cleaner air transport to the skies," said Rob Watson, director of Rolls-Royce Electrical, at the signing of the deal to bring those activities in-house.

Contracts

AFI KLM E&M won component support contracts from **Virgin Atlantic** for 12 Airbus A350-1000s and from **Air Senegal** for two A330neos.

Barfield was selected by **Arabcal** to provide repair/calibration services for ground-support test equipment in the Middle East.

Boeing signed an agreement with **ASL Aviation** to convert up to 20 737-800s to freighters and now has orders and commitments for 120. It operates conversion centers at Boeing Shanghai and Staeco and plans 17 conversions in 2019, vs. eight in 2018.

EFW signed a letter of intent from **BBAM** and an undisclosed airline to convert one Airbus A321-200 each to 14-pallet freighters for 2020.

Embraer was selected by **Helvetic Airways** of Switzerland to provide component support for four E190s leased from Nordic Aviation Capital; it also extended a deal with **Aurigny Air Services** for E195 parts maintenance. Both programs fall under its TechCare solution portfolio.

Epcor has contracted with **El Al** to maintain GTCP331-500 APUs for its six Boeing 777s using Prognos predictive maintenance software.

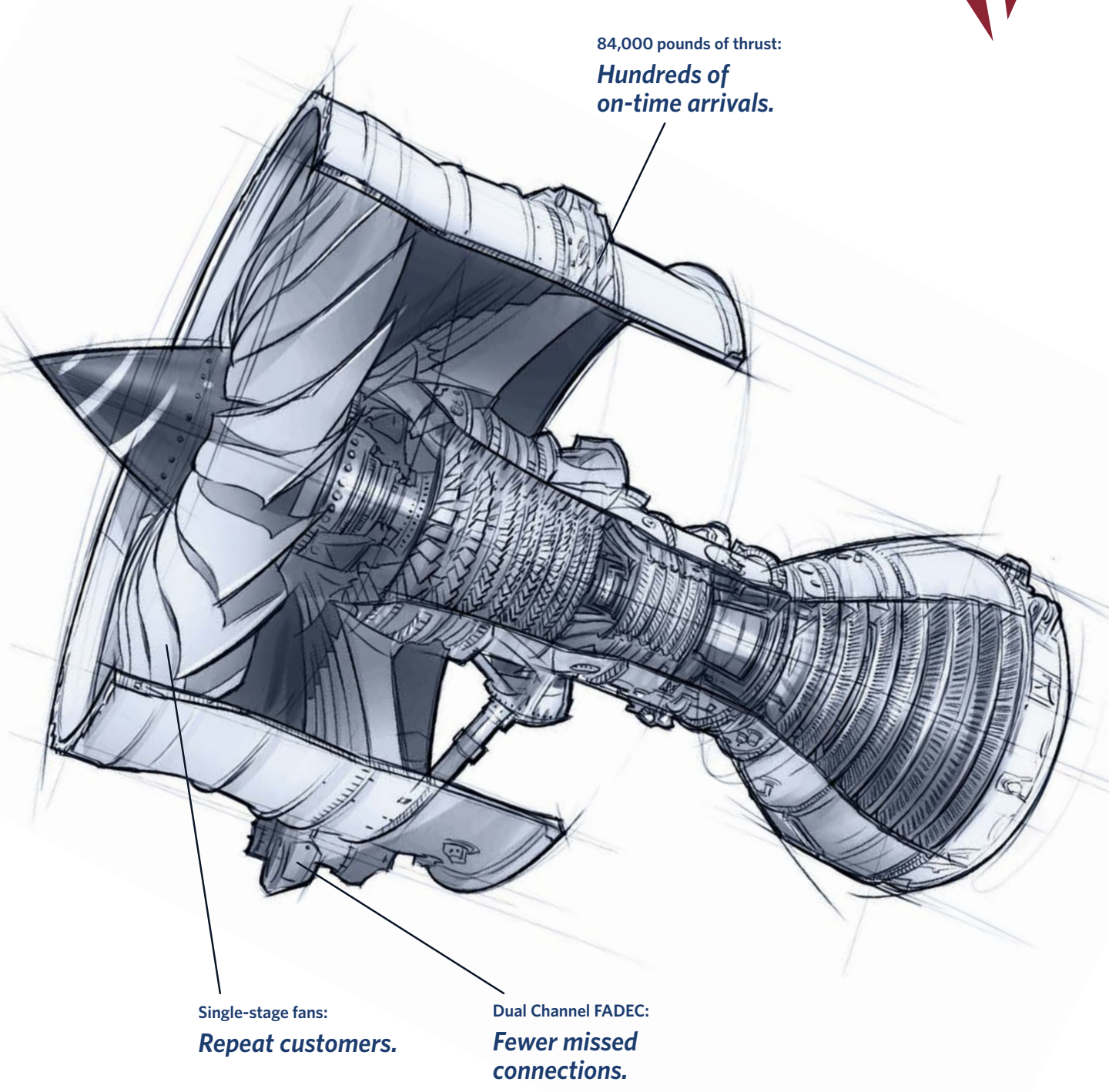
GE Aviation won a **Nordic Aviation Capital** contract to provide CF34-10E repair/overhaul to its lessees under the TrueChoice program.

KLM UK Engineering has won a **WestJet** contract to provide Boeing 737 line maintenance support at Glasgow.

Lufthansa Technik extended a deal with **Smartavia** (formerly Nordavia) to provide 737NG spare parts/CFM56 technical support.

Precision Aircraft Solutions was selected by **Jetran** to convert three ex-American Boeing 757-200s (24613/24614/25296) to freighters for lease to Swiftair. Flightstar Aircraft Services in Jacksonville, Florida, will perform the maintainence.

Contract Source: SpeedNews



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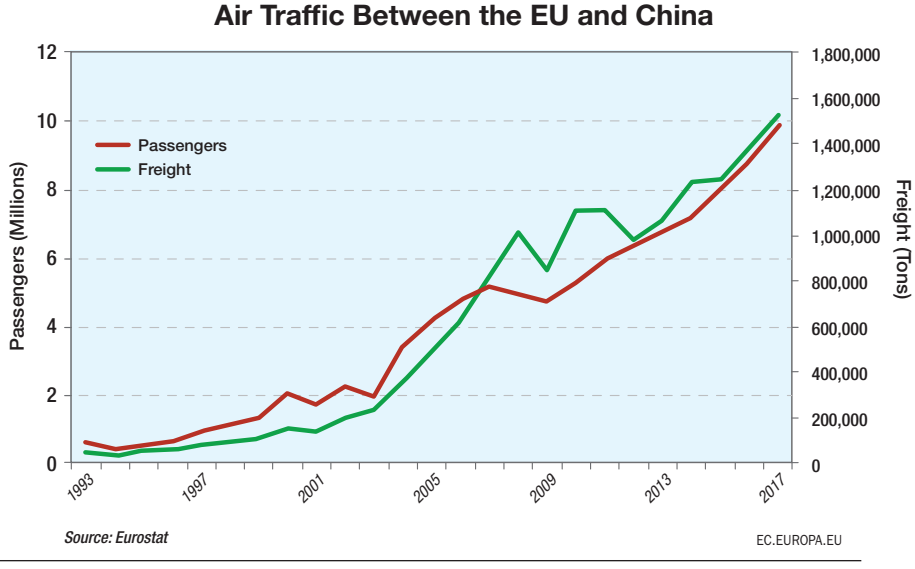
Aviation Cooperation

The Civil Aviation Administration of China (CAAC) and the European Union (EU) signed a bilateral civil aviation safety agreement in May, paving the way for cooperation in various arenas, including airworthiness.

The first of its kind between the two entities, the agreement will "remove the unnecessary duplication of evaluation and certification activities for aeronautical products by the civil aviation authorities, and therefore reduce costs for the aviation sector." It has been in the works since signature of a 2013 letter of intent and subsequent development of the EU-China Aviation Partnership Project, establishing road maps and assessments to validate future certification processes. Technical implementation procedures to facilitate acceptance of each other's airworthiness approvals are already in development.

The partnership—which will encompass operations, air traffic control, personnel licensing, personnel training and flight operations—is a key objective of the EU's aviation strategy.

Recognizing the anticipated shift of economic growth toward Asia, the plan specifically calls for ongoing negotiations with China and Japan.



Traffic between the EU and China has doubled in the last 10 years. With an annual growth rate of 6.7%, China is the 10th largest EU partner in terms of shared passengers.

The EU strategy is based on data identifying the Asia-Pacific region as the fastest-growing on Earth. According to Airbus' Global Market Forecast, it is expected to account for 40% of world air traffic by 2034.

As part of the deal, the nations also brokered a "horizontal aviation agreement" facilitating the single aviation market established in Europe. Under the system, any EU airline established in the territory of any EU member state may apply for available traffic rights.

Before the horizontal agreement was signed, only airlines owned and controlled by a given member state or its nationals could fly between that member state and China. The new agreement brings the EU-China arrangement in line with EU law.

The deal's proponents estimate that the accord will create €3.5 billion ($4 billion) in economic benefits and 11,000 jobs in its first eight years. It now goes to the European Commission and the Chinese transport administration for formal adoption.

—Crystal Maguire

Join the Club

An industry watchdog is expanding its reach in an effort to educate a broader audience on the restrictive OEM aftermarket. In response to a Federal Trade Commission (FTC) call for information on the availability of repair data, the Aeronautical Repair Station Association (ARSA) made the case for an intervention, arguing that widespread anticompetitive practices by design approval holders (DAH) negatively affect repair stations, their customers and the general public.

The FTC workshop, dubbed "Nixing the Fix: A Workshop on Repair Restrictions," examines repairability issues across all business sectors and the impact manufacturer-imposed limitations have on consumer protection under the Magnuson-Moss Warranty Act. The commission is seeking data to better understand problems that arise when a manufacturer restricts an independent repair shop's ability to make product repairs.

Comments submitted by representatives from various industries will resonate with MROs that have long sought relief from FAA mandates for inaccessible maintenance data. The Auto Care Association describes the reluctance of some manufacturers to provide requisite data despite "Right to Repair" mandates in the automobile industry. Other commenters voice parallel challenges affecting the repair of printing cartridges, iPhones and computers.

A dissenting opinion—submitted by Microsoft—contends that government should defer to the market on such matters. "If repairability is an important factor, there are devices in the market that are readily repairable, and consumers can use their purchasing power to select such devices," said the tech giant.

Not to be left out, ARSA provided a voice for independent MRO repair stations. In its submission, the association sets forth the long history of maintenance data restrictions, disjointed regulatory enforcement and disproportionate impact that the current framework has on small businesses.

"The FAA's strict enforcement of the requirement that repair stations obtain and maintain [repair data], while failing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to enforce [Title] 14 [Code of Federal Regulations] §21.50(b) and its predecessor requirements, traps businesses in a regulatory Catch-22 and has a number of negative and anticompetitive impacts." ARSA said in its comments. "By refusing to create and then limiting access to maintenance data, DAHs are able to maintain and enhance a government-induced monopoly."

According to an ARSA-conducted survey cited in its comments, the availability of maintenance data is perceived as one of the largest threats to MROs. The association set forth several examples to illustrate the prevalence of DAH repair restrictions, including one repair company that says repair-manual pricing "has risen from $5,000 to $51,000 in less than 10 years." Another respondent complains that manual pricing "increased by 38% [in] each of the last 2 years."

While the association says it does not have data to directly prove the negative impact the anticompetitive practices have on consumers, it argues that "because costs of doing business are passed along down the supply chain, it is possible that airline ticket prices have increased [due to] increased costs incurred by aviation maintenance providers . . . ." The association also cautions against limiting the term "consumer" only to members of the traveling public, pointing out that in some cases, aircraft owners encounter restrictions that keep them from maintaining their own engines.

Consumer advocates are examining ways that manufacturers restrict third-party repairs, and aviation maintainers are weighing in.

ARSA's efforts to make maintenance data available to aviation repair stations has spanned decades. A more recent campaign encouraged repair stations to petition the FAA for exemption from the §145.109(d) mandate that requires repair stations to maintain "current and accessible" data. Several members have answered the call—at least three petitions are awaiting the FAA's decision. ARSA says it will use the filings to make the broader public policy case to either "remov[e] the §145.109(d) repair data mandate, or to compel the agency to enforce the requirement that DAHs make the data reasonably available."

While most of its advocacy efforts have targeted the FAA or manufacturers, this is not the first time ARSA has submitted its grievance to another arm of the federal government. Last year, ARSA called on the Small Business Administration (SBA) National Ombudsman Office to look into inequalities imposed on small repair stations, arguing that the double standard unfairly targets the small businesses that make up the majority of the repair station community. And since the volume of comments the ombudsman receives on any given issue influences its decision to include the matter in its annual report to Congress, the association encouraged its members to do the same.

ARSA's intention is to keep the issue top of mind by whatever means necessary. "Despite decades of advocacy efforts, the FAA has not taken any discernible steps to resolve the issue," says Executive Vice President Christian Klein. "The trade association will continue to raise awareness of the issue, and FAA inaction, through every available channel."

The FTC is a bipartisan federal agency charged with protecting consumers and promoting competition. Its July 16 workshop is free and open to the public. A live webcast is available to those not able to attend in person.

The deadline to submit comment in advance of the workshop has passed; stakeholders can still provide feedback to the regulatory docket through Sept. 16.

—Crystal Maguire

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ARSA UPDATE

Make Every Day an Air Show

I COULDN'T BE PROUDER TO WORK in aviation. I don't fix, build or fly anything as part of my job, but as the spokesperson for the maintenance industry on Capitol Hill, I showcase all the ways aviation serves society and how repair stations fit into the bigger picture.

My goal is to help the industry soar by nudging the legislative process in the right direction. Sometimes that means helping good things happen (like new aviation workforce grant programs). Other times, it means preventing bad things from happening (like poorly thought-out congressional mandates).

Showcasing on a grand scale is something our industry does well. The Paris Air Show in June and EAA AirVenture in July feature what's hot and new in aviation technology as well as celebrate magnificent advancements in flight over the last century.

But we need to do more every day to showcase what we do, not just at a few big annual events attended largely by folks who've already been bitten by the aviation bug.

"Showcasing" is public relations and PR and is all about behavior; it's communicating with the goal of moving others to action. Think about everything we need people to do for our industry to be successful. We need to inspire the next generation of technicians, pilots, cabin crewmembers and engineers to join our industry. We need our current workforce to stay and grow. We need passengers to be and stay confident. We need government policymakers to provide the resources our industry needs to operate efficiently and only to impose new rules when it is absolutely necessary. The list of audiences and behaviors that affects our success goes on and on.

Every company and individual in aviation should be part of the industry's year-round showcasing effort. Host community open houses at your facilities. Invite elected officials to visit. Work with other companies in your area to coordinate air shows and other events. Speak at schools. Develop an aviation-centric activity for local scouting troops (boys and girls). Get creative!

Folks see aircraft fly overhead every day and have come to take flight for granted. Let's work together on the ground to remind them about all the ways aviation makes their lives better and showcase our amazing industry!

Work with ARSA—or any other aviation interest group representing you—to show off the value of your work. Contact the association (arsa.org/contact) to share great things you're already doing or to find ways to get started.

Together, we can make every day an air show.

ALASKA AIRLINES

Tom Rogers, an Alaska Airlines pilot, started an aviation day in Seattle that includes teaching kids about aircraft maintenance.

Christian A. Klein is the managing member of Obadal, Filler, MacLeod & Klein, overseeing the firm's policy advocacy practice. He represents trade associations as a registered federal lobbyist and provides strategic communications and legal services. He is executive vice president of the Aeronautical Repair Station Association.

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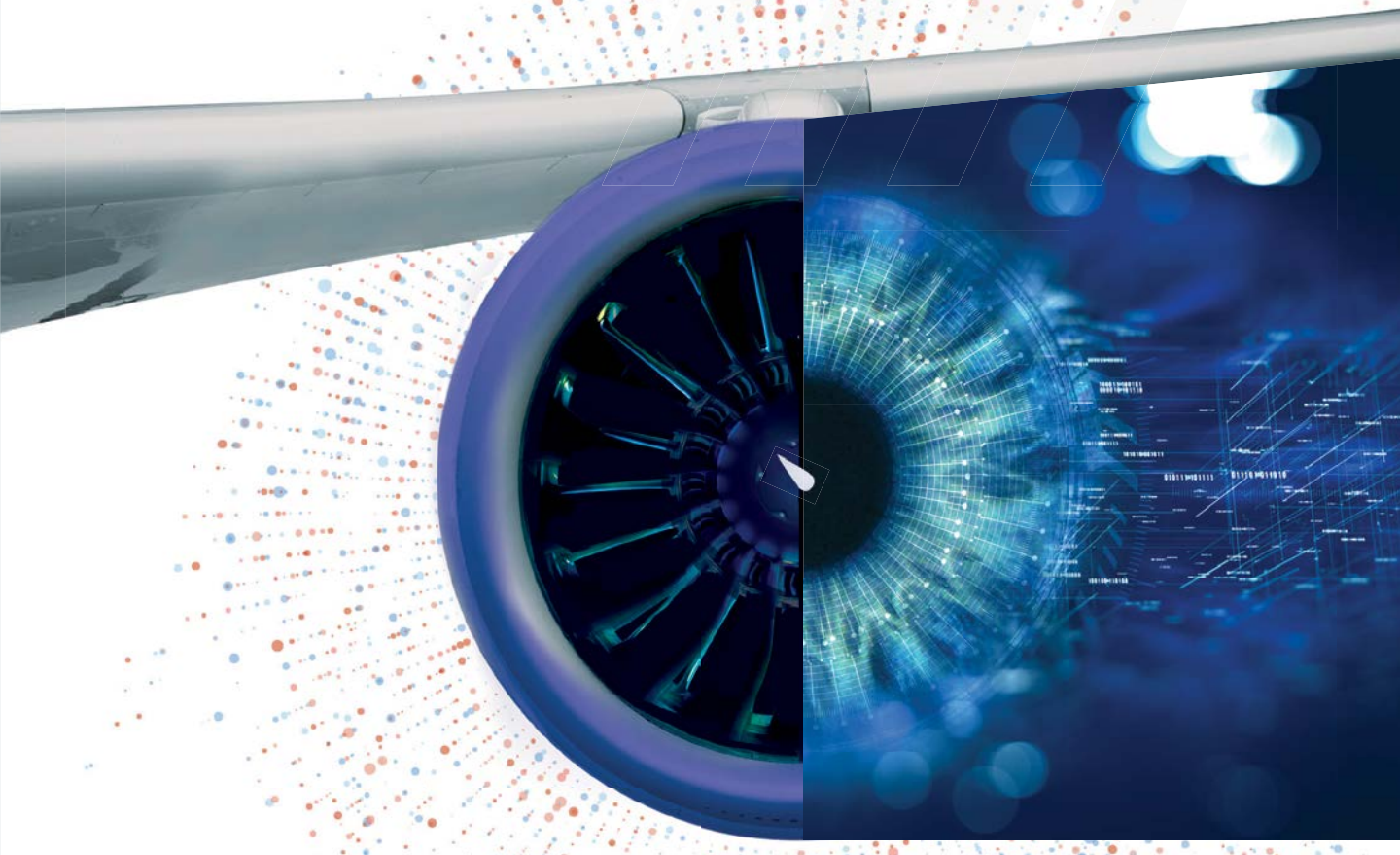

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Collaboration Dominates Paris MRO Dealings

Companies team up in search of expansion to meet customer demand

Sean Broderick and Lindsay Bjerregaard Le Bourget

AFI KLM E&M and Triumph Group announced a partnership at this year's Paris Air Show.

GIFAS

Aftermarket news never takes center stage at aerospace's annual premier exhibition, and this year's Paris Air Show was no exception. Even factoring in a relatively modest intake of 400 firm orders by air-transport manufacturers, the aftermarket space was quiet—at least in terms of headline-grabbing deals. What noise was made came largely via new service offerings and partnerships between providers seeking scale to meet demand.

"In our view, there was less focus on services, especially from both Airbus and Boeing," Canaccord Genuity analyst Ken Herbert writes in a post-show wrap-up. "However, that does not mask the view that activity levels in the commercial aftermarket remain very strong."

A budding partnership announced at the show between Air France Industries KLM Engineering & Maintenance (AFI KLM E&M) and the Triumph Group is one example of how providers are teaming up to create scale. The initial focus will be on servicing and supporting nacelles and aerostructures on newer-generation aircraft, including the Airbus A320neo and A350 and Boeing 737 MAX. The companies said in the joint announcement they envision a "wide-ranging scope," suggesting other components and services could be in play.

"Airlines are looking for integrators and integrated solutions that are both global and local," says Bill Kircher, Triumph executive vice president of product support. "This strategic partnership is all about the customer."

Among the deal's potential key benefits is leveraging complementary footprints to create a global network. Triumph has aerostructures repair capability in North America and Asia, thanks to its Arkansas and Chonburi, Thailand, facilities. AFI KLM has a similar presence both in Europe and the Middle East. "All of a sudden, our customers have a shop, no matter where they are flying," Kircher says.

Other deals saw existing vendor-customer relationships broaden. Ethiopian Airlines and Collins Aerospace are teaming to expand the airline's already sizable services business while helping the avionics supplier gain a foothold in a region primed for growth.

Also announced at the show, the agreement is written to support Ethiopian's establishment of repair capabilities on several Collins-supplied de Havilland Dash 8-400 components. The airline, which already provides Dash 8-400 airframe and propeller maintenance, plans to support its own fleet and offer services to other operators

of the former Bombardier turboprop. Collins will use the shop to support African customers as well.

"When you look at premier airlines in the world, many of them are saying, 'What do we want ourselves to look like in the future?'" Ajay Agrawal, president of Collins aftermarket services tells Aviation Week. "Many of them are looking for a strategic local capability."

Africa remains the smallest International Air Transport Association (IATA) market, but it is among the fastest-growing. The latest IATA outlook forecasts Africa's passenger growth at a 4.6% compound annual growth rate (CAGR) through 2037, trailing only the Asia-Pacific region.

The partnership is expected to ramp up quickly. Collins soon will provide Ethiopian with required technical data and tooling, clearing the way for work to begin this year.

Collins, looking to the future in another region, also unveiled a new "innovation hub" in Singapore intended to develop advanced MRO and additive manufacturing (AM) capabilities. The 15,000-ft.2 facility, set to open in early 2020, will be Collins' fourth AM lab and the first outside of the U.S. It also will be Collins' first AM facility with titanium capability, and it will feature prototyping, development, tooling and ultimately low-rate production of additive materials.

"We're experiencing tremendous growth and transformation in aerospace globally, and we are focused on innovation in order to remain at the forefront of advanced methods and materials for maintenance, repair and overhaul solutions," Agrawal says.

Meanwhile, long-time component and system supplier Hutchinson is eyeing the aftermarket as a growth opportunity through the launch of its Aerospace Services (HAS) business unit. The company plans to target OEM and airline customers by providing a wide range of aftermarket services through HAS' network of service centers, which are in Europe, Asia and the U.S.

"The aerospace aftermarket is worth billions per year for the next 20 years. In 2028, there will be almost 40,000 aircraft flying, and they [will] need maintenance. They [will] need aftermarket services," explains Norbert Langlois, HAS executive vice president. "We want to be part of this business, and the beauty of it is that the market is so big that if you do things with added value—if you bring something to the market—you'll get the business."

Langlois believes HAS will draw customers through its technical expertise backed by parent company Hutchinson's robustness within industrial markets such as aerospace, automotive and defense. The new company plans to focus on three main segments, all of which are expected to benefit from Hutchinson expertise in airframes, cabins and engines.

Within engines and airframes, Hutchinson has a large presence in composites through its subsidiary Composite Industrie, which the new aftermarket business plans to leverage for engine cold sections and airframe components. In addition to capabilities within engine buildup, thermal and acoustic management, fire testing and nondestructive testing, HAS is seeking Part 21J qualification to design and manufacture its own parts for airlines.

"This is our road map. Obviously, it's not going to happen overnight," says Langlois. The company hopes to have the business unit, including new facilities in Toulouse and Burbank, California, and a possible U.S. East Coast location, operating by late 2021.

While the order pace was slow across the board, Paris did see major MRO contracts. CFM tacked a long-term services agreement on the back of a massive order from India's IndiGo, covering 280 Airbus A320neos and A321neos. The airline was a Pratt & Whitney geared turbofan customer, so the move not only adds a huge customer for the GE-Safran joint venture, but it takes one away from its narrowbody-powerplant rival.

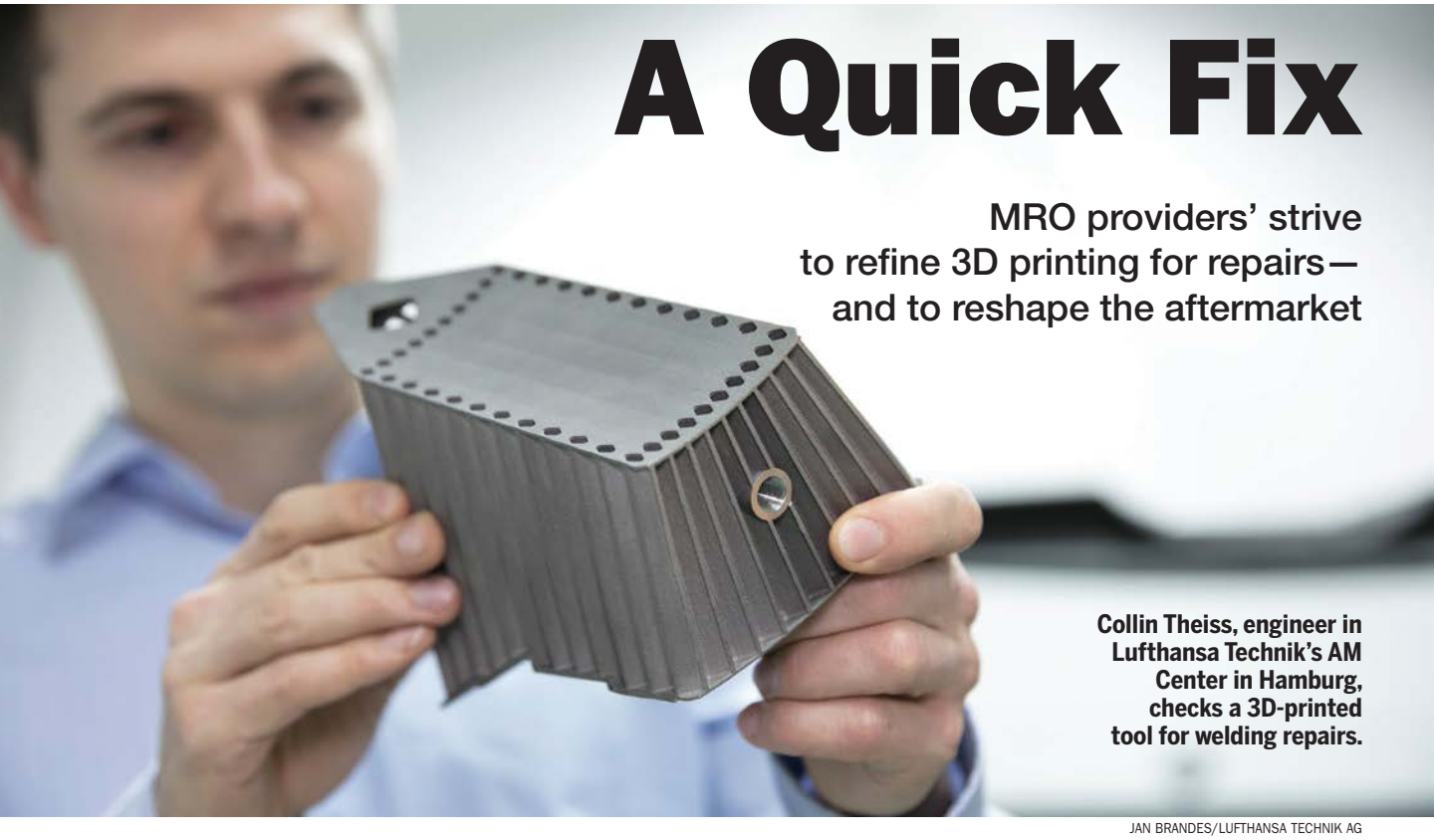
Boeing signed a notable deal with British Airways to provide component support for the UK flag carrier's A320 fleet. The first deal of its kind for Boeing will see it work with suppliers to own, manage and maintain a global exchange inventory of parts for the airline's A320s and A320neos.

British Airways parent International Airlines Group (IAG) also signed the biggest aircraft deal of the show—an intent to purchase for 200 737 MAXs.

The move from the nearly all-Airbus-narrowbody airline group caught many off guard, as the MAX remains grounded in the wake of two fatal accidents within five months while Boeing works to modify the aircraft's flight-control software. The A320 MRO deal—which was not announced as being linked to the MAX order—means Boeing will profit from IAG's narrowbody operations for years, even if the MAX order is not finalized.

A Quick Fix

MRO providers' strive to refine 3D printing for repairs—and to reshape the aftermarket



Collin Theiss, engineer in Lufthansa Technik's AM Center in Hamburg, checks a 3D-printed tool for welding repairs.

JAN BRANDES/LUFTHANSA TECHNIK AG

Alex Derber London

Amid all the excitement about the potential of additive manufacturing (AM) in the aftermarket, today's applications are often quite prosaic. Plastic air vents, window breather pipes and video-monitor shrouds are understandable starting points for MRO companies familiarizing themselves with the technology, but they are unlikely to persuade that 3D printing will transform the industry anytime soon.

Of course, much bigger developments are underway at aircraft and engine manufacturers, which are investing billions in AM and have already begun producing some metal components. Examples include fuel nozzles for the CFM Leap engine and a 1.5-m-wide (4.9-ft.) front-bearing housing for the Rolls-Royce Trent XWB engine.

In principle, the metal printing process is very similar to that used by MROs to produce plastic cabin parts, but metallic AM components can exhibit lower static and fatigue strengths than rolled billets of metal. Overcoming such challenges requires considerable investment and testing, which may keep the production of more advanced components outside the reach of airlines and MRO providers.

"The AM manufacturing methods, and to some degree the materials, lack the same degree of industry standardization that we now take for granted with metallic and composite laminated parts," notes Victor Ho, AAR vice president for engineering. "AAR has found part-to-part variability during structural tests of AM articles that were printed between similar machines."

Instead of complex structural and metal components, the MRO community is more likely to focus its AM efforts on parts and tooling that are simpler to prototype, produce and certify. The other avenue for them to explore is additive repairs.

Depending on how one defines AM repairs, the technique is either in its infancy in aerospace or is building on decades of prior experience. Certain types of welding are a form of additive manufacturing, although the techniques commonly associated with fabricating components—such as fusing or melting metal or plastic powders—are still under development in the repair context.

"Welding is one form—and there are many others—of AM that has been around for decades, and in many situations it is a great way to restore parent material that has been lost to corrosion or wear," says Travis Guenther, aerospace product engineer for Lucideon, an engineering and consultancy company for materials technologies.

Given that, he says, "AM is just as important to the repair of aircraft components as it is to rapid prototyping of mock parts or manufacturing fixtures for parts."

ADDED ADVANTAGES

Some industry experts think the first regulatory approval for a nonwelding-based AM repair could come this year, opening the door to a new way of thinking about component support.

"The sky is the limit for AM repair,"

says Ho. "Particularly for composite components, AAR foresees the use of imaging, CNC [computer numeric control] machining and AM technologies as a fully automated repair process."

Indeed, AM is set to be a crucial part of automated, end-to-end repair processes that encompass inspection, repair and testing, but the technology also has intrinsic advantages when it comes to repairing metals, composites and other plastics.

Combined with optical scanning technologies, AM allows for the repair of complex geometries, either to treat wear, restore design shape or both. Another advantage is that the amount of post-processing in powder-bed-based repairs is reduced when compared with many welding techniques, which require excess material to be machined off afterward. Repair of complex geometries is also served by the lower heat input of printed repairs, which avoids the thermal distortion that can occur with welding. The application of less material and less energy to the repair should also lower costs.

"Additive manufacturing offers the possibility to rebuild the worn material such that the repaired component is in a near net-shape condition," says Aenne Koester, head of Lufthansa Technik's additive manufacturing center in Hamburg.

In other cases, AM will allow repairs that, while already technically feasible, were economically unsound due to the cost of labor. "It will be a faster response as soon as the qualifications and precertifications have been done and validated," says Frederic Becel, additive manufacturing leader in the aircraft modification unit of Air France Industries KLM Engineering & Maintenance (AFI KLM E&M).

Ho agrees. "Performing repairs on highly contoured parts with large damage may be more economically and efficiently performed, where previously the parts had to be replaced," he says.

With more repairs on the table, MRO companies and airlines will become less subject to long lead times and price inflation for replacement parts. Long waits for replacement parts have bedeviled the engine overhaul sector recently, but this might ease as AM repairs are introduced, with turbine blade tips an early candidate for the technology. There is also a strong business case for airframe structures, particularly those that make extensive use of carbon fiber.

"As aircraft flight and fuel performance increase and external components take on more complex contours, the ability to repair and maintain previously repaired wind-swept surfaces within engineering tolerances will become more important to our customers to maintain fuel efficiency over the aircraft's life cycle," says Ho.

He says AAR aims to reverse-engineer complex contours by recreating external mold surfaces of large damaged areas where aerodynamic surface shape would normally be lost after re-

AAR

Traditional molds such as this 6-ft.-long 3D-printed production mold engineered by AAR for a supplier have lead times of 16 weeks. This can be printed in 20-30 hr.

pair. The company has a head start in this respect as a result of work with an OEM, which involved the fabrication of molds exceeding 60 in. in length for composite layup. "This developing knowledge base will lay the foundation for applying AM to the AAR's MRO operations in the future," says Ho.

TOOLING

Another application of AM, and one that is already in use, is to build and repair tooling. Until recently, Estonia-based Magnetic MRO had mostly used AM for prototyping, but it is now exploring whether it could speed up certain repair processes with custom tools. One example is a drilling jig for surfaces with complex curvatures.

AFI KLM E&M says it will need new software to add 3D-printing repair to its current manufacturing capabilities. Many of the machines used for 3D-printing production may not be suitable for repair jobs.

"Such a process would involve 3D-scanning the surface, building a necessary CAD file that would match the curvature of the scanned surface and then printing and preparing the final jig," says Partel-Peeter Kruuv, interior project manager for Magnetic MRO.

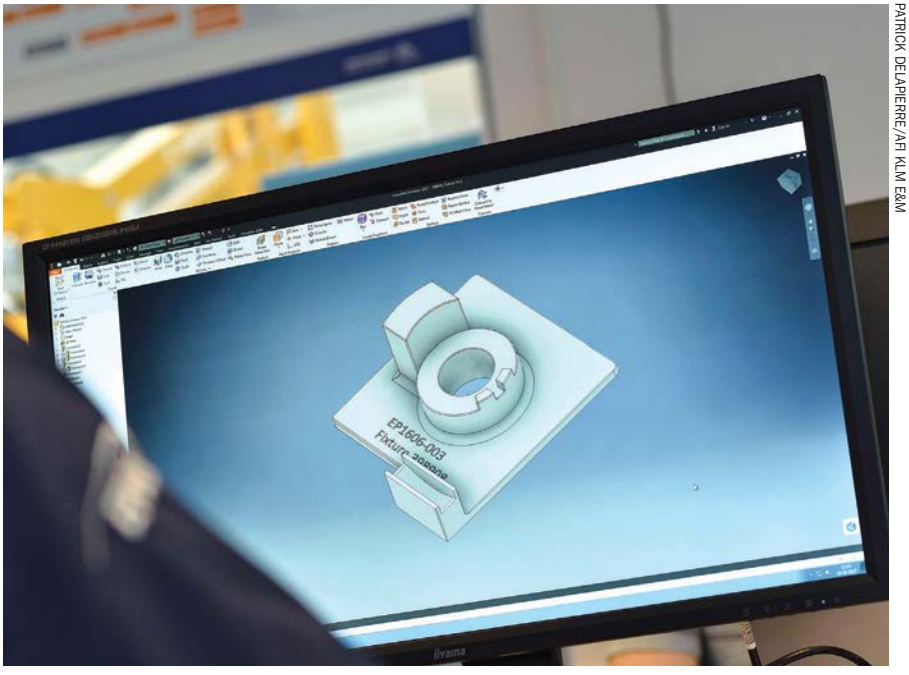
Both AFI KLM E&M and Lufthansa Technik also use AM for rapid tooling, with production time at the former estimated at roughly 1/10th of the time needed to have a new tool delivered.

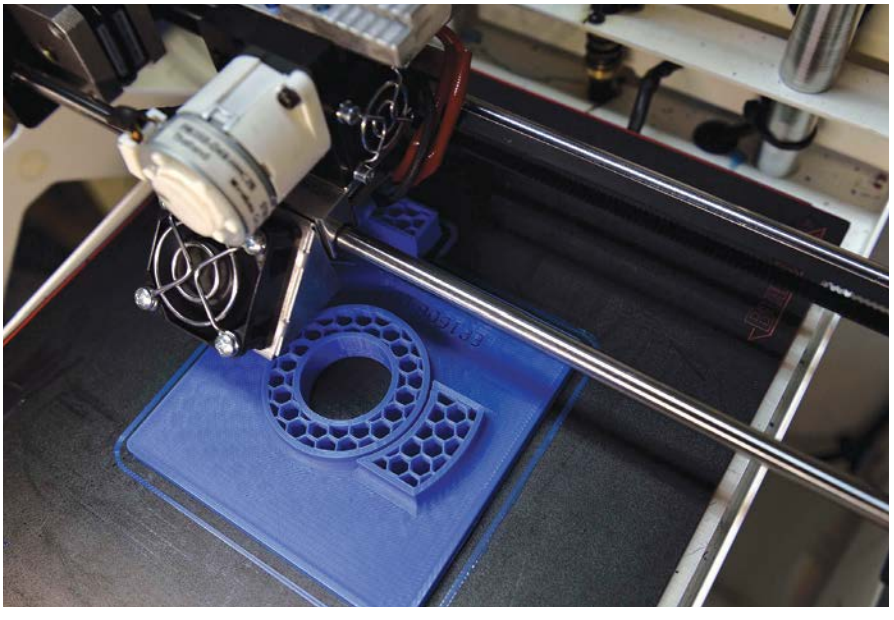
A separate issue regarding tooling is the extent to which MRO providers can use their existing AM machines—mostly used for fabricating parts—for repairs.

"It is quite likely that equipment used for AM of new components could be suitable for repairs, but it will depend on the technology used," says Guenther. "For example, powder-bed fusion [machines] may work for new-part manufacture but likely won't work well for repair."

There is also the question of how well software designed for 3D-printing fabrication works for repair functions.

AFI KLM E&M's Becel says the company's existing additive-layer manufacturing tooling is not well-suited for repairs. "The specifics of the repair need to be better managed by the software," he says, noting that simulation of the repair process and of the mechanical properties of a component post-repair are key challenges. "We are looking for equipment and software that will better allow us to do this kind of work," he adds.





PATRICK DELAPIERRE/AFI KLM E&M

CHOICE OF TECHNIQUES

There are numerous modes of 3D printing, each suited to certain jobs. Stereolithography (SLA) is often used for prototyping plastic parts and works using lasers or light to cure a liquid plastic resin to build a structure top-down, layer by layer. Selective laser sintering (SLS) works in a similar way, but instead of a liquid resin, powdered material is fused together with high-powered lasers. As a result, many different materials can be used, including metals, glass and ceramics.

Fused-deposition modeling (FDM), in contrast, builds from the ground up. A machine extrudes a plastic filament that is melted by the printing nozzle and then hardens after deposition.

Selective laser melting (SLM) fully melts the metal powder rather than just fusing it together, as occurs with SLS. This technology creates dense

components but is currently restricted to certain metals. Electron-beam melting (EBM) works in a similar way.

A form of additive manufacturing already used for engine repairs is laser metal deposition (LMD). Also known as laser cladding, this process uses a laser to generate a weld pool on the component surface. Material is then added to the melt pool as a powder or wire and the melted particles fuse and solidify while the nozzle is manipulated to add the desired structure to the component.

AFI KLM E&M and its subsidiary CRMA have performed laser-cladding repairs for many years and believe this provides a strong foundation for future repairs using AM. "At first, we will look to use new technologies on our existing

SONJA BRUGGEMANN/LUFTHANSA TECHNIK

Lufthansa Technik is pursuing powder-bed-based AM repairs that could open new possibilities for repairing engines.

use cases of surface reconstruction in order to see if we can improve results, costs and times of repair. Other cases can be for tooling, with which we can restore initial dimensions after several uses," says Becel.

Lufthansa Technik offers laser cladding as well but also is pursuing powder-bed-based AM repairs, an approach that "opens up completely new possibilities in the overhaul and repair of aircraft engines," says Koester.

Nonetheless, powder-bed repairs are difficult, mainly because powder must be applied to an existing component, rather than being fused or melted inside a standard AM manufacturing platform. As a result, specific fixtures must be developed for each component to be repaired. Even so, she is confident Lufthansa Technik will overcome such difficulties and plans to have its first powder-bed repair certified for 2020.

GAINING APPROVAL

"It is clear that there is strong interest in adding AM to the daily activities of MROs, but regulation in its current form is very unclear about printed parts or repairs," says Magnetic MRO's Kruuv.

Although certain directed-energy deposition processes such as laser cladding are already approved, as are the manufacture of certain components via powder-bed fusion, there is uncertainty about how quickly regulators will approve the latter form of AM for repairs.

"AAR expects some hurdles in showing certification compliance, especially in the areas where the repair requires equivalent strength to components previously manufactured using conventional manufacturing methods," says Ho.

AFI KLM E&M's Becel concurs: "Yes, it will be more difficult to gain approval due to the lack of general experience in our industry and the lack of feedback on this type of repair process," he says. "Those technologies have only an experience of a very few years, and it is difficult for an authority or a regulator to be very confident without sufficient experience."

That said, others point out that once-novel AM repairs such as LMD and electron-beam welding gained certification many years ago, so regulators can have reasonable confidence about applying their approval methodologies to new techniques.

"It won't be any more difficult to gain regulatory approval for AM repairs than any other new process that has been introduced to maintenance, repair and overhaul over the last 50-70 years," says Guenther, adding that electron-beam and laser welding "are very specialized AM processes that required significant testing to prove out, but it has been done."

GAINING TRACTION

Once new additive repairs are approved, the door opens to their incorporation into automated and semi-automated component overhaul processes. "Many of the technologies to do this currently exist, and it's just a matter of integrating software and systems," observes Ho.

Lufthansa Technik is developing an automated end-to-end process with its AutoInspect and AutoRepair robots, which are designed to inspect and repair cracks in certain combustor components, and this experience will prove useful if it seeks to integrate automated AM repairs.

"It won't be long before parts will be inspected by a machine, conditions identified and parts repaired through AM and subtractive manufacturing—all on one machine," says Guenther.

In time, AM repairs will extend to electronic and structural components, Becel believes, but as the technology matures it will bring new challenges. For example, today's certified and in-development AM repairs focus on conventionally manufactured parts but might not be suitable for 3D-printed parts, which have different internal structures.

Overall, AM is set to open new avenues for MRO providers to improve the speed, cost and scope of repairs. In the long term, Ho speculates that AM might even require "some alternative basis of certification or authority" if it leads to a surge in demand for quick-reaction MRO services such as AM-based just-in-time parts replacement and repair.

"We are at the ground level of application of AM technologies for manufacturing and repair and are excited for the future," he concludes.

TAP Air Portugal

Luis Pimentel de Oliveira, TAP Air Portugal's innovation specialist, talks with Lee Ann Shay about a European project he is working on to reduce airline delays due to maintenance, as well as other innovation projects that are applying new technologies to MRO. In Europe, 5.8% of all flights are delayed due to aircraft technical issues that subsequently delay other flights. Those disruptions cost about €2.8 billion ($3.14 billion) annually.

As an innovation specialist, what do you do?

I joined TAP as an engineer in the aircraft maintenance department. With another colleague, we were faced with the challenge of setting up a Europe-wide project to reduce maintenance-related delays. Our project ended up being a consortium of 12 partners, approved and funded by the European Commission. While working on this, we decided that the scope was too big to just do one project and then go back to our normal jobs. We realized innovation can be something much bigger inside a company. That's when we started to create the innovation department here at TAP.

The European project tackles disruptions caused by technical problems with aircraft in two ways: It either prevent faults from happening on the aircraft in the first place or streamlines maintenance processes. I was more responsible for the work processes for line maintenance issues.

My job for the last few years has been focused on this project, because we are not just working on it but also studying what types of opportunities we could exploit as part of the project's scope. For example, early this year we were able to fully test digitalized line maintenance processes at TAP. My task was not just to coordinate the project but to try to learn what we could do better at TAP to shift from paper-based processes to the next step: a digitalized airline.

Was your project part of the Clean Sky 2 aircraft maintenance research program?

Yes. Clean Sky 2, which is the biggest European aviation research program so far, is a partnership between 16 major players in the European aviation industry and the European Commission. As a whole, it has about €4 billion ($4.5 billion) for research. It addresses a multitude of issues, including next-generation engines and aircraft, and there is a work package for maintenance, named Advance, which is the umbrella for the Airmes project. [Airmes focuses on optimizing end-to-end maintenance activities within an operator's environment.]

In Europe, we have an advisory council for major research in aviation, ACARE (Advisory Council for Aeronautics Research in Europe), which provides broad guidelines for aviation research in Europe. In the Flightpath 2050 document, one of the objectives is to have no technically induced aircraft operational disruptions to European air traffic by 2050. This means we need to reduce technical disruptions. Airmes aims to achieve this in two ways. First, we have a work package for prognostics, which will reduce technically induced aircraft disruptions by preventing faults from happening. Second, we are streamlining the processes for line maintenance, which usually tackles most of the unscheduled maintenance events day-to-day. Within the project, we also explored some opportunities in data analytics and steps that can enhance the back office, such as maintenance planning optimization and configuration management.

What are the things that you think will have the most impact, and how will airlines apply them?

We have to take into account that this project tests several things and see if some of the concepts we are testing actually work. It's not something that, af-

TAP AIR PORTUGAL

Airmes Project at a Glance

The EC's Airmes project addresses the problem that 5.8% of all flights in Europe are delayed due to aircraft technical issues, which subsequently delay other flights. Those disruptions cost about €2.8 billion annually.

THREE PILLARS

- Prognostics, mobile tools.
- Collaborative environment IT platform.
- Shifting scheduled maintenance to condition-based maintenance.

12 PARTNERS

L Up, Mostert-Ploog & Partners, Onera, TU Delft, Meggitt, PTC, ISQ, Cranfield University, Tekever, Aerospace International Services, Atos, TAP Air Portugal

PROJECT DURATION

Dec. 1, 2015-Nov. 30, 2019

Airmes has received funding from the Clean Sky 2 Joint Undertaking under the European Union's Horizon 2020 research and innovation program.

Clean Sky 2

ter it ends in November, will allow us to deliver off-the-shelf processes that are ready to use. In this sense, we tested prognostics solutions with some of the partners. We had some good results but also have some issues that are normal in the exploratory stage. For the optimization of maintenance scheduling, we had very good results and saw improvements. In terms of digitalization of some maintenance processes, we learned a lot. For instance, we need an electronic logbook on the aircraft, which we are working on, and all the systems need to be very integrated, which is one of biggest challenges we found. Integration can be done, but it is very challenging—especially for legacy airlines like TAP.

Can you tell me more about the challenges? Are they more operationally oriented?

For the Airmes project, we did not integrate TAP's own operational systems, because that would not be feasible in the scope of the project. In terms of integration, the main challenges are about how data is produced and stored. We have to think about how people work because electronic work orders are the backbone of all maintenance processes. It's where we produce and store all of the information. After that, we have to manage systems that can read and follow up on the work orders. The challenge is rethinking how people work and how we can produce electronic work orders. This project is a proof of concept.

What was TAP's role? How did it come to be?

CleanSky issued a call, and we bid for it. TAP contacted a multitude of partners from our day-to-day life. Then we built a consortium and bid for the project. The project will end in November, and then we'll do several things: We'll see what other opportunities arise, and we will also consider partnerships we could build to exploit some of the solutions we developed in the scope of this project.

Beyond this European project, at the ap&m Expo in Frankfurt you said that TAP is looking into augmented reality?

TAP AIR PORTUGAL

We are testing a virtual reality concept, and we're also working with Honeywell on an augmented reality concept. We tested and learned that virtual reality can be very good for training and work preparation. It could be cost-effective if we have access to the 3D models, and this is a question that has to be explored very seriously with the OEMs. We think there is very good potential for augmented reality but there are still a lot of technical issues that need to be sorted out to make it practical. These usually involve the mismatch between the 3D models and the real world. I think working out these issues will be very hard in the short-to-medium term.

Are you looking at using drones for inspections or other applications?

We had a demonstration, but we're still not very focused on it.

Are there any other innovation projects?

TAP is very involved in the Single European Sky ATM research project. We have others too, but it's too early to discuss them.

You have some automotive experience. How has that crossed over to aviation?

Most of my work with automobiles was in safety research while I was getting my master's degree. The auto industry

TAP Air Portugal is testing an augmented reality prototype as part of a European project to reduce maintenance-related airline delays.

is not as constrained by regulations as the airline industry. In some ways, the automotive industry is moving ahead of aviation. The auto industry has always been focused on maintenance since its foundation. This mindset is just starting in aviation. In some cases, automotive set the pace, but now manufacturers are trying to make cars smarter with autonomous drive and adaptive cruise control. Aviation has had autopilot functionality for years, so perhaps the aviation industry can teach the auto industry to improve how drivers interact with the machine.

What's your favorite part of this job?

Interacting with key users for the tools we're trying to develop, for things we think will shift the way people work. Imagine if you can't have manuals on the aircraft: How do you want them to appear on an iPad? They have to stop and think how it could be—what is optimal? We then show them a prototype and keep iterating. The key to success of evolving a prototype is involving users from the early stages. Don't be too enthusiastic with flashy new things: First understand people's questions and then develop answers. Think of the smartphone: It's not flashy, but it has kept adding features that make people's lives easier, such as images.

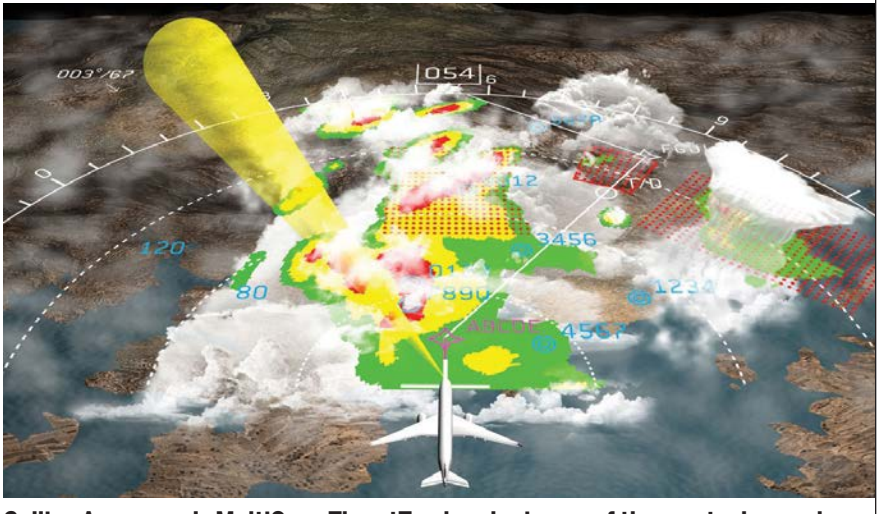
Radar Renaissance

OEMs are pursuing greater capabilities, more automation and longer life for radar technologies

Paul Seidenman and David J. Spanovich San Francisco

For onboard weather radar, there are changes in the air. Reacting to customer demands, the OEMs are pushing the technology to generate a wider range of data, greater durability and a more user-friendly experience for pilots of commercial airliner and business aircraft.

COLLINS AEROSPACE



Collins Aerospace's MultiScan ThreatTrack radar is one of the most advanced weather-detection systems available today. Collins Aerospace predicts that weather depiction will go beyond tactical information to provide more data for the entire flight, through the combined integration of radar weather depictions and uplinked meteorological data.

Newer radar systems have longer-range capability, are calibration-free and have a mean time between failure (MTBF) north of 30,000 hr., compared with legacy systems where MTBF was 7,000-15,000 hr., explains Paul Hart, chief technology officer at the Defense Solutions, Aerospace Electronics and Motion Control business unit of Curtiss-Wright Defense Solutions. This is the result of getting away from magnetron-based radar, which uses high voltages and cavity-tuning mechanisms to change frequency, which inherently reduces reliability.

Hart points out that the latest radar technology also incorporates gallium arsenide (GaS), the semiconductor doping compound used within the transistors that provides the amplification stages for transmission from the slotted grid antenna typical of weather radars. "At the moment, GaS is being superseded by gallium nitride (GaN) technology, which can operate at much higher junction temperatures. This increases amplifier efficiency to generate much higher radiated powers from the antenna," he says.

According to Vipul Gupta, senior product marketing director of radar and safety systems at Honeywell Aerospace, modern radar "identifies and differentiates critical weather conditions from normal precipitation," enabling pilots to avoid hazardous weather, including hail, lightning and wind shear. "At the same time, lower weight, smaller size and improved reliability are also in demand," he says. "We are also considering touch-screen interactivity for the radar and are working on touch-screen controllers."

Gupta notes that Honeywell's new radar system, the IntuVue RDR-4000, as well as its newest iteration—now in development—provide complete weather coverage from both a lateral and vertical perspective, with detection extending 320 nm ahead of the aircraft and from ground level to 60,000 ft. "Our newest IntuVue radar will bring predictive wind shear to the regional jet and business aviation market," he says. "We expect that radar will evolve from just being a weather sensor to being able to sense multiple items simultaneously. In the future, it will recommend options to the pilot for an optimized and comfortable journey to destination."

Michael McDowell, Collins Aerospace's commercial avionics product marketing manager for communication, navigation and surveillance, also predicts that weather depiction "will eventually go beyond tactical information," providing more data for the entire flight regime to enable the flight crew to make more efficient decisions pertaining to weather and routes. "This will happen through the integration of radar-detected weather depictions and uplinked weather data combined," he explains.

Given the fast pace of technology developments with avionics, McDowell was asked about the degree of scalability of new radar systems. The goal, he replies, is to "always have robust hardware" that will accommodate increased capabilities through software-only upgrades. "This allows avionics manufacturers to be more efficient and flexible with the introduction of new features," he says. "However, this is not always achievable, depending on the capability being introduced."

McDowell says Collins Aerospace's MultiScan ThreatTrack Weather Radar system provides a more complete view of weather and that it highlights inferred threats through "Core Threat Analysis" of each weather cell. The ability to infer lightning, for instance, has resulted in a 60% reduction in lightning strikes on aircraft that use Collins' MultiScan ThreatTrack products.

Other radar products McDowell cites include the RTA-4200 MultiScan for business aircraft and regional airliners, as well as the ISS-2100 Integrated Surveillance System. "The ISS-2100 includes the MultiScan weather radar, and is certified on the [Boeing] 787, with availability on the new 777X upon its entry into service," he points out.

But while these weather radar systems represent the state of the art in threat evaluation, with a 320-nm forward detection range, McDowell stress-

es that the avionics OEM continues to pursue product improvement.

"We are looking at high-altitude ice crystal detection, volcanic ash detection and the vertical profile of weather cells," he says. "We are also employing connected weather solutions, which provide the capability to download and upload weather data to provide a more complete weather depiction."

As for any plans to add touch-screen interaction with radar, McDowell notes that while Collins Aerospace has touch-screen capabilities in display systems for business and commercial aircraft, there is no touch-screen capability specifically related to weather radar. However, he stresses that as the aircraft OEMs continue to determine how best to use the touch-screen capability, this will likely be considered. "It is likely that touch-screen capability will begin to emerge as [automatic dependent surveillance-boradcast] 'In' applications are introduced with more crew interface requirements, such as cockpit display of traffic information (CDTI), assisted visual separation (CAVS) and flight deck interval management (FIM)."

For the retrofit market, Collins Aerospace holds supplemental type certificates (STC) for the MultiScan ThreatTrack on multiple platforms. Boeing and Airbus, McDowell reports, have service bulletins to upgrade to MultiScan ThreatTrack. "We see a growing market for retrofits to take advantage of the advanced features of MultiScan ThreatTrack. As more airlines get these [modern radar] capabilities on forward-fit aircraft, it is likely that they will want to upgrade their existing fleet to be consistent," says McDowell.

According to Joel Andrews, team leader of design engineering for Garmin in Olathe, Kansas, weather radar "has traditionally involved a high degree of pilot workload and considerable experience" to interpret the data displayed onscreen. He reports that Garmin is taking major steps to address this issue with its new GWX 80, which he calls the company's "major focus."

Currently, the GWX 80's primary market is business aircraft, with line fit on Cessna's new Citation Longitude jet. "But it is also available under a Garmin STC, for line fit on the King Air twin turboprop family," he notes, adding that a derivative for commercial airliner application is also under study.

"Automated weather-threat detection is behind a lot of the technology that Garmin has put into the GWX 80," Andrews says. With a conventional radar system, he explains, pilots need to use multiple tilt angles to determine what is being displayed as weather or ground clutter, then differentiate between the two.

"But with the GWX 80, there is less need for the pilot to interact with it to provide the correct tilt settings," he says. "In fact, the pilot can look at the screen quickly to get a better feel for the weather and the degree of threat the weather indicates."

GARMIN

Garmin's GWX 80 weather radar incorporates a high degree of automated weather-detection technology, minimizing the need for pilots to provide the correct tilt settings. Pilots can look at the screen and, at a glance, get a better feel for the weather and potential threats.

In addition to a simplified interface, says Andrews, customers also want the highest-quality information—on an as-requested basis.

"Basically, pilots want to do with radar what they are already doing with smartphones," he remarks. "They want a smart radar that will be totally automated, displaying what the weather will look like over the course of a flight plan—and they only want to be alerted if the weather predicts a threat."

Andrews describes the GWX 80 as a software-defined radar for control of the waveforms and tailoring of the signals to what the pilot is specifically trying to view. "It also provides improved resolution, which allows the pilot to see farther out, and is as flexible as possible," he explains. "The software itself has been designed to be upgradeable in the future."

In addition to the software, Andrews stresses that "a considerable amount of engineering" has been put into the GWX 80's hardware. "We have installed a larger, dual-core processor for expandability and to accommodate more memory," he says. "This allows for future growth for new, more powerful signaling display, as well as how that information can be generated and passed to the pilot."

In addition to weather threats, the GWX 80 has been designed to support predictive wind-shear standards as defined by the FAA, through the use of a 12 in. antenna, which Andrews says is the smallest antenna certified for wind-shear detection. "As we move into larger antennas, predictive wind-shear will get even better," he remarks.

While weather detection is the main focus of civil airborne radar, Andrews says there is a push for multimission radars normally associated with military aircraft.

"We are looking at being able to present some of this technology to commercial pilots as well," he reports. "Terrain avoidance is definitely a potential function, as well as noncooperative traffic such as balloons, drones or birds, for example. The software, in fact, has the flexibility to accommodate multimission tasks."

As for coming technology developments to watch, Andrews says that Garmin is improving internal monitoring and fault recording systems to provide better data analytics and enhanced capabilities to predict potential failure at specific points in the radar's service life. "The obvious advantage is that if you have a pretty good idea of when the system will fail, you can plan for it and not find yourself in a situation with unplanned down time."

Smart APU Maintenance

How predictive maintenance offerings from OEMs and MROs are evolving

Henry Canaday Washington

In which direction is maintenance that exploits big data and the Internet of Things headed? The ideal predictive or prescriptive maintenance program would turn every expensive unscheduled maintenance event into a scheduled event, with no false warnings and no premature removals of a costly piece of equipment. It would miss absolutely no problems—that is, it would have a zero false-negative rate. And it would generate no unnecessary fixes or even checks—a zero false-positive rate.

This kind of predictive accuracy is impossible in the real world. But it is a useful yardstick against which to measure the increasingly valuable predictive programs that major OEMs and MROs are offering based on connected assets and huge volumes of data. Another good place to look for progress is in auxiliary power units (APU), which are physically similar to the propulsion engines for which predictive techniques were first applied decades ago.

OEMs should be best at this game. They have the design data on which to base physical predictive models. They have test data to confirm and refine these design models. And assuming their equipment is widely installed, they should be able to gather operating and repair data from huge, multi-airline fleets to develop statistical routines to boost predictive power.

LUFTHANSA TECHNIK

Lufthansa Technik repairs various Pratt & Whitney Canada and Honeywell APUs, including the 131-9 pictured.

But there are advantages in having other suppliers of predictive services. First, of course, is competition. No customer wants to rely on a monopoly vendor, no matter how brilliant. With the evolution of predictive analytics still young and well short of perfection, there are virtues in having different teams trying different approaches.

Let's start with the 1,000-lb. gorilla of APUs, Honeywell, which equips two-thirds of mainline commercial aircraft. The company is the sole supplier of APUs on Boeing 737s and 777s, Airbus A330s and A350s, and it is one of two suppliers on the A320 family, notes Bob Buddecke, Honeywell's vice president and general manager for power systems.

As part of its new Forge nose-to-tail predictive maintenance service, Honeywell offers predictive maintenance on all these APUs, including Pratt & Whitney's on the A320 family. In total, the OEM provides predictive maintenance for APUs on almost all 7,000 aircraft under the Forge umbrella. This service is available for APUs on 737NGs and MAXs, but not on 737 Classics, simply because "we have not focused on them," Buddecke explains.

For APUs, the most important sensor data includes temperatures, pressures, start times and exhaust gas temperature margins. Non-APU data can also be important, including data from line-replaceable units upstream of APUs that affect them. Data on the operational environment, from the aircraft maintenance computer, quick- access recorder and flight data acquisition unit are helpful, too. It is by integrating all this APU and non-APU data that better predictions are made, Buddecke explains.

The value of APU predictive maintenance is avoiding cancellations, delays and disruptions by turning unscheduled maintenance into scheduled maintenance. Honeywell's predictive techniques have so far yielded a 35% reduction in APU-related cancellations, delays and disruptions by advising operators about 3-5 days ahead of possible events what the risk is and what should be done about it. All this has been achieved while reducing premature APU removals by 15% and holding the fault-found rates down to 2%.

This is far short of predictive perfection, but is nevertheless a big money-saver, conserving as much as $10,000-20,000 per aircraft, per year, Buddecke says.

Honeywell's predictive tools can work under a variety of business arrangements. In most cases, Honeywell is the MRO provider. "We alert them; they understand and follow up," Buddecke explains. If necessary, the APU comes off wing and is sent to Honeywell or one of its partners. Or the alert may just mean help with troubleshooting a problem on-wing or removing a simpler

part, like a surge valve or flow control. "We like the simplest possible actions," he says.

Honeywell first aims to keep APUs on wing and reduce troubleshooting time, then to do the simplest maintenance possible by removing an LRU, and only last removing the APU itself in an orderly, planned fashion.

Honeywell is further refining its APU predictive tools and expanding its coverage of other components under Forge's nose-to-tail predictive program. More sensors, more data and combinations of data, and more aircraft lie in the future.

But so do competitors.

AFI KLM E&M subsidiary EPCOR offers Prognos for APU predictive maintenance for all Honeywell and Pratt & Whitney APUs on Boeing 737NGs, 777s and 787s, as well as the Airbus A320 family, A330s and A340s and Embraer 170s and 190s—essentially all the APUs that EPCOR repairs.

All these APUs generate sufficient data for Prognos' predictions, according to EPCOR's APU Program Manager Niels van Hofwegen. Airlines must also have the right hardware and software to support data connections, connecting APUs to central computers and then moving sensor data to the ground. For a few aircraft, this is difficult. "But we can always find a way," van Hofwegen says. By the end of this summer, Prognos will be covering about 800 APUs.

In looking for the right sensor data, Prognos starts with possible APU failure modes and then searches for the combination of sensors that help predict them. Common are bearing failure and carbon-seal failure, but frequent modes can differ by both APU and by airline.

"Sensor data is basic, but in order to have absolute control you need enriched-context data," van Hofwegen says. For example, important contextual data could include sandy environments. The methods Prognos uses to collect this environmental data are part of the MRO's confidential intellectual property.

EPCOR's APU engineers use Prognos to predict failures and communicate these warnings to the airline's powerplant engineers for action. "A prediction is always confirmed by physical evidence of wear and tear before the APU is removed," van Hofwegen says. This confirming evidence can include excess wear, scratches or evidence such as contamination in oil filters. If no evidence is found, the warning is false, and the APU or part is not removed. But van Hofwegen says that with the necessary confirmation process before removal, no false removals occur.

Honeywell's predictive maintenance has yielded a 35% reduction in APU-related cancellations, delays and disruptions.

The other kind of error—failure to predict a failure—can occur at several points, with Prognos or EPCOR's engineers or a failure to take action by the airline. The MRO will not publish this failure rate for strategic reasons.

Typical actions based on Prognos warnings are inspections or removals of either APUs or their components.

The benefits of the program are what van Hofwegen calls "operational excellence," the replacement of APU failures with scheduled maintenance. Unanticipated failures reduce aircraft availability and may require last-minute leases of APUs, the most expensive kind of acquisition.

EPCOR also wants to reduce costs in both scheduled and unscheduled maintenance by avoiding "consequential damage," the damage that occurs during the last minutes of a catastrophic APU failure. "That is huge," van Hofwegen stresses.

EPCOR, which works closely with both Honeywell and Pratt & Whitney, is certified as a licensed warranty repair station by both OEMs. The MRO has access to certain OEM data, but not all. In any case, EPCOR developed the Prognos predictive algorithms for APUs on its own.

But van Hofwegen emphasizes that smart predictions are "not about algorithms but about processes, having the right information and the right people." His main focus is getting the right raw data and the right calculated data for Prognos.

He will not specify savings but says Prognos can now significantly improve operational reliability and reduce APU maintenance costs.

Others are also working on the challenge. Lufthansa Technik's Aviatar offers predictive maintenance on Airbus A320 APUs, but the MRO is increasing its support of other aircraft types. Aviatar's sales director, Frank Martin, says newer aircraft types generate more data and thus better predictions, but all APUs generate data Aviatar can use.

Aviatar can prevent APU shutdowns and improve performance. For example, data on oil temperature helps trigger maintenance to prevent shutdowns. All shutdown data is analyzed to pinpoint causes and improve troubleshooting.

To predict degradation of APU performance, Aviatar focuses on exhaust gas temperature, bleed pressure, inlet-guide vane angle and start-time data. "Analyzing those parameters in relation to others helps with finding error causes," Martin says. Other useful inputs can include non-APU data, such as on flight schedules, airline networks and status of components related to APUs.

He acknowledges that no predictive tool foresees every APU failure. But Aviatar is adjusting its APU predictions with every operator that joins, so predictions are constantly improving. Even now, users are reporting significant improvements in APU availability and reduced times to troubleshoot and fix problems.

Aviatar algorithms combine with OEM technical documents and Lufthansa Technik engineers to provide the warnings. The process can be customized for each new airline. Martin believes that automated troubleshooting at airlines will fit well with Aviatar tools, further reducing troubleshooting costs.

Digital Drive

Rolls-Royce reaffirms digital focus and is optimistic on Trent 1000 fixes

James Pozzi Derby, England

As a company driven by technology, Rolls-Royce continuously looks to new innovations to drive positive change. In recent years, these have ranged from exploring the potential of engine health monitoring to using tools such as virtual reality for training and robotics for engine inspection.

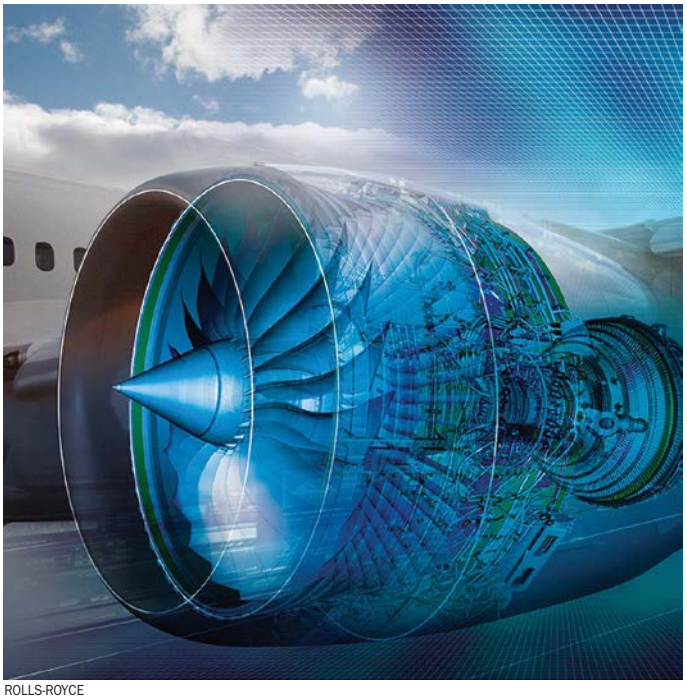
The company also is looking to accelerate its aircraft electrification strategy, as demonstrated by its recent agreement to acquire the electric and hybrid-electric aerospace propulsion activities of Siemens.

While focusing on new ways to both manufacture engines and service them, Rolls is combining these innovations with a commitment to advance existing digital capabilities to better handle data generated from powerplants.

Much of this is centered on using data and digital technologies, which Rolls is developing through its R2 Data Labs division, established in late 2017 as an acceleration hub for data innovation.

"Our industry is being reinvented and will change and deliver new capabilities and new levels of efficiency and performance because of digital technology," Dominic Horwood, Rolls' chief customer officer for civil aerospace, told the media at its headquarters here in late May. "We want to drive forward our culture and improve the capabilities of our people. As we think about investing in digital and electrification and broadening out from the gas-turbine investment, the people and skills that we need are going to change."

Some of these digitally driven innovations are expected to become more prevalent in an aftermarket where the engine-maker holds an estimated 31% share of the global widebody fleet. As Rolls has been growing its maintenance and spare-parts programs, its services revenue also has become a more valuable contributor to its bottom line, increasing 15% year-over-year to £4.2 billion ($5.3 billion) in 2018.



ROLLS-ROYCE

Rolls-Royce has developed digitally focused concepts such as the IntelligentEngine program.

Further growth is expected across its service network, with Horwood stating that Rolls is aiming to lead the expansion of aftermarket services. "Our MRO network has evolved significantly over the past few years," he notes, alluding to additions of authorized service centers (ASC) in which Rolls holds no equity taking places in its network alongside joint-venture businesses and customer-service centers. "Companies like Delta TechOps will be taking an increasingly significant role in our network as authorized service centers," Horwood says, following Delta's induction of the first Rolls engine into its Atlanta shop last October. "Others such as AFI KLM E&M and StandardAero are also coming into our business. Through the growth of our ASCs, we are changing the footprint of our MRO."

Another key part of Rolls' commercial engine future is its Trent 1000 program. The Boeing 787 powerplant option entered service in 2011 as a rival to GE Aviation's GEnx. However, since early 2016, several technical issues related to the engine's Package B model followed by the Package C variant have caused disruptions.

Rolls is working to resolve the issues, with the company reporting earlier this year that it aims to reduce the number of grounded 787s with Trent 1000 engines to fewer than 10 by the end of 2019. There were 31 in March. "We are working intensely with our customers every day to support the recovery of their fleets," Horwood says of the "unacceptable" level of disruption.

He says good progress is being made regarding technical fixes to the engines, centered on improvements to the intermediate-pressure (IP) compressor on the Package C version along with modifications to the IP turbine and fan seal. Horwood says the company is also confident that issues related to blade deterioration are unique to the Trent 1000 and will not occur in other engine types.

The engine manufacturer is looking to learn from these issues and feed lessons into future designs, too. "The lessons from an engineering [standpoint] are very much in the detailed design of the components and in a greater understanding of potential mechanisms that can cause deterioration of those components that we now see in service," Horwood explains. "It is not about mistakes or things people got wrong, it is about getting a detailed understanding of what caused the behavior."

Aviation's Middle Age

Midlife aircraft and engines are still popular with airlines and investors. But can that demand last?

Alex Derber London

Jet fuel prices have trended upward since early 2016, although they are still about 40% lower than during the early part of this decade. However, few within the industry would be surprised by further increases, which raises questions about whether growth in the midlife aircraft and engine market can be sustained.

Despite the introduction of new-technology widebodies and narrowbodies, midlife aircraft have seen a surge in demand in recent years due to relatively low fuel prices, teething problems with new equipment and the much better reliability associated with several mature platforms. The grounding of the Boeing 737 MAX in early 2019 provided another boost as airlines sought replacement capacity, although the premium several operators are paying in rent to cover the shortfall is likely to be short-lived.

Even so, values and lease rates of global workhorses such as the Airbus A320 and 737-800 are strong, report lessors and appraisers, though some softness is reported for the smaller A319 and 737-700.

"We continue to see strong demand for midlife A320- and Boeing 737NG-family aircraft," says a statement from lessor GECAS. "Although new technology is in the market, lower fuel costs and mature reliability mean that these remain attractive assets."

The definition of "midlife" varies by organization, but a practical guideline is the age at which an aircraft would complete an initial lease, normally 8-12 years. GECAS says that about 60% of its portfolio have had their leases renewed with existing customers, while the rest are transitioning to new operators. It is in that remaining 40% where opportunities lie for MRO providers, as they can provide the reconfiguration, modification and painting that new users require.

"Other technical challenges arise when transitioning the aircraft from one regulatory jurisdiction to another, [as] compliance in one jurisdiction rarely means compliance in another without making the necessary changes," says John Leech, senior vice president of midlife aircraft leasing for Aircraft Recycling International, which is part of Hong Kong-based China Aircraft Leasing (CALC).

Leech adds that nonregulatory configuration demands can be significant. For example, Chinese airlines tend to prefer

The average age of the Boeing 777-200 fleet is about 17 years, and values are declining.

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two-class narrowbodies, whereas U.S. and European operators are increasingly opting for single-class layouts. However, within the CALC portfolio Leech observes more customers renewing initial aircraft leases, he says, due to "familiarity with the specific aircraft, quantifiable fleet planning [and] relative ease for operations and the redeployment of technical staff within these airlines."

WIDEBODIES

The widebody market has seen considerable upheaval over the past decade, with new models such as the Boeing 787, Airbus A350 and A330neo entering service. At the same time, the appeal of four-engine aircraft has plummeted: The former long-haul workhorse 747-400 is being rapidly phased out of

Demand for smaller midlife narrowbodies like the Airbus A319 is softening, although demand for larger models is still robust.

passenger service; production of the A380 is to stop, and initial leases are not being renewed; and the popularity of the A340 continues its long slide.

"Today, the Airbus A340-200 is all but finished as a passenger aircraft, while the active Airbus A340-300 fleet is in decline," says Mike Yeomans, head of valuations for aviation consultancy IBA. The malaise has spread to larger models such as the A340-600, he adds, with Virgin Atlantic and Qatar Airways operating their last services this year, and Lufthansa transitioning slowly away from the type. For MRO providers that service the type, opportunities for reconfiguration work appear slim, as Yeomans reports little ongoing interest in the A340 platform. That said, the -200/-300 models have teardown appeal since their CFM56-5C engines share some commonality with the in-demand -5B engine that powers Airbus narrowbodies.

Another widebody suffering in its middle-to-later years is the Boeing 777-200ER, which has an average age of 17 years across the global fleet. Much more popular than the A340, its situation is not as grave as the Airbus model, but Yeomans reports that "storage and availability levels have crept up" and that "IBA has seen some quite soft pricing and lease rates on Boeing 777-200ER aircraft."

ENGINES

Unsurprisingly, the most popular midlife engines are those that power the most in-demand narrowbodies, the CFM56-5B/7B and the IAE V2500. "In the narrowbody market the -5B, -7B and V2500-A5 markets have seen unprecedented value performance despite the [CFM] Leap and [Pratt & Whitney geared turbofan] engines rolling out," confirms David Archer, senior analyst at IBA.

In contrast, Archer reports a "limited aftermarket" for older 777 engines such as the Rolls-Royce Trent 800, PW4000-112 and GE90-7/-8-/9. However, there has been a recent uptick in demand for A330 powerplants—the Trent 700, CF6-80E and PW4000-100—due to engine issues on newer widebody platforms, notably the Trent 1000-powered 787.

"For midlife widebody aircraft, the CFM56-5C and Trent 900 have both suffered heavily from the A340 market downturn over the last decade, [although] -5C engines can reach a relative premium for teardown due to material commonality with the -5B program," Archer adds.

Another potential source of demand for midlife engines is as a life-extension option on older aircraft platforms. Years of low fuel prices have pushed several operators to keep aircraft in service longer, but a more recent rise in prices might cause some to reassess that strategy. Fitting newer engines might be a compromise position, although GECAS' Campbell says, "There isn't much evidence of this at present, although from time to time it happens."

What has been the case, however, is engines staying in service longer, which has increased the maintenance burden with repairs being made on engines that might once have been torn down. Fewer teardowns also mean tighter stocks of materials. Combined with new-parts shortages from OEMs busy with issues affecting their latest products, this situation has contributed to severe engine-overhaul bottlenecks.

One solution to avoid the time and expense of an overhaul is to rent short-term capacity. "There is some evidence of engines being swapped onto older airframes, though this is primarily driven by the economic principle of avoiding the expense of engine shop visits during the course of the lease," says Leech.

Archer confirms this, saying that some 737 Classic operators have bought CFM56-3C1 engines with attractive remaining green time (the engine cycles left to be burned before teardown) rather than pay for overhaul of their existing engines.

"A similar example would be the Pratt & Whitney PW4168A engine, the least popular powerplant for the A330 family," he says. "We have seen a healthy leasing market develop for this engine as owners have sought to avoid expensive shop visits."

However, much of this replacement activity is in the mature rather than midlife segment of the market. In the latter, en-

gine availability is generally too tight to permit opportunistic engine-swapping.

TECHNICAL CHALLENGES

Trading any aircraft equipment requires good technical knowledge, and that need only increases as aircraft age. In middle age, aircraft and engines have already undergone heavy checks and had expensive life-limited parts replaced, so knowledge about the current condition of the aircraft—especially the engines, which represent the major part of an aircraft's value as it ages—is essential.

"When leasing midlife aircraft, it is crucial to have the exact technical status of the engines and airframe to be able to predict and plan for future maintenance events during the term of the lease," says Leech.

Accurate and up-to-date records are essential to satisfy potential buyers and lessees of midlife aircraft, because values can plummet without the right documentation. "We find that the parties in this space are very savvy around value so it's important to have up-to-date records and status of the aircraft," Campbell notes.

The move to electronic record-keeping should also help in this respect. GECAS has scanned all of its paper documents into a digital archive. Developed by GE Aviation Digital Solutions, the AirVault Asset Transfer System is a continually updated digital records archive that gives GECAS staff instant access to technical information. As well as guarding against the loss of paper records, AirVault helps GECAS and airlines lower transition costs by eliminating the need to thumb through thick binders of documentation.

PAST THE PEAK?

Assessing whether the popularity of midlife aircraft has peaked is difficult. Numerous investors have entered the trading space in recent years, as midlife aircraft tend to offer better yields than aircraft ordered new or bought via sale and leaseback. As a result of more new money chasing older aircraft, Leech says that it is "a seller's market, and therefore the value to the potential purchaser has decreased, with returns diminishing."

Nonetheless, Campbell says that GECAS still expects to see "decent demand" for midlife aircraft for the next few years at least. "Also, with the OEMs sold out on new-technology models through 2024, midlife aircraft should still have a role to play for several years to come."

On the engine front, Archer points out that any downturn in the aircraft market tends to have a delay before it hits engines. "Investment in engine assets is invariably tied to the performance of the asset in the market. If investing in costly maintenance will not see a return, then workscopes will inevitably be reduced."

He concludes: "As for now, aircraft are continuing to fly, shop visit demand remains high, and investor appetite remains strong."

MRO on the Go

Will operators opt for customized MRO services delivered to their doorstep?

Lindsay Bjerregaard Chicago

The evolution of business models including Amazon Prime, Uber and Postmates has led to the average smartphone user having quick, easy access to products and services delivered to their doorstep on demand. The convenience factor of this business model is undeniable for consumers, but is it something that could be leveraged in the MRO space?

Engine repair and overhaul provider Dallas Airmotive thinks it can. The company says its F1rst Support field services model is targeted at providing the same type of instant satisfaction for customers needing help with aircraft-on-ground (AOG) events, unscheduled repairs and scheduled maintenance.

"If your aircraft is down in the middle of a desert or has to make an emergency landing in an unplanned destination due to an engine emergency, the operator only has to make a call or submit an online form to our website to get assistance, and our field service dispatchers will send a technician on-site as soon as possible," says a representative for Dallas Airmotive.

The company says its field service technicians can be dispatched to an aircraft operator's site within hours to provide engine repair, maintenance and troubleshooting support for business, general and military aviation as well as helicopter operators. The field service team is made up of more than 50 technicians who handle more than 5,000 field service events per year.

New Hampshire-based Pro Star Aviation provides a similar service called On-The-Fly Maintenance, which has seen the most success for AOG situations or avionics installations. Jeff Shaw, the company's business development director, says many of Pro Star Aviation's customers handle most maintenance in-house, but they do not have the ability to perform avionics installations. For these scenarios, On-The-Fly installations enable operators to combine scheduled maintenance downtime with avionics work such as automatic dependent surveillance-broadcast or connectivity installations.

Shaw says On-The-Fly maintenance is much more sporadic, whereas On-The-Fly installations are very popular. The service is particularly appealing for larger aircraft less able to tolerate downtime, he adds, since multiple maintenance items can be completed at the same time without needing to reposition the aircraft and maintenance crew.

"It's cost-effective because in almost all cases, you can bring a team of installers into a location for less than it costs to reposition the aircraft, and it allows you to get things done on a minimal downtime basis, which is always king," says Shaw.

He adds that the service is also popular for helicopters due to their limited range. "Your typical helicopter is only going to fly 200-300 mi., so if we can come to their facility it saves a two-day trip in some cases. If you've got an aircraft that's based 800 or 900 mi. away, that's nothing for an airplane—but that's a big event for a helicopter to fly it that far," says Shaw.

Although Pro Star Aviation has the capability to provide On-The-Fly services internationally, Shaw explains that the service is typically performed only domestically due to other countries' hesitancy to outsource work. Within the U.S., Shaw says the service becomes more appealing for customers the farther away an aircraft is located from Pro Star Aviation's New Hampshire headquarters.

"Even if the money stops looking great as far as travel expenses versus aircraft repositioning costs, you still have their convenience at stake. Because if you have to send your own mechanic on-site to manage the project or babysit the airplane, so to speak, that means they have to be on-site for three weeks," says Shaw. "If we go to their hangar, then they can go home every night, and that's a big convenience factor."

PATTONAIR

Pattonair's Agile Warehouse is designed to be rapidly deployable and customizable.

The convenience factor can also go both ways—Russian MRO S7 Technics recently launched a "mobile warehouse" project called KitCar that it says can save engineering and technical personnel more than 4,000 working hours per year while also providing efficiency benefits to clients. The KitCars

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are stocked with all the necessary spare parts, consumables and equipment needed for specific types of maintenance tasks, which are delivered to aircraft maintenance staff on the apron while cutting down on the time needed to locate these items. Technicians can use the KitCars as a mobile office as well, thanks to an onboard printer and climate control.

"The idea to create a fully fledged automobile office came into being at S7 Technics as part of our lean production tools implementation," explains Artyom Ilyin, head of S7 Technics' lean production department. Prior to the project's launch in the summer of 2018, the company's technicians only had access to vehicles with single-use functionality such as transporting tools, "but there was no possibility of fully supporting our apron work using one vehicle," Ilyin says. "The KitCar project has successfully accomplished this task."

S7 Technics is now using KitCars on a daily basis for line maintenance, where they average 28 "missions" per day. The company has five KitCars based at its Moscow Domodedovo Airport location, with two KitCars devoted to Airbus and Boeing aircraft respectively, one KitCar for cabin maintenance work and two KitCars to deliver technical fluids. S7 Technics plans to add an all-purpose KitCar at its Novosibirsk base this summer, which will contain spare parts for Airbus, Boeing and Embraer aircraft.

S7 Technics says it will be tracking KitCar statistics during its summer high season for the first time, to further evaluate how to best implement the project. For now, the company is using KitCars only for in-house maintenance on S7 Airlines aircraft, but a company representative says the MRO provider plans to expand KitCar functionality and its client list in the future.

Pattonair, meanwhile, is already targeting global customers with its Agile Warehouse, which it describes as a "warehouse-in-a-box." Launched in 2018, the customizable product packs parts, tooling and instrumentation into a rugged box on wheels, so it is "mission-ready to fly anywhere in any suitable form of transport," says Jim Smith, Pattonair's commercial director for MRO.

Being self-sufficient and secure, the Agile Warehouse can stay at a station for as long as needed. "This makes it great for remote-site rescue, fly-away situations or away-from-main-base emergency repairs," Smith says. "A big use of the Agile Warehouse is for remote-site development and experimental endurance, performance and cold-weather testing." As an example, Smith says some of Pattonair's Agile Warehouses have three complete sets of engine products for five different engine types.

This S7 Technics' KitCar is filled with tools, parts and consumables for Airbus aircraft.

S7 TECHNICS

"We also have applications where we can load the Agile Warehouse with a complete set of inventory to support a new engine entry into service or the first time a MRO shop has a new engine type in their facility. [There is] nothing worse than starting to rebuild and finding undeclared shortages that stop the job," says Smith.

The Agile Warehouse features automated control over access to inventory, replenishment and stock reporting, and inventory can be replenished in situ or returned to Pattonair for replenishment. Overall, the product is aimed at global mobility and zero lead-time by reducing inventory-related downtime and operational disruptions.

According to Smith, interest in the Agile Warehouse has mostly come from OEM and MRO powerplant-related customers, but Pattonair has seen some interest from companies focused on component repairs, landing gear and rotables as well. "If I had £1 [$1.27] for every time people tell me, 'I would love one for my garage,' I could probably retire this year," he adds.

Smith says the Agile Warehouse was designed to be "rapidly deployable and cost-effective, but customizable enough to meet bespoke needs," so he is confident an "on-the-go" model like this for MRO is scalable, repeatable and sustainable. However, "the physical element you see every day is just like the tip of an iceberg," he stresses. "It is part of an integrated activity that makes the whole solution brilliant."

In terms of the industry-wide feasibility of MRO on-the-go models, Pro Star Aviation's Shaw sees the most demand in specialized applications like On-The-Fly avionics installations rather than more generalized maintenance tasks. "As a business model, I'm not sure that it's something that would have lasting staying power. You can't really do significant maintenance on the road," he says. "That being said, the amount of times an aircraft is down for maintenance versus the amount of times that it's down for refurbishment or an avionics upgrade is just not comparable. You might do a refurbishment once every 10 years and an avionics installation every five. You're going to do maintenance every year."

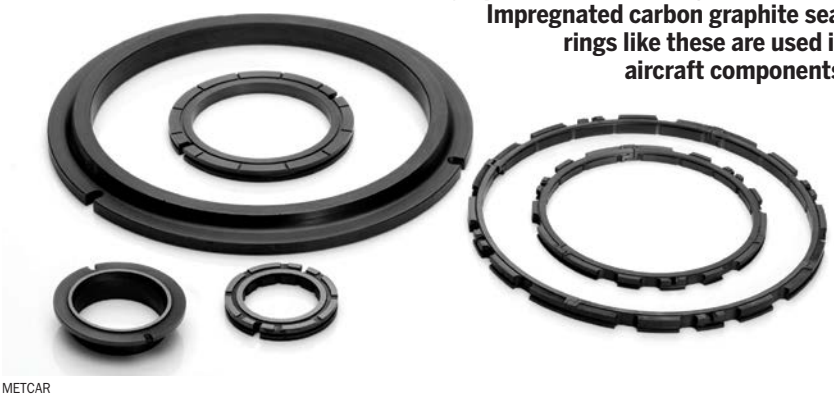
Shaw says airlines come to Pro Star Aviation fairly regularly to combine parallel downtime efforts for avionics work, so he does see value there. "But that's not something that I would say everybody could do," he notes. "I don't know if it's going to be a widely utilized model. I think it's still kind of a boutique thing."

Sealing the Deal

Seals develop to keep up with extreme temperatures and higher pressures.

Paul Seidenman and David J. Spanovich San Francisco

Whether for a super-jumbo commercial jet or a single-engine piston model, fluids, ranging from highly refined propulsion fuels to viscose lubricating greases and oils, are an aircraft's life blood. But fluids are at risk of loss due to leakage. For aerospace seal manufacturers, that presents a dual engineering challenge—more robust containment and longer on-wing life.



Metcar developed a proprietary process to impregnate carbon graphite within a variety of materials. Impregnated carbon graphite seal rings like these are used in aircraft components.

METCAR

New technology applications are moving that along. Among them is carbon graphite, a material that has been manufactured by Metallized Carbon Corp. (Metcar) for nearly 75 years. Specifically, the company is targeting the seal face, which is the primary sealing surface—in a mechanical assembly—that Metcar supplies to the seal OEMs.

Keith Hoge, an application engineer for the Ossining, New York-based Metcar, says the company "has significantly advanced the properties of carbon graphite material." It has also developed a proprietary process to impregnate carbon graphite with a variety of materials, which has improved its temperature resistance, among many other properties.

"At higher temperatures, oil can carbonize—or coke—which tends to increase wear and can ultimately lead to seal failure," he points out. "To combat this, we have been developing materials with higher thermal conductivity and lower coefficients of friction. By reducing the coefficient of friction, we have been able to improve wear resistance by minimizing the amount of thermal buildup at the sealing surface."

In addition, he says, the company's proprietary impregnation process has enabled Metcar to develop pressure-tight materials to stem fluid leakage.

Hoge confirms that with implementation of the new carbon graphite technology, in tandem with new seal designs, durability has improved. "Our customers have reported that seal service intervals have increased from 5,000 to 20,000 hr.," he says. The seals are used in a variety of systems, including engines, gear boxes, auxiliary power units (APU) and hydraulics. "Carbon graphite material has been replacing old labyrinth seals, which had a higher acceptable leakage rate than seals using impregnated carbon graphite," he adds.

Looking ahead, Hoge says that a challenge is to design seal faces that provide a longer life with even higher temperature resistance, at higher rotating speeds.

TEMPERATURE EXTREMES

In that regard, Vinay Nilkanth, vice president of the Global Mobility Sector for Freudenberg Sealing Technologies, reports that the Weinheim, Germany-based company has focused its research and development on technology impacting high- and low-temperature performance, friction reduction and safety. That has been driven, in part, by the necessity for seals to respond to temperature extremes.

"Jet aircraft are flying at higher altitudes to save fuel," Nilkanth says. "For short-haul regional aircraft, this means a severe cold soak at altitude followed by a rapid descent for landing. This puts a major thermal shock on all components, including seals."

In addition, fuel and hydraulic systems "have been driven to increasingly higher pressures" to provide the required performance, Nilkanth notes. "When you couple thermal shock with higher system pressures, this puts a premium on seal resiliency and the seals' abilities to cope with these pressures and thermal changes."

The resiliency of a seal to temperature fluctuations varies, depending on the material selection and design. "If material and design variables are not considered by application, the sealing function may not be optimal and could potentially be compromised," he says.

Freudenberg Sealing Technologies unveiled several high- and low-temperature-resistant products at the 2019 Paris Air Show. They include a new high-temperature, fireproof material; a developmental low-temperature ethylene propylene diene monomer (EPDM) material for commercial aircraft hydraulic systems; and a developmental low-temperature fluoroelastomer (FKM) material for engine fuel and lubrication systems. Among other developments announced by the company in Paris is its EPDM LM426288 material for application to low-pressure static sealing. According to Nilkanth, the material offers temperature resistance down to -77C (-107F), and short-term resistance to +150C, for high-temperature hydraulic systems—such as braking.

Another material he cites, the FKM LM426776, is used for low-pressure static sealing in such aerospace applications as O-rings and small, homogeneous rubber-molded shapes. "It is engineered to withstand temperatures as low as -67C and high-temperature resistance—short-term—to +270C," he explains.

EXTENDING SEAL LIFE

Jared Manry, an engineering specialist at Swedish seal OEM SKF, reports that

innovations are aimed at increasing the functional life of the seal on-wing. "For most engine manufacturers, 20,000 hr. of seal life is now the minimum requirement our designs must meet, with many engine programs demanding even longer life," he notes.

Citing a few examples of recent technology trends, Manry includes "hydrodynamic liftoff," which enables seals to operate on a thin film of gas rather than making full contact between the static and rotating components. Others include hard coatings applied to the sealing surfaces. "That has focused on improved tribology and wearing characteristics between those sealing surfaces, which must remain in contact, and are often exposed to fretting wear due to engine vibration," he explains.

Increasing shaft speeds, along with higher pressure differentials across the seals, contribute to increased seal heat generation and wear.

"New engine designs are running with faster shaft speeds, hotter air and oil temperatures, and higher sealing pressures," he says. "To address this, we have utilized a patented hydrodynamic lift augmentation to the sealing bore of our circumferential seals along with a hardened coating applied to the secondary axial sealing surfaces to reduce both heat generation and wear. Testing has demonstrated a 30% reduction in heat generation, which reduced measured seal interface temperatures by 10-15% and yielded a three-times improvement in measured seal wear when compared to a conventional circumferential seal," Manry notes.

SKF has investigated the mating and wear characteristics of various carbon grades against a variety of aerospace materials and coatings. "We have evaluated the relative performance of these mated materials for both 'sliding' wear and fretting wear," he adds. "These evaluations will be ongoing as new materials emerge on the market."

Asked about self-lubrication/polishing features being applied to some sealing applications, Manry states that "carbon grades advertising self-lubricating properties" have been shown to reduce friction—and therefore heat generation—in laboratory testing. However, he cautions that full-scale testing to quantify the advantages of those properties is warranted.

He adds that new hydrodynamic technologies developed by SKF have been shown to extend seal life "so that the seal is no longer a limiting component" in engine maintenance and overhaul—and may either be replaced or reused during engine removals for scheduled maintenance events.

CHANGING MATERIALS

Torben Anderson, director of the global aerospace segment for Trelleborg Sealing Solutions—headquartered in Sweden—points out that the exclusion of chromed rods in hydraulic systems, due to the European REACH (Registration, Evaluation, Authorization and Restriction of Chemical Substances), and emergence of High-Velocity Oxygen Fuel (HVOF) coatings, have prevented the use of elastomer contact seals in dynamic aerospace sealing applications.

"This has necessitated their replacement with tougher seals in polytetrafluoroethylene-based (PTFE) materials," he explains. "Coatings made from HVOF are more corrosion-resistant and therefore far less likely to sustain scratches, extending the life of the seal and the system as a whole. Also, polymer seal materials have become more wear- and fatigue-resistant [to the] millions of cycles they are exposed to, especially in fly-by-wire systems," he says.

Seal manufacturers, Anderson says, have responded well to the challenges presented to them by primary flight-control applications. "During the past 25 years, the working pressure of aircraft hydraulic systems has increased from 1,500 to 5,000 psi, and the expected service life of the sealing system in the hydraulic cylinder has gone from 1,500 to more than 100,000 flight hours," he reports. "At the same time, leakage criteria has been lowered from one drop in 25 cycles to 'dry rod.'"

Anderson specifically attributes that to the use of PTFE materials, developed to withstand the "many thousands of miles" a seal has to work in the tough environment of an electro-hydrostatic actuator or fly-by-wire system.

Asked if life-extending seal technology could mean increased time between engine and hydraulic system overhauls, "for hydraulics, we are already there," Anderson says. "For gearboxes and engines, substantial amounts of R&D resources are being spent on developing sealed-for-life solutions."

DO BRUSH SEALS MAKE A DIFFERENCE?

Paul Seidenman

Seals in aerospace and other industrial applications often prevent fluid leakage through a complex pathway or "labyrinth" design. In contrast, a simpler "brush" seal architecture is proving to increase fluid containment, as well as operating efficiencies in turbine engines, according to Benjamin Grosskurth, head of brush seal production at MTU Aero Engines in Germany.

MTU holds a patented manufacturing process, specific to its brush seals, marketed under the MTU Power brand.

"The seals consist of thousands of thin bristles fixed together using core wire and a clamping tube to form a flexible seal," Grosskurth explains. "Incoming gases press this wire pack against a supporting ring, compressing it further."

Grosskurth says that the seal continuously adapts to the moving surface being sealed and eliminates up to 90% of leakage, which translates into an increase in engine efficiency of approximately one-third compared to conventional labyrinth seals, he notes. The result is lower fuel consumption and reduced CO_2 and nitrogen-oxide emissions.

Brush seals are also lighter than conventional labyrinth seals and wear more slowly, which can reduce maintenance costs, he adds.

Typical applications of brush seals are in the bearing chamber, shaft and static components of turbines and compressors. MTU's brush seals are being used on the Pratt & Whitney geared turbofan family powering the Airbus A220 and A320neo, Mitsubishi SpaceJet and Embraer E-Jets. MTU, he adds, has also been selected to supply brush seals for the PW1400G-JM for the Irkut MC-21 airliner.

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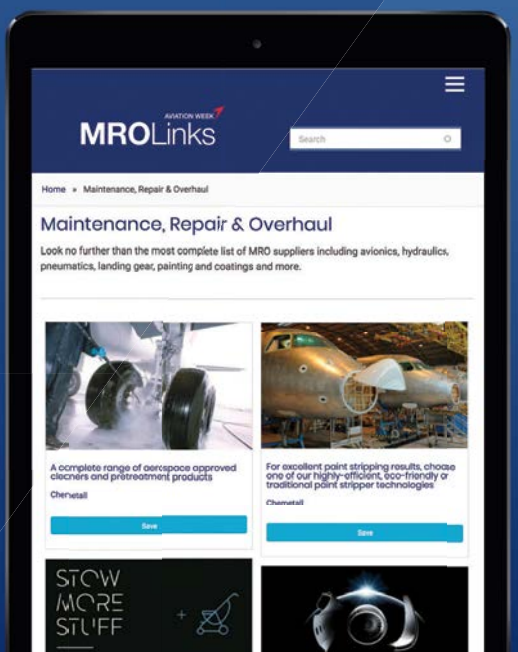


AVIATION WEEK NETWORK

Mobile MRO Delivery

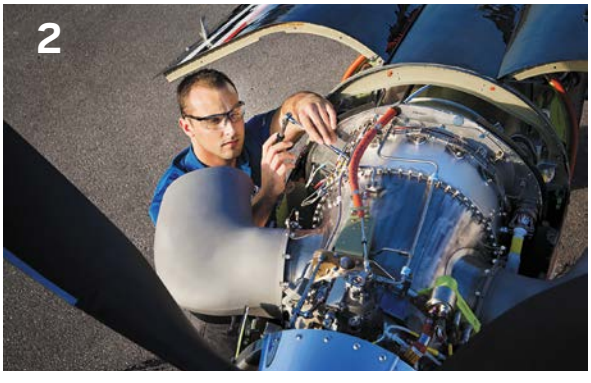
Lindsay Bjerregaard Chicago

1. Mobile MRO Warehouses

Company: S7 Technics
Specifications: Russian MRO S7 Technics is growing its KitCar "mobile warehouse" program, first launched in the summer of 2018. The KitCars, which are stocked with tools, parts and consumables for specific types of maintenance, are delivered to maintenance technicians on the apron to cut down on inventory and transport-related delays. S7 Technics says the KitCars save engineering and technical personnel more than 4,000 working hours per year. The company plans to expand their usage to more locations and clients. S7 Technics has five KitCars based at its Moscow Domodedovo Airport location and one at its Novosibirsk base.
mrolinks.mro-network.com/company/s7-technics

2. Engine MRO Delivered Fast

Company: Dallas Airmotive
Specifications: Dallas Airmotive's F1rst Support field service team is available 24/7 to assist customers with scheduled maintenance, unscheduled repairs and aircraft-on-ground events. Its team of more than 50 technicians can be dispatched to an operator's site within hours to perform comprehensive engine MRO support ranging from single and large fleet-management operators to military operators, airlines and fixed-base operators. The company says its First Support team handles more than 5,000 service events per year and uses a mobile application to help improve on-site information handling.
mrolinks.mro-network.com/company/dallas-airmotive-inc



3. Making the Most of Aircraft Downtime

Company: Pro Star Aviation
Specifications: New Hampshire-based Pro Star Aviation aims to help operators make the most of their aircraft downtime with its On-The-Fly maintenance services. When an aircraft is down for maintenance or planned work, Pro Star Aviation's team will travel to the location to provide on-site aircraft-on-ground assistance or installations, such as avionics upgrades and automatic dependent surveillance-broadcast connectivity. Pro Star Aviation says the service is cost-effective because bringing a team of installers on site is cheaper than repositioning aircraft. This feature is particularly appealing for aircraft operating far from their home base or helicopters with shorter ranges, Pro Star Aviation says.
mrolinks.mro-network.com/company/pro-star-aviation-llc

4. Warehouse-in-a-Box

Company: Pattonair
Specifications: Pattonair has developed a "warehouse-in-a-box" product that seeks to achieve zero lead-time thanks to improved parts-inventory management. The Agile Warehouse is a rugged box on wheels that can be stocked with customized parts, tooling and instrumentation, which are carefully controlled and replenished via automated inventory functionality. The Agile Warehouse can be transported to a customer's location and stay on site for as long as needed, which Pattonair says works well for remote-site rescue and development situations or for performance and cold-weather testing.
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5. Contract Lifetime Kitting

Company: **HC Pacific**
Specifications: HC Pacific has been offering full MRO and OEM kitting solutions since early 2017 and says it has seen exponential growth due to its unique practice of buying parts for the life of a contract. Kits come in both bagged and laminated options, with the latter being the most popular. The company says customers purchasing HC Pacific kits do not have to place a purchase order for multiple parts in the bill of materials, reducing administrative work in procurement and quality inspection. HC Pacific says it has kits built and ready for immediate delivery to customers on a just-in-time basis to optimize working capital.
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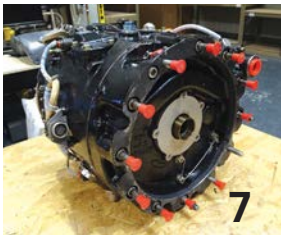

6. Overnight Line Station Setup

Company: **Northern Aerotech**
Specifications: Danish MRO Northern Aerotech launched a mobile line maintenance product in November 2017 aimed at supporting customers as quickly as possible while providing flexibility and reducing cost. The Deployable Line Station (DLS) consists of a large branded box filled with everything required for line maintenance at a remote location. The boxes can be fabricated in a few days, depending on tool lead-time, and are shipped via air freight to a customer's station, typically arriving the following day. Northern Aerotech says DLS boxes allow for quick line-station setup that can work in any location.
northern-aerotech.com/

7. Quick Engine Replacements

Company: **ITS**
Specifications: Arizona-based supply chain specialist ITS offers a variety of kitting products such as Fly Away Kits (FAK) and Quick Engine Change (QEC) kits to help operators and MROs quickly replace engines and release aircraft for operation. The company offers both complete and partial kits, depending on customer requirements, and says it has added dedicated experts to speed up kit assembly. ITS reports that its QEC kits for CFM56-5B and -7B engines are particularly popular.
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By JONATHAN BERGER

Jonathan M. Berger is managing director of Alton Aviation Consultancy, a global aviation and aerospace advisory firm.

The Looming MRO Capacity Crunch

'The times they are a-changin'

A funny thing happened recently when sourcing several airframe heavy maintenance checks. For the first time in my 25-plus-year career, there were no near-term slots available.

Sure, perhaps it was just poor timing, as no airline wants to have an aircraft out of service during the peak summer months. But recent discussions with several major airframe suppliers confirm a common theme—their hangars are full, and some are even turning away work.

For the past few decades, MRO supply has easily exceeded demand. All three MRO supplier segments—OEMs, independents and airline-affiliated providers—had excess capacity, which fostered a very competitive MRO sourcing environment that kept prices low and supplier options high.

As Bob Dylan famously sang, "for the times they are a-changin'."

It now appears that several industry trends that began more than a decade ago have resulted in the current MRO capacity crunch through a combination of legacy airlines divesting in-house maintenance capabilities to cut costs, low-cost carriers outsourcing their MRO from the very start and the exponential fleet growth experienced during the airline industry's longest period of sustained profitability. Most MRO hangars and engine shops are at or near capacity.

That said, airlines are not sitting idly by. Moreover, we are starting to see operators reconsider their traditional MRO buying behavior. In an effort to mitigate the flight schedule risks associated with limited hangar slot availability, several forward-thinking airlines have initiated discussions with their preferred suppliers to negotiate capacity agreements for 3-5 or more years to secure future slots and lock in favorable rates. Consequently, MRO providers are being forced to rethink their existing pricing strategies to accommodate these long-term deals.

MRO demand will grow at a compound annual growth rate of 4.2%, from $73 billion to more than $110 billion over the next decade.

MRO executives clearly have some big decisions ahead of them regarding how best to manage the looming capacity crunch. The obvious strategic options to increase capacity are adding additional shifts, implementing best-practice process improvements to increase throughput and/or building new facilities.

The major dilemma facing these executives, as well as many of their private equity owners, is the risk associated with building new facilities.

With economists and industry analysts predicting a recession or industry slowdown within the next few years, is now really the right time to invest tens of millions of dollars in new hangars? And given the industry labor shortage, will they be able to find enough skilled technicians to support the capacity increase? Or could not adding capacity inadvertently encourage airlines to bring MRO work back in-house to protect their core flight operations?

According to Alton's independent, global MRO forecast, MRO demand will grow at a compound annual growth rate of 4.2%, from $73 billion to more than $110 billion over the next decade. Given this tremendous growth, one thing we know for sure is that airline customers in the near term will undoubtedly see their maintenance costs increase as MRO providers selectively allocate their limited slot capacity to the highest bidders.

And perhaps more consequential, we just might be witnessing the genesis of MRO procurement-negotiating leverage transition from buyer to seller. The times are indeed changing.

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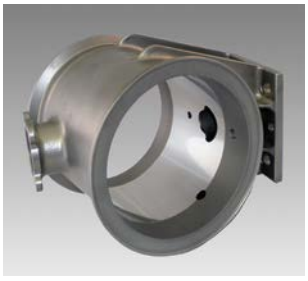

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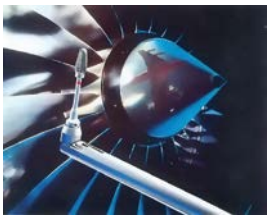

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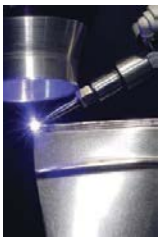

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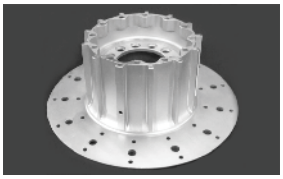

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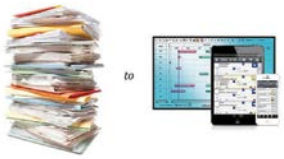

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Richard Kendall
Group Director Airframe Services, HAECO Group

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Janite Quiran Parmanande
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Rahul Shah
SVP Strategic Growth, Business Development Asia Pacific, Middle East and Africa, AAR Corporation

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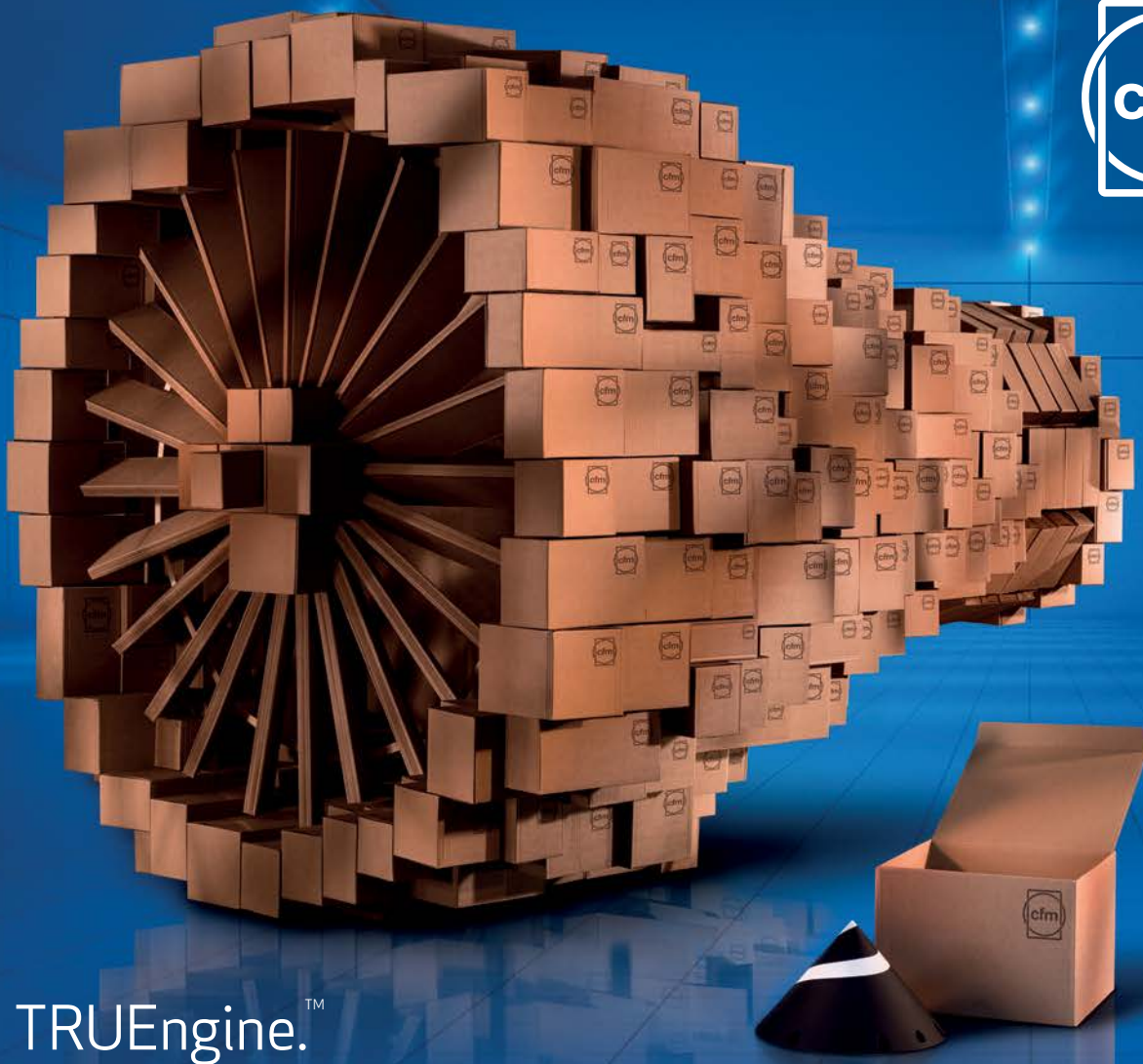

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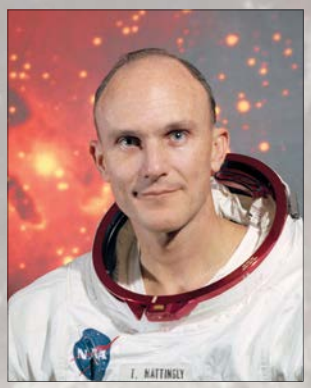
Captain, U.S. Navy, retired

Born: March 25, 1928, in Cleveland, Ohio

Education: B.S., U.S. Naval Academy; Aviation Safety School, University of Southern California; Harvard Business School Advanced Management Program

Spaceflights: Pilot, Gemini 7; command pilot, Gemini 12; command module pilot, Apollo 8; commander, Apollo 13



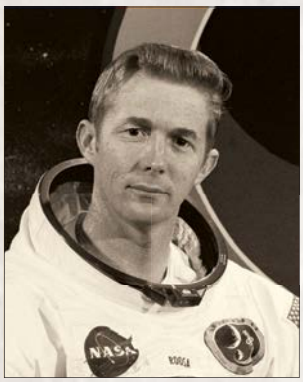
Thomas Kenneth Mattingly II

Rear admiral, U.S. Navy, retired

Born: March 17, 1936, in Chicago

Education: B.S. in aeronautical engineering, Auburn University

Spaceflights: Command module pilot, Apollo 16; commander, STS-4; commander, STS-51C



Stuart Allen Roosa

Colonel, U.S. Air Force, retired

Born: Aug. 16, 1933, in Durango, Colorado

Died: Dec. 12, 1994, at age 61 in Falls Church, Virginia, of complications from pancreatitis

Education: B.S. in aeronautical engineering, University of Colorado; Harvard Business School Advanced Management Program

Spaceflights: Command module pilot, Apollo 14

Walter M. Schirra

Captain, U.S. Navy, retired

Born: March 12, 1923, in Hackensack, New Jersey.

Died: May 2, 2007, in La Jolla, California, at age 84, of a heart attack

Education: Newark College of Engineering, New Jersey; B.S., U.S. Naval Academy

Spaceflights: Pilot, Mercury-Atlas 8; pilot, Gemini 6; commander, Apollo 7

David Randolph Scott

Colonel, U.S. Air Force, retired

Born: June 6, 1932, in San Antonio, Texas

Education: B.S., U.S. Military Academy; M.S. and engineer of aeronautics and astronautics, Massachusetts Institute of Technology

Spaceflights: Pilot, Gemini 8; command module pilot, Apollo 9; commander, Apollo 15

Alan Bartlett Shepard, Jr.

Rear Admiral, U.S. Navy, retired

Born: Nov. 18, 1923, in East Derry, New Hampshire

Died: July 21, 1998, in Monterey, California, at age 74, of leukemia

Education: B.S., U.S. Naval Academy

Spaceflights: Pilot, Mercury-Redstone 3 (Freedom 7), first U.S. human spaceflight; commander, Apollo 14

Alfred Merrill "Al" Worden

Colonel, U.S. Air Force, retired

Born: Feb. 7, 1932, in Jackson, Michigan

Education: B.S. in military science, U.S. Military Academy; M.S. in astronautical and aeronautical engineering and in instrumentation engineering, University of Michigan

Spaceflight: Command module pilot, Apollo 15

John Watts Young

Captain, U.S. Navy, retired

Born: Sept. 24, 1930, in San Francisco

Died: Jan. 5, 2018, at age 87

Education: B.S. in aeronautical engineering, Georgia Institute of Technology

Spaceflights: Pilot, Gemini 3; commander, Gemini 10; command module pilot, Apollo 10; commander, Apollo 16; commander, STS-1; commander, STS-9

What Would Top Apollo? A Visit From ET

Irene Klotz Cape Canaveral

©CATVINTON

Apollo may have started off as a technology showdown with the then-Soviet Union, but the worldwide enthusiasm for and awe at the first human landing on the Moon were big surprises for **Michael Collins**, the command module pilot of Apollo 11. Fifty years ago, Collins circled the Moon aboard Columbia, nervous that crewmates Neil Armstrong and Buzz Aldrin might not be able to lift off from the lunar surface after their historic landing, and he would have to return to Earth alone. As the golden anniversary approached, Collins, 88, spoke to Aviation Week from his home in Florida.

AW&ST: **What do you think is the most lasting effect of the Apollo program?** Right after the flight of Apollo 11. Right after the flight—we were very lucky—Neil, Buzz and I got to take a trip around the world and visit 20-some world capitals. I was amazed by the reaction we received as we traveled. I thought people would say, "Well you Americans finally did it." Instead of that, everywhere we went people said, "We did it. We, humankind, we have left this dinky little planet and we have gone elsewhere."

That was partially thanks to Neil Armstrong because he was a master at doing his homework, and he was our spokesman. When he was talking to people, he understood a bit about their country and local issues, and by the time he finished he had them just about ready to crawl onboard Columbia with us.

I don't know of any human accomplishment, before or after, that has had that kind of effect of bringing nations everywhere together and agreeing on anything. I think probably that was one of the accomplishments of the Apollo program and perhaps the most important one.

What could be as transformative to our way or life, our evolution as a species, as the accomplishments of the Apollo program? A visit from an extraterrestrial.

That's a great answer. What about the discovery of life as it once existed on Mars, or a human trip to Mars? I think Mars is inevitable as a goal for us and probably should be our next goal. Then I guess it depends on what we find on Mars, and I'm not able to say, without having gone, how transformative that might be to our way of thinking or to our society. But certainly I don't think you can discuss our future in space without having Mars pop up two or three times in the same sentence.

Has NASA labored since Apollo to find its footing? Are the achievements of the shuttle and space station programs, and the greater diversity of people who have now flown, worthy heirs to the Apollo program? After the lunar landing, a period of technical consolidation was a necessity, and we're still undergoing that. We're building our ability to take on a roughly two-year roundtrip to Mars. Consolidation is not as sexy as doing things for the first time. We just have to sit back and say, "Well, yes, this may be not as exciting, but it's just as necessary." It's a foundation we are building, and then we can go on to the next large leap forward.

What do you think about the private space efforts underway today? I love it. I know Jeff Bezos just a little bit. I don't know Elon Musk at all, but I welcome their billions of dollars with open arms. That money can be piled on top of congressionally appropriated federal funds, and that gives us that much more cash with which to accomplish the things we want to do or to do them faster or better. It's wonderful.

What do you think about the current program of record to return to the Moon in a more sustainable way before going on to Mars? It's been well-researched. It's the most popular way of getting to Mars, and I heard Jeff Bezos very recently say he thought returning to the Moon was the fastest way to get to Mars. Also, Neil Armstrong, who was a much better engineer than me, thought there were gaps in our knowledge that we could fill by a return to the Moon before we set sail to Mars. I just happen to disagree with all of them. They put a lot more time, effort and intelligence into it than I have, but I would just go for what I refer to as the "JFK Express." Just as President [John F.] Kennedy put down, in a masterpiece of simplicity, our task for Apollo, I would say we ought to say the same thing when we want to go to Mars. Pick a date and put our assets to work directly on that goal. That would be my preference.

What would be your wish for the 100th anniversary of Apollo 11? I'd like to plant the American flag and a bunch of others on the surface of Mars and name that installation Tranquility Base Two.

Check 6 *Astronaut Michael Collins talks with Irene Klotz about Apollo 11 and more:* **AviationWeek.com/podcast**

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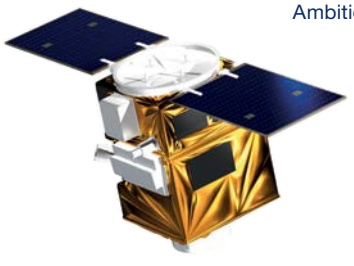

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Searching FOR Spacesuits

The suit that Buzz Aldrin wore during the Apollo mission did not enhance mobility, something NASA vows to change during the proposed Artemis mission.

NEIL ARMSTRONG/NASA

Mark Carreau Houston

There are spacesuits. And then there are spacesuits.

NASA's most successful have been very much safety- and mission-driven. Some have been worn inside a spacecraft during launch and entry in case of decompression, to enable mission abort and astronaut rescue. The venerable but aging Extra Vehicular Mobility Unit (EMU) suits were fashioned specifically for space shuttle-satellite encounters—including upgrades to the Hubble Space Telescope—and International Space Station (ISS) assembly and maintenance.

The lessons from the Mercury, Gemini, Apollo, Skylab, shuttle and ISS wardrobes live on as NASA readies garments for Orion crews and astronauts assigned to low-Earth-orbit activities. And now NASA will have to outfit astronauts for Artemis, the 2024 sprint to the lunar surface that the White House recently called for, as the U.S. and others mark the 50th anniversary of Apollo 11, the first human Moon landing.

In the case of Apollo, NASA attempted to address both spacecraft safety and lunar surface exploration requirements with one garment. It is evident from NASA video that the Apollo astronauts often moved awkwardly as they explored the Moon, stumbling due to a lack of spacesuit mobility. The agency is determined to change that with Artemis as it plans to establish a sustainable lunar surface presence after the 2024 return.

A New Suit for Artemis?

NASA's proposed $21 billion 2020 budget, which Congress received on March 11, 15 days before Vice President Mike Pence, chairman of the White House National Space Council, directed NASA to advance plans for a human return to the lunar surface beginning in 2028. Lunar spacesuit development is a part of the agency's broad Advanced Cislunar and Surface Capabilities budget line that calls for $363 million for 2020 and is forecast to rise to $2.36 billion by 2024.

The White House asked for $1.6 billion for fiscal 2020 above the initial 2020 NASA budget request of $21 billion. That addition was to kick off a 2024 Artemis landing, and a new Moon suit strategy is anticipated as part of that supplemental request. The House has not responded to the $1.6 billion; the Senate has still to act.

The Moon will require new, well-designed spacesuits as well as pre-mission training in simulated environments. Presumably, Mars exploration will have the same spacesuit requirements. Astronauts there will be called upon to stroll and climb unfamiliar terrain while subjected to a vacuum or thin atmosphere, much reduced gravity levels, temperature extremes, abrasive dust and increased radiation.

NASA has not yet completed an integrated Moon suit, though components are in development, says Bill Gerstenmaier, associate administrator for human exploration and operations.

Before NASA finishes a lunar garment, it must decide what activities the astronauts will pursue during the 2024 return, which is targeted for the Moon's heavily cratered south pole.

Upgrade or Retire?

As part of the George W. Bush admin-

istration's Constellation return-to-the-Moon initiative, NASA awarded a lunar suit development contract to Oceaneering International Inc. in 2009 valued at up to $148 million. The Obama administration canceled it a year later, though efforts to deliver design data and advanced suit components under the agreement continued until early 2016 at a cost of $135.6 million, according to an April 2017 NASA inspector general's (IG) audit.

The agency must be more cost-conscious on further development, Gerstenmaier says. Still, experts agree NASA's Extra Mobility Unit (xEMU), the current spacesuit, should be retired soon.

The EMU came together more than four decades ago and has been updated and maintained well beyond the original 15-year design life. It originally was developed for arm- and hand-intensive extra vehicular activities (EVA) in the shuttle's payload bay and later adapted for the ISS. Of the 18 fabricated, 11 of the multiple-component EMUs remain available for ISS use, either on Earth or in orbit.

Both NASA's IG audit and more recently the agency's independent Aerospace Safety Advisory Panel (ASAP) have declared it is time to at least replace the aging EMU, while policymakers contemplate deep-space options and timelines and their spacesuit needs.

"It is time to retire the current suit and move on to a next-generation suit," stressed ASAP member Susan Helms, a retired U.S. Air Force lieutenant general and veteran of five shuttle flights, during an April 25, ASAP session hosted by NASA's Marshall Space Flight Center. ASAP member Patricia Sanders endorsed Helms' verdict.

To contain costs, NASA has been leading an "in-house" spacesuit development effort with Collins Aerospace, the EMU's prime contractor and a unit of United Technologies Corp., as well as representatives from a small community of aerospace contractors involved in the field.

The effort has been focused on the xEMU, an upgraded suit that can pioneer components for a new Moon suit.

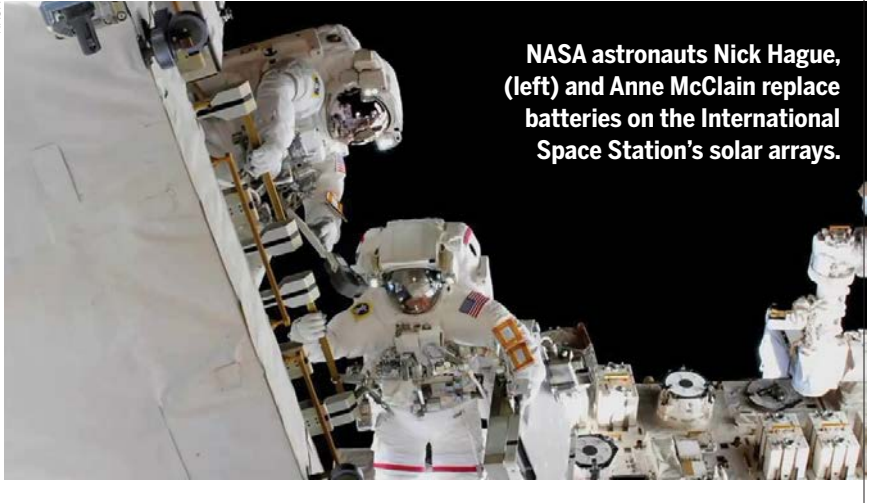
A Suit for Exploration

The xEMU is to begin a lengthy preliminary design review this month and head to the ISS in the early to mid-2020s. There, it is to participate in spacewalk demonstrations of a much-upgraded Primary Life Support System (PLSS), the backpack that holds the breathing air, carbon-dioxide removal, cooling and power elements, as well as the shirt-like Hard Upper Torso (HUT) upon which the PLSS attaches and the helmet and pant-like lower-torso assembly connect.

The xEMU PLSS and HUT are intended to shape the architecture for a new Moon suit. Once the agency has logged a satisfactory ISS demonstration, it plans to seek contractor proposals for production.

Looking a bit beyond the Moon, in July 2020, NASA's Mars 2020 rover is to launch to the Jezero Crater to look for evidence of past microbial life and cache rock and soil samples for future return to Earth. When the rover descends in February 2021, it will be carrying four samples of spacesuit fabric and a helmet piece as part of the Scanning Habitable Environments with Raman & Luminescence for Organics and Chemicals (Sherloc) instrument, a first.

NASA



NASA astronauts Nick Hague, (left) and Anne McClain replace batteries on the International Space Station's solar arrays.

ABIGAIL WEIBEL

HANNAH **KERNER**

Arizona State University

"Repeatedly landing on and traversing the Moon remains the most impressive technical feat in American history, an achievement largely made possible by human computers who were predominantly women."

Known hazards of the Martian environment include windborne dust and increased levels of solar ultraviolet radiation. While mounted on the rover's robot arm, Sherloc's spectrometers, laser and cameras will monitor changes to the samples fastened to a calibration target as they study the Martian terrain for evidence of organics and minerals altered by water.

"The end goal is to have a purpose suit for lunar exploration that then informs you for Mars," says Amy Ross, the advanced spacesuit pressure garment and technology lead at NASA's Johnson Space Center.

"The xEMU is not our whole exploration EMU, but it does demonstrate a lot of the new-core new technologies, especially the PLSS," notes Ross. "We have options here, from which NASA can choose."

As part of its human return to the Moon, NASA plans to assemble a human-tended, lunar-orbiting Gateway, starting in 2022 and equipped with solar-electric propulsion, a modest habitat and docking ports for Orion and

reusable lunar surface descent and ascent vehicles.

Key PLSS advances that include battery power, breathing-air supply, carbon-dioxide removal and cooling are intended to add robustness to subsystems whose failures could bring an abrupt end to a spacewalk, Ross explains.

As conceived, the xEMU will sport a new automated amine swingbed scrubber to remove carbon dioxide from the suit's breathing air. As one bed becomes saturated with CO_2, it will rotate into the surrounding vacuum of space to recharge by allowing the CO_2 to dissipate, while a second amine bed filters inside the suit.

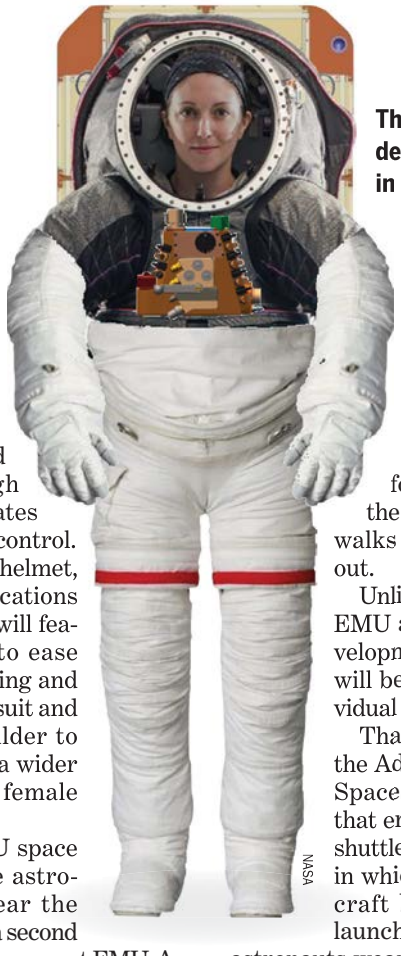
The rapid-cycle amine upgrade alone could help to extend current EMU spacewalks well beyond the current 6-7 hr. typically allotted for work outside the ISS, notes Shawn Macleod, Collins' director for space, who has contributed to the effort.

The xEMU also features dual-loop liquid cooling. Underneath the visible pressurized portion of the current EMU spacesuit is a full-length undergarment laced with loops through which water circulates to provide thermal control.

Along with a new helmet, visor and communications system, the xEMU will feature a rear entry to ease the process of donning and removing the spacesuit and an adjustable shoulder to help accommodate a wider range of male and female body types.

During the xEMU space station testing, one astronaut likely will wear the new garment, while a second spacewalker dons the current EMU. As it stands, the astronaut wearing the xEMU will wear the pant-like lower body assembly from the current EMU, which is not optimized for walking on a planetary surface, a feature expected to emerge as NASA returns to lunar soil on a sustained basis, which is called for under White House Space Policy Directive-1 issued by President Donald Trump on Dec. 11, 2017.

The xEMU work is funded through NASA's ISS budget. Ross' 27-member team integrating the system includes engineers and technicians from Jacobs Engineering Group Inc. and KBRwyle as well as Collins plus NASA civil servants.



The xEMU Lite is designed for operations in low Earth orbit.

Orion Crew Survival System

On the second broad front, the Orion Crew Survival System (OCSS) suit, a launch-and-entry garment derived from the shuttle era, is intended to provide each member of the four-person Orion crew capsule with launch-and-entry protection as well as up to six days of pressurized life support should the spacecraft face a life-threatening emergency during its journey to the Moon and back. Artemis 2, the first joint flight of NASA's Space Launch System and Orion with astronauts on board, is planned for 2023.

When astronauts board Orion for launch, they are to be wearing the OCSS suit modified from its shuttle days but currently not envisioned for EVA activities like the xEMU, though spacewalks have not been ruled out.

Unlike the shuttle and ISS EMU and the xEMU in development, each OCSS suit will be tailored for an individual astronaut.

That heritage garment is the Advanced Crew Escape Spacesuit System (ACES) that emerged after the 1986 shuttle Challenger accident, in which the winged spacecraft broke apart during launch, exposing the seven astronauts wearing jumpsuits in the pressurized shuttle crew cabin to a pressure loss as they plummeted toward the Atlantic Ocean.

ACES became the follow-on shuttle launch-and-entry suit, which was to support a crew bailout scenario should a parachute-equipped shuttle crew experience a pressure loss but manage to achieve level atmospheric flight and access to a side hatch and escape pole to guide them away from the shuttle as they jumped. Working with the David Clark Co., known for its development of the flight suits worn by military pilots, NASA continued modifications of ACES into the mid-1990s.

"Spacesuits are a tricky business," says Dustin Gohmert, NASA's Orion Crew Survival Systems manager. "Anything you do has pros and cons."

Some of the cons emerged as NASA's second shuttle tragedy, the 2003 Columbia loss during reentry, was investigated. The helmet was judged heavy enough to cause shoulder injuries, and an outflow of oxygen from the ACES into the shuttle cabin was deemed a potential fire hazard. The shuttle was not designed to manage long-term use of pressure suits by its astronauts, who were to open and close their ACES helmets at specific points in the mission to

RISING STARS

PHOTO CREDIT

HAZZA
AL MANSOORI
UAE Astronaut

"Our leadership is focusing on making the United Arab Emirates economy based on knowledge and innovation and knowing more about space. There is a payback for the youth who hopefully will give us more interest in and passion about space."

manage the cabin oxygen content.

"We took the lessons from the Columbia accident and started looking at Orion, asking: 'If we can do it from scratch next time, what would we do?'" Gohmert says.

As a result, the OCSS and Orion's Environmental Control Life Support System (ECLSS) work together autonomously to recover the oxygen in the astronauts' exhaled breath and adjust the suit pressure in response to changes in the cabin pressure. As part of Orion's Atmosphere Revitalization System, amine beds remove and dispose of carbon dioxide and moisture.

As the astronauts prepare to launch, the OCSS suits will provide breathing air for Orion crews with a 35-40%/65-60% oxygen-nitrogen ratio. Far from Earth, the oxygen content is programmed to rise to 95%. In each phase of flight, the pressure balance will be regulated to prevent decompression sickness from nitrogen enrichment.

Each OCSS-suited astronaut will be linked to Orion's ECLSS components through an umbilical, whose final length has yet to be established—though it might be 13 ft. for the commander and pilot and 6-8 ft. for their two crewmates. The Orion suit umbilicals are to be secured within the cabin every 2 ft. so the cables will not float around in the weightlessness and interfere with crew activities.

Perhaps most significant, the OCSS suit is designed to provide Orion astronauts with six days of life support should the capsule depressurize in its lunar journey, time enough to return to Earth or perhaps find refuge at the lunar Gateway.

The design includes visor ports through which the astronauts can rehydrate and consume liquid nutrients while confined to the garments.

NASA

The xEMU is a design being considered for deep space.

"I would say of all aspects when we started this project, waste management was the biggest technical hurdle we had to get over," Gohmert says.

Six days is too long for skin to be exposed to a diaper soaked in urine with a rising ammonia content. Thus, crew urine will make its way to a cabin septic tank for disposal overboard, using gender-specific accessories.

In late 2016 and early 2017, NASA sponsored an infamous "Space Poop Challenge," an open competition to entertain a wide range of proposals to address OCSS suit fecal disposal. Though helpful, the more than 5,000 responses did not provide a breakthrough.

Currently, the OCSS team is working with a vendor of waste management systems for wounded veterans on a system for containing fecal matter in the spacesuit, while exposing a minimal amount of tissue to possible infection.

"Remember, we are in the mother of contingencies," says Gohmert of the emergency scenario far from Earth. "The first thing is check your modesty at the door because everybody is stripping down in a volume no bigger than this [conference] table. You and your buddies will be doing things in awkward places. If we have a good day, this hardware will never be touched."

While his team is not prepping the OCSS suit for a specific Artemis 2 spacewalk, they are not ruling out the activity in Orion operations to deal with an external spacecraft issue or mission activity. However, without an airlock, the Orion cabin would have to be depressurized with the crew in their OCSS suits and the destination of the excursion restricted to the length of the life-support umbilical.

A Contractor Perspective

At Collins, forged in 2018 from UTC Aerospace Systems and Rockwell Collins, Macleod has helped to size NASA's shuttle-era fliers with EMU components individually.

HOLLY HENLEY

KAYLA **WATSON**

Amazon Prime

"There are many world issues that may be tackled by aerospace technology, but aerospace is often not thought to be a source for a solution."

Looking ahead, he says, Moon and Mars garments must offer high mobility to both genders and the widest possible range of body types with the fewest interchangeable components and an open, evolvable architecture sturdy enough to be maintained far from Earth, even if the garments must be stowed for many months.

"Being able to put someone in a suit and have them fit in it is one thing, but actually being able to put them in there to be sure it optimizes their performance is another," Macleod says.

As PLSS fans, pumps and other life-support components wear out or more advanced replacements emerge, they could be replaced without regard to vendor, Macleod believes.

The spacesuit helmets he envisions will be equipped with advanced avionics, including head-up displays that can respond to voice commands so strolling astronauts can call up fresh images of their surroundings.

"We are working on those technologies right now," adds Macleod. "They may or may not make some of the first Moon missions, but we believe there will be block upgrades for some of the later ones."

Digital Extra *See how spacesuit construction and materials have evolved since the 1960s:* **AviationWeek.com/Evolution-Spacesuit**

Expanding Commercial USE OF THE ISS

> THE GOAL IS TO FAN LEO ECONOMY

> NASA HOPES TO FREE UP FUNDS FOR LUNAR INITIATIVES

Irene Klotz Cape Canaveral

While the world marks the 50th anniversary of the Apollo 11 Moon landing on July 20, NASA astronaut Andrew Morgan plans to board a Russian Soyuz capsule at the Baikonur Cosmodrome in Kazakhstan for a 6-hr. flight to the International Space Station (ISS).

Morgan, a rookie from the Astronaut Class of 2013, will ride with Russian cosmonaut Alexander Skvortsov, who is returning to the ISS for a third time, and Italy's Luca Parmitano, who will be making his second spaceflight. Morgan is due to become the 237th person to live and work aboard the orbital outpost, a $150 billion project of 15 nations and the surviving heir to the 1961-72 Apollo Moon initiative that sent 24 men to the Moon, 12 who walked its surface. The space shuttle program, which followed Apollo, ended in 2011.

NASA always believed the ISS would be the steppingstone to the country's future in space. At times though, the station, which required 37 space shuttle assembly missions, seemed more of a doorjamb than a highway to Mars—the long-term goal of the human space program.

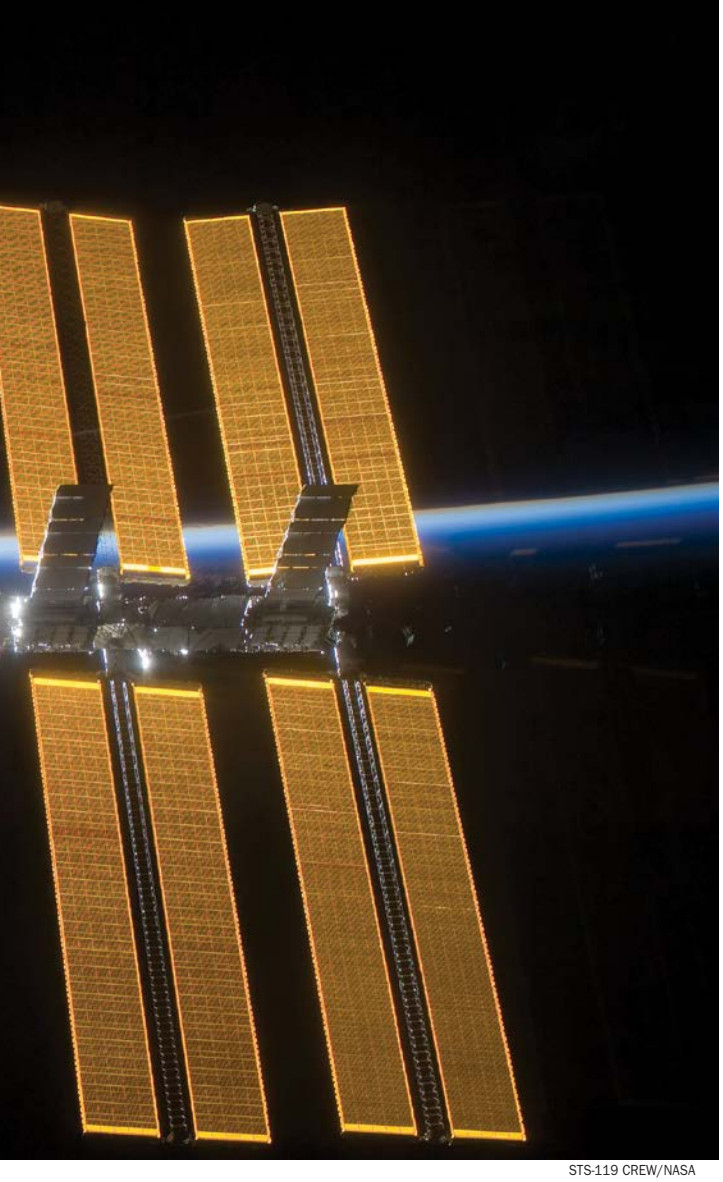
Since 1985, U.S. taxpayers have contributed about $100 billion—roughly two-thirds the total construction cost—for the ISS program and continue to provide more than $3 billion annually for transportation and operations. Now, with a final wave of investment and a new blueprint for expanding commercial use of the ISS, NASA is about to see if the station indeed will become the bridge for its next venture, a lunar exploration

Steppingstones and Bridges

From Apollo to the International Space Station

	APOLLO COMMAND MODULE	SPACE SHUTTLE	INTERNATIONAL SPACE STATION
Length		122 ft.	240 ft. (pressurized)
Width/diameter	12 ft. 8 in.	78 ft. (wingspan)	357 ft. (end to end)
Height	10 ft. 7 in.	56 ft.	45 ft.
Volume	218 $ft.^3$	2,600 $ft.^3$	32,898 $ft.^3$
Weight	26,300 lb.	200,000 lb.	~930,000 lb.
Computers	1	5-10 (including payload laptops)	52 (including payload laptops)
Flight length	14 days (design life)	12 days (average)	20+ years and counting

Source: NASA



STS-119 CREW/NASA

The STS-119 crew took this iconic photo of the International Space Station after undocking the shuttle Discovery from the station on March 25, 2009. The crew delivered and assembled the fourth starboard Integrated truss segment and the fourth set of solar arrays and batteries to the orbital outpost. Two years later, Discovery and the rest of the fleet were retired, kicking off an eight-year, ongoing suspension in orbital human space launch from the U.S.

initiative known as Artemis. At stake is not only a return on the sizable taxpayer investment in the ISS, but also NASA's future in the human spaceflight business.

"We need to think of a different way of doing business and a way we can use commercial low Earth orbit (LEO)," NASA human spaceflight chief Bill Gerstenmaier said during a June 7 press conference at the Nasdaq headquarters in New York to unveil the new ISS commercialization plan. "We put together this space station to do research, education, outreach and development, and now it's going to be used to help put together a business plan and business models. . . . This is a hugely different way for us to do business."

About 50 companies already conduct commercial research and development aboard the ISS through the auspices of the Center for the Advancement of Science in Space (CASIS), a Florida-based nonprofit that operates a U.S. National Lab aboard the station alongside NASA's program.

The new plan is intended to not only add more companies to the mix but also enable them to generate a profit from their products and services, including in-space manufacturing, marketing, advertising and flying fare-paying tourists. "This is a shift for NASA that will be beneficial for the American economy and for the American citizens," Gerstenmaier says. "The commercialization of low Earth orbit will enable NASA to focus resources to land the first woman and the next man on the Moon by 2024 as the first phase of creating a sustainable lunar presence and preparing for missions to Mars."

In addition to nurturing a LEO economy, NASA wants commercial options for its research needs and astronaut flight opportunities when the ISS no longer is available. NASA has not set a date for de-orbiting the ISS, which has been staffed permanently since November 2000. A guiding principle of the agency's transition plan is that there be no gap in NASA's access to LEO.

Ideally, NASA is looking for an expanded LEO marketplace to reduce its costs for operating the station, particularly the amount it spends for crew and cargo transportation services. NASA Chief Financial Officer Jeff DeWit says he expects to have a better idea of how much the agency can expect to trim from its ISS budget in 6-12 months.

An early indicator may come from NASA's offer to host up to two dedicated commercial passenger flights per year to the ISS beginning as early as 2020. Each flight could last up to 30 days. Spaceships under development by SpaceX and Boeing to ferry four NASA and ISS partner astronauts to and from the station can be configured to seat up to seven.

NASA, which has been buying rides from Russia since the retirement of the space shuttles in 2011, expects to pay an average of $58 million per seat on the U.S. commercial vehicles. It currently pays around $80 million per person for Soyuz flight services.

Private researchers and tourists would need to not only buy their own rides from SpaceX, Boeing or a future provider but also reimburse NASA for ISS housing expenses—including life support, food, communications and other services—which DeWit estimates run about $35,000 per night.

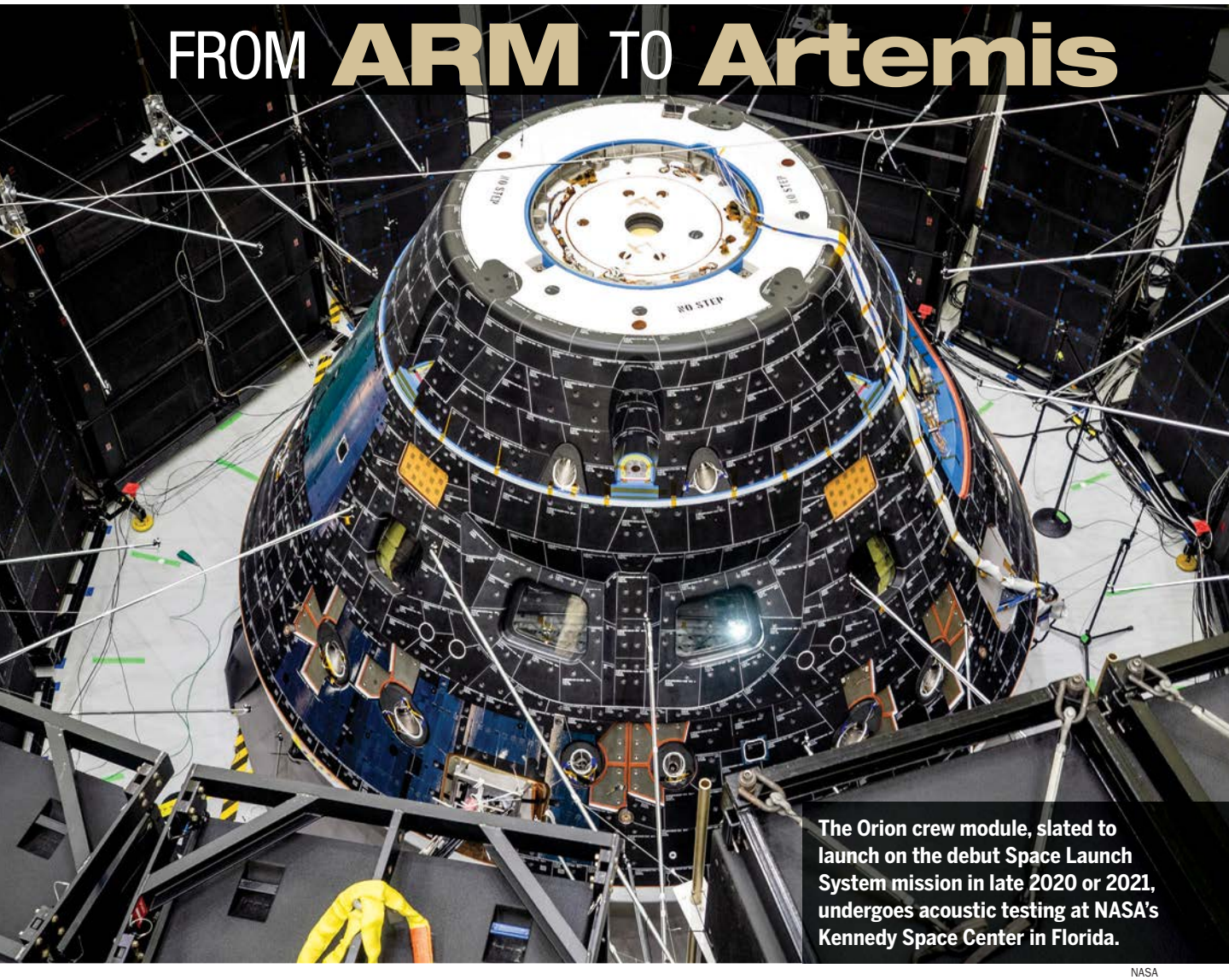
NASA's five-part plan for commercial LEO development includes an inventory and price list of ISS services, facilities and resources available to the commercial sector. "Our approach is designed to lower but not totally remove the risk from the private-sector entrepreneurs and companies. NASA's goal is ultimately to be one of many users of the next-generation, low-Earth-orbit research facilities," Gerstenmaier notes.

The commercialization plan kicked off with a June 21 solicitation for a commercial module that could be attached to a docking port on the ISS's Harmony module. Several contracts for studies, business development and possibly initial design work are expected before year-end.

The agency also plans this summer to release another solicitation to support development of a commercially owned and operated free-flying outpost, which occasionally could rendezvous and dock with the ISS. Combined, the programs are expected to cost NASA $561 million.

"NASA by its very nature is an exploration agency," says Gerstenmaier. "We like to challenge the status quo. We like to solve impossible problems and do amazing things, but NASA realizes that we need help. We can't do this alone."

FROM ARM TO Artemis



The Orion crew module, slated to launch on the debut Space Launch System mission in late 2020 or 2021, undergoes acoustic testing at NASA's Kennedy Space Center in Florida.

NASA

Irene Klotz Cape Canaveral

Fifty years after NASA's 1969-72 sprints to the Moon, the U.S. is preparing for deep-space human travel for the long haul, parlaying the international and commercial partnerships forged in the post-Apollo space shuttle and International Space Station (ISS) programs into an exploration blueprint that includes a lunar surface sortie as early as 2024, full-time global lunar access for crewed and robotic missions, followed by future expeditions to Mars.

The Trump administration has proffered tepid support for a 2024 lunar landing, supplementing its $21 billion fiscal 2020 budget request with an extra $1.6 billion to kick-start a plan to return U.S. astronauts to the Moon's surface four years sooner than previously scheduled.

Vice President Mike Pence, who chairs the U.S. National Space Council, has championed the 2024 date, timed to take place before the end of a possible second Trump administration. But President Donald Trump himself has yet to pick up the mantle and in June seemed to even undercut Pence's efforts. "For all of the money we are spending, NASA should NOT be talking about going to the Moon," Trump wrote in a June 7 Twitter post. "We did that 50 years ago. They should be focused on the much bigger things we are doing, including Mars."

Further, the administration asked that the $1.6 billion down payment to expedite landing astronauts on the Moon come from a projected surplus in the Federal Pell Grant Program for low-income college students, sparking immediate controversy and raising questions about the White House's long-term financial commitment to NASA's lunar exploration initiative.

Landing on the Moon in 2024 was announced as a presidential initiative, but every indication is that the Office of Management and Budget (OMB) has not signed on, says John Logsdon, professor emeritus of political science and international affairs at George Washington University and founder of the school's Space Policy Institute.

"If they don't, and you try to move on with OMB resisting presidential direction, that's not a recipe for success," he adds. "The program NASA was proposing, aiming at a 2028 landing, probably was not politically sustainable. It was moving too slowly, so the willingness of the administration to say, 'We want to do it faster,' and the implication that it would provide the resources to make that possible was very promising. What has happened since then is very puzzling. This rollout doesn't seem to be something that can be translated into sustainability."

Accelerating the schedule for a crewed Moon landing, under a program newly named Artemis, will require $20-30 billion over the next five years, on top of the agency's baseline annual budget of $20-21 billion, says NASA Administrator Jim Bridenstine. Depending on commercial and international participation and how much redundancy the agency decides to buy for key services and hardware, "it could actually be less than $20 billion," he tells Aviation Week (see page 28).

Without the plus-up, NASA could accomplish a lunar landing in 2028 under current, inflation-adjusted budgets, provided the space agency continues to win political support, which is not guaranteed, says Bridenstine, citing previous failed exploration initiatives such as the George W. Bush administration's 2005-10 Constellation program.

"We've tried to do this activity before, and it hasn't worked. The timescales are so long that administrations change; Congress, budgets and priorities change. By accelerating the timeline [for Artemis] we are reducing the political risks," he says.

But navigating shifting political winds actually has become one of NASA's fortes. With bipartisan support, the agency has managed to keep key programs and contractors funded, despite redirection in its human spaceflight initiatives. For example, work on the Orion capsule, a key part of the Artemis program, began during Constellation. The successor Obama administration replaced Constellation with a human and robotic asteroid exploration program that included the Asteroid Redirect Mission (ARM).

Orion, designed for active support of a four-person crew in deep space for 21 days, survived, though Constellation's Ares heavy-lift rocket program did not. Under ARM, NASA also began planning for a high-power, solar-electric spacecraft bus to host scientific and technology payloads, including a robot arm to grapple and relocate a piece of an asteroid into high lunar orbit. The agency also began work on the Space Launch System (SLS) family of expendable rockets to replace Ares.

Under Trump, ARM gave way to Artemis, but NASA kept Orion, the SLS and the ARM spacecraft bus, now repurposed into the Power and Propulsion Element (PPE) for a planned lunar-orbiting assembly node and science outpost called the Gateway.

In May, NASA awarded a $375 million contract to Maxar Technologies (formerly SSL) to develop, launch and operate the 50-kW PPE. Launch aboard a commercially procured rocket is expected before the end of 2022.

The space agency is developing additional partnering arrangements for other elements needed for the Gateway and Artemis, including a small habitation/docking node and a human-class lunar landing system. Of the Trump administration's $1.6 billion Artemis plus-up for fiscal 2020, $1 billion is earmarked to accelerate development of human lunar transportation.

The bulk of the rest of the funds goes to Orion and the SLS, which combined already have consumed about $25 billion, not including $4.7 billion spent on the capsule during the Bush-era Constellation program.

In June, the Government Accountability Office (GAO) flagged the Orion and SLS programs for projected cost growth that nearly doubles the $1 billion overrun NASA already acknowledges. GAO auditors also criticized the payment of tens of millions of dollars in award fees to Orion prime contractor Lockheed Martin and SLS prime Boeing despite continued budget overruns and schedule delays.

Over the course of their current contracts, Lockheed Martin and Boeing have earned about $294 million and $271 million, respectively, in award fees, the GAO said.

NASA has paid the majority of available award fees to both contractors—Lockheed Martin about 93%, or $88 million, and Boeing about 81%, or $146 million—since their respective program-confirmation reviews, when the program cost and schedule baselines are established, according to the GAO.

NASA established baseline costs and schedules for the SLS in 2014, with

RISING STARS

JIACHEN WANG

LUC **RIESBECK**

George Washington Univerity

"I'd like to see the removal of 85% of all debris in Earth orbit and a more robust dedication of data from space systems to fight climate change."

RISING STARS

ZACK CRISOSTOMO

BIANCA **VASQUEZ**

Society of Women in Space Exploration

"The Apollo program showed us two very important things: It was possible, and space exploration unites everybody."

RISING STARS

ACCION SYSTEMS

NATALYA **BAILEY**

Accion Systems

"The Apollo program continues to live on through all the technology development that occurred to make it a reality."

the rocket then slated for a November 2018 debut. Officially, the newly renamed Artemis-1 mission remains targeted for launch between December 2019 and June 2020, but NASA says it will not be ready by then.

The agency now aims to launch Artemis-1, an uncrewed trial run of an Orion spacecraft around the Moon, in late 2020 or early 2021. But with several key ground tests still to come, the GAO says the first SLS-Orion flight actually may not occur until June 2021 due to possible technical issues that NASA has not yet allocated time to resolve.

Chief among pending tests is the planned full-duration firing of the SLS core stage, a shuttle-heritage booster powered by four refurbished, shuttle-era Aerojet Rocketdyne RS-25 engines. NASA considered skipping the so-called "green-run" test at NASA's Stennis Space Center in Mississippi as a way to recoup lost time but so far has left the test on the schedule.

During the green run, NASA will fuel the completed core stage with liquid hydrogen and liquid oxygen and fire the integrated four main engines for about 500 sec. "The test carries risks because it is the first time that several things are being done beyond just the initial fueling," the GAO said. "For example, it is also the first time NASA will fire the four main engines together, test the integrated engine and core-stage auxiliary power units in flight-like conditions and use the SLS software in an integrated flight vehicle."

In addition, because flight hardware for Artemis-1 will be used for the test, any damage would need to be repaired prior to launch, the GAO added.

NASA has no schedule margin between the end of core-stage production and the start of the green-run test, no margin to address any issues that may arise during testing and no margin between the test and delivery of the stage to Kennedy Space Center, Florida, for integration. Nevertheless, NASA's safety oversight and advisory boards urge the agency to keep the test.

ISS as Role Model

NASA IS PRACTICING DIFFERENT WAYS TO DO BUSINESS with the International Space Station (ISS), a permanently staffed research laboratory owned and operated by 15 nations. "We're not going to achieve our goals on the Moon until we commercialize the ISS," says Mike Gold, a Maxar Technologies vice president who chairs a NASA Advisory Council committee on commercial space policy and regulatory issues.

In addition to ISS cargo transportation services provided by SpaceX and Northrop Grumman, NASA expects SpaceX and Boeing to begin operational crew rotation missions, currently handled by Russia, next year. A third U.S. company, Sierra Nevada Corp., is developing a reusable lifting body spaceplane called the Dream Chaser that will join the fleet of ISS cargo ships in early 2021.

Onboard the station, nine companies own and operate a total of 15 commercial facilities, including Made In Space's 3D printer and Nanorack's cubesat launcher. A newly unveiled ISS commercialization plan (see page 46) seeks to greatly expand space-based business opportunities for U.S. companies, including tourist flights, advertising and marketing. If successful, NASA hopes to not only kick off a new wave of interest and investment in low-Earth-orbit activities but save enough of the ISS' $3 billion annual operating budget to help bankroll its lunar exploration and deep space initiatives.

In addition to partnering with Maxar for the Gateway Power and Propulsion Element, NASA has purchased rides from startups Astrobotic Technology of Pittsburgh, Intuitive Machines of Houston and Orbit Beyond of Edison, New Jersey, to deliver up to 23 small science and technology experiments to the Moon's surface on three commercial landers slated for launch in September 2020-July 2021. Six more companies—Deep Space Systems of Littleton, Colorado; Draper Laboratory, Cambridge, Massachusetts; Firefly Aerospace, Cedar Park, Texas; Lockheed Martin Space, Littleton; Masten Space Systems, Mojave, California; and Moon Express, Cape Canaveral—are authorized to bid for future Commercial Lunar Payload Services contracts.

In May, NASA announced six-month contracts, worth $45.5 million, through its Next Space Technologies for Exploration Partnerships to study and/or develop prototypes to support the descent, transfer and refueling elements of potential human-rated landing systems. The companies receiving contracts are: Aerojet Rocketdyne, Blue Origin, Boeing, Dynetics, Lockheed Martin, Masten Space Systems, Maxar, Northrop Grumman, Orbit Beyond, Sierra Nevada and SpaceX.

An additional Next Step solicitation for an integrated lunar landing service is pending, as is an upcoming call for commercial launch service proposals to deliver cargo and other hardware to the Gateway. A formal solicitation for a firm fixed-price contract for Gateway cargo launch services is expected this summer. NASA anticipates the maximum contract award for all Gateway services over the course of 15 years will be $7 billion.

"I cannot emphasize more strongly that we advise NASA to retain this test content in the program of work," Patricia Sanders, chair of the Aerospace Safety Advisory Panel, said in April. An alternative plan for shorter-duration engine firings at the launchpad "will not achieve an understanding of the operational margin and could result in severe consequences conducted in a much less controlled environment than Stennis," she added.

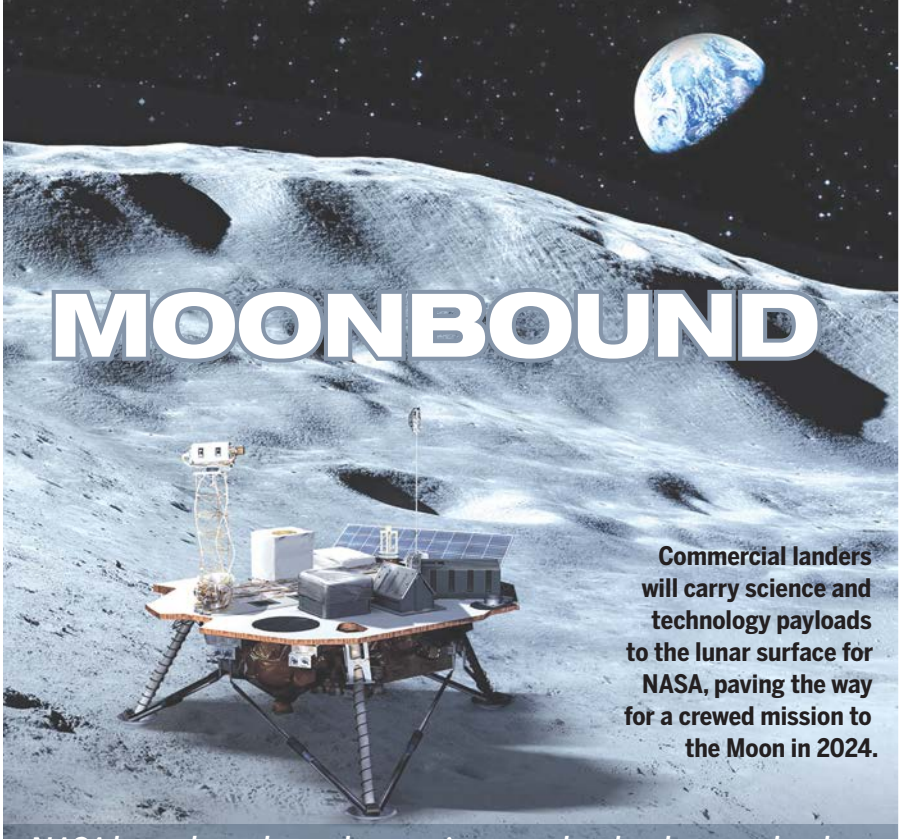
While Orion's schedule is less challenged, it also is over budget and delayed. The baseline cost and schedule for Orion is tied to the first crewed mission, Artemis-2, officially slated for April 2023, though NASA says it is working toward a September 2022 date and has budgeted accordingly, a practice the GAO criticized.

"GAO considers the cost estimate incomplete because it does not account for Orion costs in those intervening seven months," the report said. "According to scheduling best practices, performance is measured against the program's baseline even if a program is working to an earlier date."

NASA insists that Orion is the only spacecraft capable of carrying and sustaining astronauts on missions to deep space and safely plunging though Earth's atmosphere at lunar-return velocities. The agency also says the SLS is the only rocket with the power and capability required to carry astronauts to deep space on Orion capsules. But the strength of Orion and the SLS may be measured by another metric: Combined with development of launchpad and ground-support systems at the Kennedy Space Center, NASA estimates that 3,800 suppliers and more than 60,000 workers, across 50 states, are working on the program.

"We've been down the SLS path since 2010, and here we are coming up on 2020 maybe being able to launch it after 10 years," says Logsdon. "We launched Saturn V after five years of development, so why is it that we're not able to move with anywhere near the speed that we were in the past?

"One of the problems has been providing just enough resources to keep the program going without enough resources to make it successful," he adds. "The intent of Pence's initiative is that doing business as usual is no longer acceptable. But there is no willingness to spend the political capital to change things."



MOONBOUND

Commercial landers will carry science and technology payloads to the lunar surface for NASA, paving the way for a crewed mission to the Moon in 2024.

NASA

NASA has selected two-dozen science and technology payloads to fly on small commercial lunar landers, with the first mission slated to launch in September 2020. Here are the latest payloads and sponsors selected for missions, announced July 1:

MoonRanger, a lander-accompanying rover with a 0.6-mi. range and equipped to map terrain, built by Astrobotic Technology, Pittsburgh.

Heimdall, a flexible imager to model the upper layers of the lunar soil and identify potential landing hazards, from the Planetary Science Institute, Tucson, Arizona.

Lunar Demonstration of a Reconfigurable, Radiation-Tolerant Computer System, a payload to characterize lunar surface radiation, from Montana State University.

Regolith Adherence Characterization Payload, to assess how the lunar soil adheres to an assortment of materials, from Alpha Space Test and Research Alliance, Houston.

Lunar Magnetotelluric Sounder, instrumentation designed to characterize the structure and composition of the lunar mantle by studying the electric and magnetic fields, from the Southwest Research Institute, San Antonio.

Lunar Surface Electromagnetics Experiment, instrumentation to measure lunar surface electromagnetic phenomena, from the University of California, Berkeley.

Lunar Environment Heliospheric X-ray Imager, instrumentation to observe interactions between the Earth's magnetosphere and the solar wind, from Boston University.

Next-Generation Lunar Reflectors, targets placed on the lunar surface for Earth-based lasers to measure the distance between the two planetary bodies, from the University of Maryland.

Lunar Compact Infrared Imaging System, a radiometer equipped to monitor infrared emissions revealing lunar surface composition, temperature distribution and identification of potential lunar resources, from the University of Colorado.

Lunar Instrumentation for Subsurface Thermal Exploration with Rapidity, a drill probe designed to measure thermal properties at depths of up to 10 ft., from Texas Tech University.

PlanetVac, hardware for extracting lunar regolith and placing the material in analytical instrumentation or in spacecraft for return to Earth, from Honeybee Robotics, Pasadena, California.

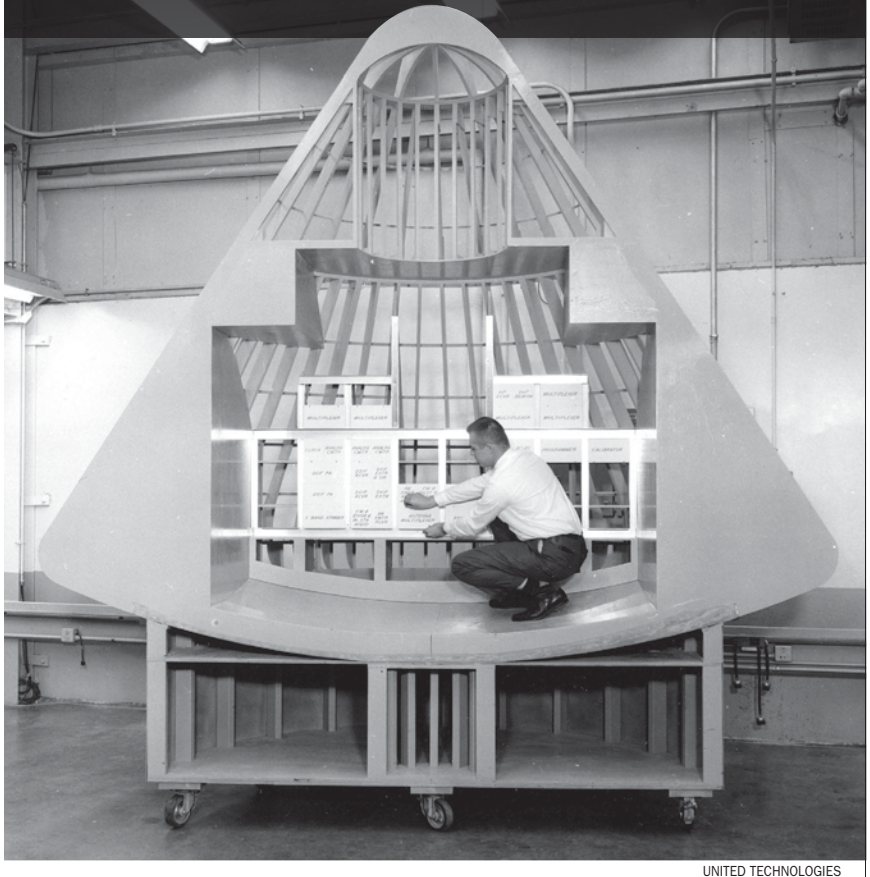
Sample Acquisition, Morphology Filtering and Probing of Lunar Regolith, a robot arm for lunar surface sample acquisition, from Maxar Technologies, Westminster, Colorado.

Source: NASA

Apollo's Reforging

> APOLLO-ERA SPACE INDUSTRY LIVES ON IN CONSOLIDATED PRIMES

> AEROSPACE LEADERS CITE HISTORY OF WORKING TOGETHER FOR THE MISSION



UNITED TECHNOLOGIES

Then-Collins Radio built a mockup to visualize the placement of communications equipment within the Apollo Command Module.

Michael Bruno Washington

In 1962, 11 companies were invited to bid for Apollo's Lunar Module (LM). Nine responded that September, answering 22 questions from the NASA request for proposal, itself a 60-page limited technical document. Grumman Aircraft won the award two months later.

"That gives you a little bit of an idea" of how things have changed, says Jeff Foote, vice president for NASA programs at successor Northrop Grumman. "Each of us that work proposals today . . . [work on] thousands of pages digitally transmitted, and then [there are] years of negotiations, fact-finding, etc., to get things on contract. [But] that was the environment of the time."

Another difference is in the workforce. According to a NASA history, by 1966 the agency's civil service rolls had grown to 36,000 from the 10,000 employed in 1960. "Additionally, NASA's leaders made an early decision that they would have to rely upon outside researchers and technicians to complete Apollo," says NASA. Part of that might have come from a holdover mistrust of large government establishments from the Eisenhower administration.

Not surprisingly, private industry, research institutions and universities were responsible for the majority of personnel working on Apollo, NASA says. During the 1960s, 80-90% of the agency's overall budget went to contracts to purchase goods and services from others.

But contrast that total workforce explosion with today's modest expectations, where no major staffing buildup has been outlined. Frank Slazer, Aerojet Rocketdyne's vice president for strategy and business development and a former space policy lead at the Aerospace Industries Association, notes that is thanks to technological improvements. It is one reason why, when compared with the Apollo program, current NASA programs are still a better deal, even if they are not necessarily less expensive, for what is in some ways a repeat of old achievements.

"What we've been spending so far is relatively modest. This [Artemis] program is expensive, but we have learned; we have come up with cheaper ways of building things [with] additive manufacturing and other technologies that are out there," he says. "You look at some of these pictures of the old days, you see people everywhere; that costs a lot of money. Now we have automated manufacturing. We do these things much more cost effectively. You've got to put it into context in what you're getting now and how much we spent back then."

During Apollo, the expenditures went to an industrial base that included more than 500 contractors, according to NASA. The prime contracts awarded to industry for the principal components of just the Saturn V included Boeing for the S-IC/first stage, North American Aviation for the S-II/second stage, Douglas Aircraft Co. for the S-IVB/third stage, the then-Rocketdyne division of North American Aviation for the J-2 and F-1 engine and IBM for the Saturn's instruments.

"These prime contractors, with more than 250 subcontractors, provided millions of parts and components for use in the Saturn launch vehicle, all meeting exacting specifications for performance and reliability," the agency says.

With the 50th anniversary of Apollo 11, many of the companies—or at least, many of the successor companies—are reveling in their roles. "It was Collins Aerospace's life-support systems that enabled Neil Armstrong's first steps on the atmosphereless Moon, and it was our communications equipment that brought the world the audio and video of those historic steps," the United Technologies Corp. (UTC) division recalls to Aviation Week.

According to the company, in the early 1960s then-Hamilton Standard—later Hamilton Sundstrand, then UTC Aerospace Systems and now Collins Aerospace after UTC's acquisition of Rockwell Collins—was selected as the systems integrator for the Apollo spacesuit. It further provided the Portable Life-Support System, the backpack that sustains life within the suit. In 1965, however, NASA awarded a new suit contract to International Latex Corp. (ILC), later known as ILC Dover.

But UTC claims much more Apollo heritage. During Apollo missions, then-Collins Radio supplied the communications system for the program. "All voice transmissions to and from the Apollo aircraft for the mission were made possible by our technology," the company stresses. "This also included the transmission equipment to relay images and video, allowing for the famous video feed of Neil Armstrong stepping onto the Moon."

Likewise, Northrop's ancestor companies were significantly involved beyond the LM. Its Mission Systems and Aerospace Systems businesses were then part of TRW, which developed the Lunar Excursion Module Descent Engine (LEMDE) for Apollo. Mission Systems, some of which was the defense and electronics business of Westinghouse, also manufactured the camera that captured the lunar walk images.

Dalmo Victor and the Amecom division of Litton Industries give Northrop's Electronic Systems further pride. Dalmo designed and supplied the S-band, 2-GHz high-gain antennas that transmitted the live lunar images, says Northrop. Amecom produced flush-mounted antennas that transmitted and received all S-band signals during near-Earth operations and served as a backup for the high-gain antenna. Legacy Northrop, meanwhile, provided the Earth landing system, including the space vehicle recovery parachutes.

So what has happened to these companies? As evidenced by UTC and today's Northrop Grumman, most have become part of larger corporations as the aerospace and defense sector has consolidated. An Apollo-era engineer could have had a career in one business unit that had a half-dozen different owners, for example.

Among the bigger players, Northrop Corp. and Grumman Aircraft merged in 1994 and then acquired Westinghouse Defense Electronics, TRW and Orbital ATK—itself a merger of Orbital Sciences and the space and defense side of Alliant TechSystems—among others. Likewise, North American Aviation, which provided the Apollo command and service modules, became part of North American Rockwell, then Rockwell International and finally Boeing, which along the way also bought McDonnell Douglas, including the earlier Douglas Aircraft.

Today, legacy industry is going through another turn of consolidation, as evidenced by the recent announcement that UTC and Raytheon could merge (*AW&ST* June 16-30, p. 18).

"There have been a series of mergers and acquisitions in [the] defense industry in recent years (in the areas of services, space and defense electronics) that have accumulated into a substantial degree of industry consolidation, such as the combinations of General Dynamics and CSRA, Northrop Grumman and Orbital ATK, and L3 Technologies and Harris," say Andrew Hunter and Rhys McCormick of the Center for Strategic and International Studies. "And the Raytheon-United Technologies merger continues this consolidation trend specifically in the space and defense electronics sectors. Any ensuing moves by competitors that follow are likely to concentrate in these areas as well."

All this consolidation portends a competitive marketplace, but modern executives stress there also has been a camaraderie of sorts as industry worked to meet Washington's objective. "Spaceflight is the ultimate team sport," notes Tony Antonelli, Orion EM-2 Mission Director at Lockheed Martin Space.

NASA Administrator Jim Bridenstine wants even more of that as the Trump administration pushes for U.S. astronauts to return to the Moon by 2024. "Work together," he exhorted contractors in an interview with Aviation Week (page 28).

Maybe that sort of collaborative effort has not changed much. As Northrop representatives were preparing their own Apollo anniversary, they unearthed an unusual artifact that recalls a moment of levity around the Apollo 13 crisis, when the company's LM served as the unplanned lifeboat for the crew as they raced back to Earth.

"We came across this interesting invoice-looking thing, from Grumman Aerospace to North American Rockwell, 'invoice for services rendered,'" Foote says. "Line items include charges for insp ection, a towing charge—$1 a mile, times 300,000 mi.—vehicle rental, air conditioning, and room and board for three astronauts for five days," he says. The pseudo-invoice totaled $324,750 but offered a 2% contractor discount if paid within 30 days.

"Interestingly enough," adds Foote, "fifty years later, this invoice still hasn't been paid.

NASA

JESSICA **WATKINS**
NASA

"I've always been interested in exploring space and how we, as humans, could reach those outer stars and learn more information about who we are through that process. What would I take to Mars? Matt Damon and extra ketchup."

Digital Extra *See the history of A&D consolidation in a diagram from Renaissance Strategic Advisors:* **AviationWeek.com/AerospaceConsolidation**

Human Orbital Spaceflight Statistics

As of June 30, 2019

SINCE THE DAYS OF APOLLO, more than 500 individuals have traveled beyond Earth's atmosphere. On the 50th anniversary of the U.S. Moon landing, a three-member crew, including rookie astronaut Andrew Morgan, is scheduled to launch July 20 to the International Space Station (ISS). Highlighting how international human spaceflight has become in the decades following Apollo, the crew will launch aboard a Russian Soyuz MS-13 rocket from the Baikonur Cosmodrome in Kazakhstan. Veteran Russian cosmonaut Alexander Skvortsov, who was 3 when Apollo 11 launched, returns for a third trip to the ISS. He will be joined by NASA's Morgan and the European Space Agency's Luca Parmitano, who will serve as the ISS commander during his second trip to space. The trio will become part of the current ISS Expedition 60 crew, headed by Commander Alexey Ovchinin of Russia and including NASA flight engineers Christina Koch and Nick Hague.

International Space Station

236 Total visitors
102 Cargo missions
94 Crewed missions

Mir

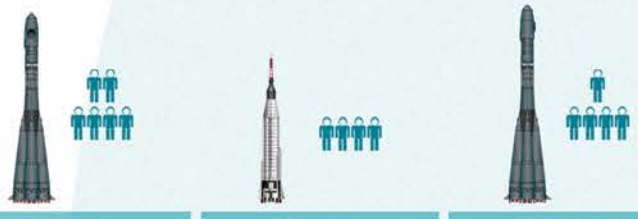
137 Total visitors
64 Cargo missions
39 Crewed missions

Skylab

3 Crewed missions
9 Total visitors

Salyut (4) and Almaz (2)

39 Total visitors
25 Cargo missions
18 Crewed missions



	Vostok	Mercury	Voskhod
Total Launches	6	4	2
Total Occupants Launched	6	4	5
Notes	Crewed flights took place from 1961 to 1964, beginning with Yuri Gagarin's flight on April 12, 1961.	Crewed orbital flights took place from 1962 to 1963.	Crewed flights took place from 1964 to 1965. First multiple crew and first space walk conducted during this program.

SPACEFLIGHT

RISING STARS

WEISSSAT-1 TEAM

Jupiter, Florida, Middle School

"Eventually, we want to send a rover to the Moon."

Tiangong (2)

8 Total visitors

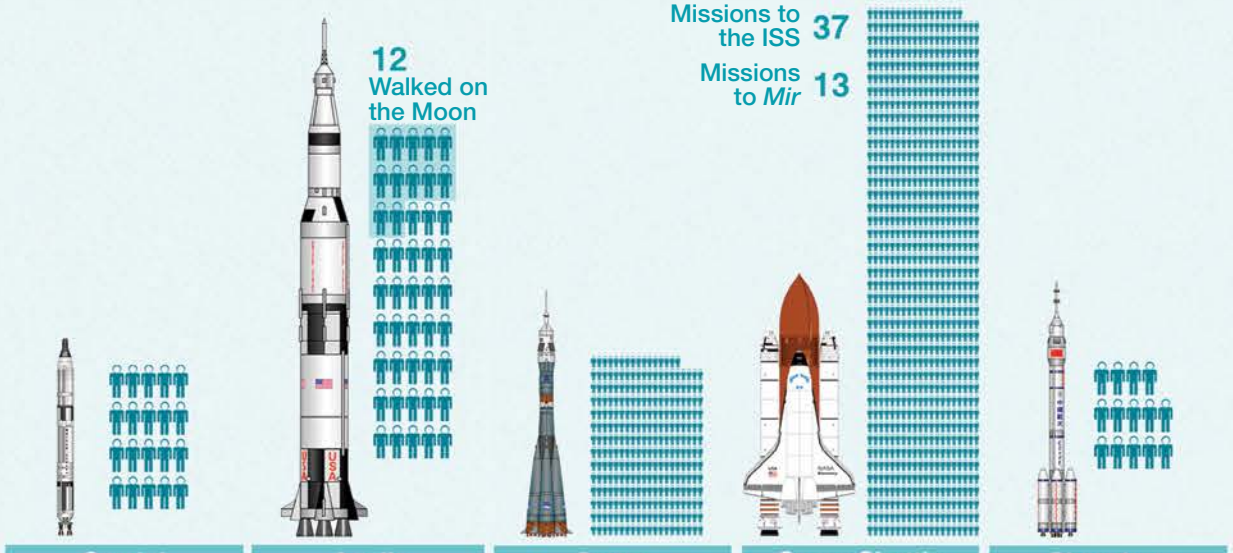
1 Cargo mission

3 Crewed missions

319 Crewed Orbital Launches

1,322 Spacecraft Occupants Launched into Orbit

558 Individuals



Gemini	Apollo	Soyuz	Space Shuttle	Shenzhou
10	15	141	135	6
20	45	376	852	14
Crewed flights took place from 1965 to 1966. Purpose was to develop long duration flight, rendezvous, and space walks in support of the Apollo Program.	Crewed Apollo missions took place from 1968 to 1972. Three Skylab missions took place in 1973. One Apollo-Soyuz Test Project flight took place in 1975.	Crewed flights began in 1967 and continue to this day. Soyuz 18A and Soyuz MS-10 were aborted during launch with no casualties. The Soyuz is expected to remain in service well into the 2020s.	Missions took place from 1981 to 2011, conducted by *Columbia* (28), *Challenger* (10), *Discovery* (39), *Atlantis* (33), and *Endeavour* (25). Some occupants have flown multiple times on the Shuttle.	Crewed flights began in 2003 and continue to this day.

BRYCE

VIRGIN ORBIT

RISING STARS

WILL **POMERANTZ**
Virgin Orbit

"A single goal set by a political leader is not the only way to focus and motivate a program. I'd love to see many different goals that each provide an Apollo-like level of focus and motivation to the smaller groups of women and men who helped conceive the goals and who are working hard to reach them."

China Prepares FOR A Lunar Base

> CHANG'E 4 IS ON THE FAR SIDE OF THE MOON

> THE NEXT MISSION, CHANG'E 5, SHOULD BE LAUNCHED IN LATE 2019

> AT LEAST THREE MORE MISSIONS WOULD PRECEDE BASE CONSTRUCTION

Bradley Perrett Beijing

Step by cautious step, the China Lunar Exploration Program is hitting its targets. Thanks to that success, the scope of the program is widening. Missions have been added and the main objective will soon turn to preparing for a possible manned polar base on the Moon.

Twelve years after the Chang'e 1 flight demonstrated that China could get a spacecraft to lunar orbit, the country's fourth lunar exploration mission, Chang'e 4, in January became the first of any country to land on the Moon's far side. Chang'e 5, delayed by a failure of the Long March 5 rocket, is scheduled for launch around the end of 2019 with the objective of bringing samples back to Earth.

This is where the scheduling has changed to accommodate expanded ambition. The exploration program was originally intended to consist of three phases, successively demonstrating orbiting the Moon, landing on it and returning samples. Each phase was to have two missions, the second of which would be primarily a backup in case of the failure of the first.

But Chang'e 5 will now be the only mission in the third phase. Chinese space officials describe Chang'e 6 as part of a fourth phase that has emerged as the early missions have generally achieved their objectives. Success has been bolstered by cautious programming, notably including a stately rate of progress that can hardly be compared to the frantic U.S.-Soviet race to the Moon in the 1960s.

The fourth phase is aimed at preparing for the base, called a research station. Chang'e 6 will be undertaken in 2023-24 with cooperation from France, says the China National Space Administration. It will land close to the south pole and bring back samples; whether the site is on the near or far side will depend on results from Chang'e 5, says Wu Yanhua, the deputy director of the lunar exploration program. Following the pattern of earlier missions, the spacecraft will presumably be similar in design to that of Chang'e 5 so it can serve as a backup.

Three officials of the China Academy of Sciences (CAS) said last year that scientists had proposed a tentative plan for establishing the base. The first of the base-preparation missions—implicitly, Chang'e 6—would check out the geology of its landing site and look for water in a permanently shadowed crater, they wrote in a paper presented to the conference, which was organized by the Committee on Space Research.

Chang'e 7 will survey topography, material composition and space environment at the south pole, says Wu Yanhua. According to the tentative plan described by the CAS officials, it will return lunar rock and soil to Earth for further analysis.

Chang'e 8 will test technology. The mission will be used to determine how to apply 3D printing on the lunar surface and whether lunar soil can be used for creating the base's buildings. The results of this mission will inform an assessment as to whether the base can be established at all.

Li Guoping, the head of systems engineering at the space administration, said in 2018 that China would land on both lunar poles by 2030. That seems to suggest that Chang'e 8 is headed for the north pole, even though program managers would presumably be interested in accumulating knowledge from the south pole—the region targeted by earlier missions.

Considering its unusual mission, the design of the Chang'e 8 spacecraft should be very different than that of its predecessors. It will evidently have no sample-return function, since Li said only three missions would bring back samples, referring to Chang'e 5, 6 and 7.

The base is only at the stage of concept design, says Wu Weiren, chief designer of China's lunar program. Wu Yanhua suggests it could be built in a joint project with the U.S., Russia and other European countries.

According to the paper by the CAS officials from the academy's lunar exploration center, three or four base-preparation missions should be launched in 2021-30. This suggests that the timing of Chang'e 6 has slipped since they wrote and that another mission could be needed after Chang'e 8. No Chang'e 9 mission is described by other officials, however, so it is clear that it has not been been authorized. (In 2013, Chang'e 9 was named as the mission that would take the first astronauts to the Moon.)

Given that the base has only been proposed, the missions for manning it are not yet authorized. However, the Chinese space sector is working on critical technology, notably a kerosene-burning engine generating 480 metric tons (1.06 million lb.) of thrust for the proposed Moon rocket, the Long March 9. As described in 2018, this vast launcher would depart with thrust approaching 6,000 metric tons to propel its mass of more than 4,000 metric tons. Payloads to translunar injection would be only 50 metric tons, about the same as the best results achieved by the smaller U.S. Saturn V

of the Apollo program.

The first Long March 9 flight is intended for around 2030; that would dovetail with the end of the preparatory missions. Officials presumably envisage several Long March 9 demonstration shots before committing the launcher and the Communist Party's reputation to a high-profile manned mission to execute lunar exploration—which would therefore occur well into the 2030s.

But exactly what launcher will deliver the crew and what will deliver equipment is not clear—and it may depend on progress with technology for making building materials on the Moon rather than transporting them there. But it seems certain that the Chinese are thinking of more than dropping a spacecraft and two astronauts on the Moon for a short-duration visit of the type done in the Apollo program.

Conceivably, the maximum version of the Long March 9, with a 50-metric-ton translunar payload, could deliver fabrication equipment and some building structures. But a smaller version of the launcher has also been mentioned and could be sufficient, especially if a succession of launches were used. Also, the state enterprise that has been working on the Long March 9, Calt, has proposed a concept for a completely different and smaller launcher for crewed missions. This unnamed rocket would economically use engines and airframe parts from existing launchers. Although not yet authorized for development, it would be capable of throwing 25 metric tons toward the Moon—which looks like enough for a proposed 20-metric-ton lunar spacecraft plus a lander.

Chang'e 5 was originally scheduled to fly in 2017 but later shifted to 2018. In 2017, the launcher it required—the Long March 5—failed on its second flight, delaying the mission (and much else in the space program). The Long March 5 is due to return to service in July 2019, clearing the way for the Chang'e 5 shot at the end of this year.

Chang'e 6 will presumably also use the Long March 5 but, apart from the launcher concept for crewed missions, no bigger Chinese rocket is in development or even proposed for service before 2030. So Chang'e 7 and 8 launch masses are unlikely to be much greater than the 8.2 metric tons of Chang'e 5.

The Chang'e 5 spacecraft will consist of four main parts, similar to the Apollo configuration. It will include a lander that will descend with an ascent module and an orbital module and reentry capsule that will stay above the Moon. After the samples are collected, the ascent module will return to the orbiting assembly and transfer the soil and rocks to the reentry capsule, the only part that will come back to Earth.

Chang'e 5 is designed to collect about 2 kg (4.4 lb.) from the Moon's crust, according to Kedo, an agency for the promotion of science.

China Lunar Exploration Program

Phase	Mission	Launch Year	Destination	Key Objectives	Configuration	Launch Mass kg (lb.)	Launcher
1	**Chang'e 1**	2007	200-km (120-mi.) orbit	Reaching Moon, 3D imaging	Orbiter	2,350 (5,180)	Long March 3A
	Chang'e 2	2010	100-km (60-mi.) orbit	Reaching Moon, 3D imaging	Orbiter	2,480 (5,470)	Long March 3C
2	**Chang'e 3**	2013	Near side	Landing, rover deployment, soil measurement	Lander, rover	3,780 (8,330)	Long March 3B
	Chang'e 4	2018	Far side	Landing on far side, rover deployment, soil measurement	Lander, rover, relay satellite**	3,780 (8,330)	Long March 3B
3	**Chang'e 5**	2019*	Near side	Sample return	Lander with ascent module; orbiter with reentry capsule	8,200 (18,000)	Long March 5
4	**Chang'e 6**	2023-24*	South pole	Sample return, geological asssessment, search for water	Similar to Chang'e 5****	About 8,200 (18,000)****	Long March 5****
	Chang'e 7	By 2030*	South pole	Sample return, study topography, material and space environment	—	—	—
	Chang'e 8	By 2030*	—	Testing 3D printing, use of soil for construction	—	—	—
	Chang'e 9* **	By 2030 if approved	—	Preparing for manned base	—	—	—

—Unknown or undisclosed. *Planned. **Relay satellite launched separately. ***Mentioned as a possibility in a tentative plan. ****Aviation Week estimate.

Sources: Chinese government agencies and state media, except for Aviation Week estimates

INCHING TOWARD THE MOON

> RUSSIA'S SPACE STATIONCOOPERATION IS IN FLUX

> SUPER-HEAVY ROCKET SCHEDULE LAGS

Russia's crew-transporting Federatsiya is scheduled to fly to low Earth orbit without crew in November 2022, though the date may be pushed back.

RUSSIAN FEDERAL SPACE AGENCY

Anatoly Zak Newark, New Jersey

Half a century after the first Apollo Moon landing, Russia still has a dream: to put its own cosmonauts on the Moon.

But the ambitious goal is farther away from reality than it was in the Soviet Union on the day Neil Armstrong and Buzz Aldrin left their footprints on the lunar surface.

Ever since the Russian economy emerged from the post-Soviet crisis of the 1990s, Russia's space strategists pushed hard for making a visit to the Moon the national goal.

However, development of key components needed for reaching the Moon was hampered by economic problems in Russia and the failings of its space industry. Last year, after several lengthy delays, the Roscosmos State Corp. began development of the Yenisei super-heavy launcher with a payload of around 100 tons. Like its U.S. equivalent, NASA's Space Launch System (SLS), the Yenisei was conceived to carry crew vehicles, lunar landers and components of the lunar base to the Moon's vicinity. However, unlike the SLS, the Yenisei is barely on the drawing board. Officially, the first launch is scheduled for 2028, but that date seems wildly unrealistic.

Behind the scenes, Roscosmos and the Russian Academy of Sciences (RAN) are working on the detailed lunar exploration plan, but its completion is not expected before October, a Russian space industry source says.

Roscosmos also recently directed the formation of the new working group of experts under the auspices of TsNIIMash, the leading certification center at the space agency, which spent decades drafting the nation's space plans. However, even that formal step is behind schedule, an industry source says.

Most important, to go forward with development of the super-rocket, Roscosmos needs a super-budget in the range of $22 billion from now until 2030. Because the existing 10-year federal space program only covers 2016-25, its structure was found to be ill-suited to absorbing the oversized line item. Instead, the Kremlin authorized formation of a separate program dedicated to the super-heavy rocket. However, its approval process, originally planned to start as early as January, quickly became bogged down as more and more items were squeezed under its umbrella, including robotic lunar probes and the Sfera satellite communications project, which is practically unrelated to lunar exploration.

"[It] was proposed to 'pack' all the work, including new developments associated with the Moon, super-heavy [rocket] and the Sfera into a single state program [dubbed] Space Activity of Russia until 2030," said Yuri Koptev, chairman of the scientific and technical council at Roscosmos, in a June 14 interview with the official TASS news agency.

He promised to submit the proposals for the new program by Aug. 1, as mandated by the Kremlin's security council. At the same time, Koptev explained the final revision of the document, suitable for consideration by the government, would not be ready until year-end.

This is a major caveat, because the government appears to be having either second thoughts about lunar ambitions or to have been influenced by skeptics when it comes to big, expensive space projects. The opposition manifested itself several times recently in public statements by Prime Minister Dmitry Medvedev. Although avoiding a direct collision with the lunar doctrine, reportedly endorsed by President Vladimir Putin, Medvedev aimed criticism at Roscosmos.

At the ministerial meeting dedicated to space policy on Jan. 23, Medvedev was quoted as saying: "Stop empty talk about where we are going to fly in 2030. We need to work, talk less and act more, [and] actively deal with commercialization of our space industry and increasing the Russian share on the international market."

Then in February, Medvedev's cabinet rejected the first draft of the super-rocket budget and sent it back to Roscosmos for revisions, an industry source tells Aviation Week. So the wrangling continues.

At the press conference in Moscow on June 27, RAN President Aleksandr Sergeev said the project for lunar exploration (probably meaning the super-heavy rocket budget) and its road map had been under consideration by the government. "This program has to be built in a such a way that at least, in some respects, we could maintain our leadership in the world," Sergeev was quoted as saying by TASS.

Although internal Russian doctrine decreed the development of an independent lunar exploration program by Russia with the full complement of rockets and spacecraft, Roscosmos did explore cooperating with its traditional partners in the International Space Station (ISS): NASA and the European Space Agency (ESA).

However, here progress has been slow and uneven, too. After committing to supply a single airlock module to the U.S.-led Gateway cislunar station, Roscosmos officials after September 2018 stopped attending regular meetings of the working groups, which included engineers and officials from the U.S., ESA, Canada and Japan.

Roscosmos Director General Dmitry Rogozin has criticized NASA for its constant "jactation" between the Moon and Mars.

Behind the scenes, Russian officials made repeated overtures to China, trying to forge a joint program in practically every potential field of human spaceflight, including the ISS, the super-heavy rocket and lunar exploration. In June, Rogozin said he had proposed joint construction of a lunar base. Rogozin also discussed with the Chinese cooperation on the super-heavy launcher program.

Attempts to approach China have not produced any definitive agreement, industry insiders say.

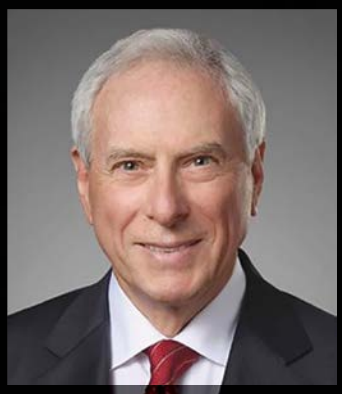
Besides money and politics, the Russian space program faces technical problems. The new-generation transport ship, known as Federatsiya, which was designed to carry crews to lunar orbit, has been on the drawing board since 2009, but its first components started appearing in metal only last year. The program zig-zagged through changes and simplifications, and its first prototype now is officially scheduled to fly without crew in low Earth orbit in November 2022, seven years behind the original schedule. Sources familiar with the matter say even this date is under tremendous pressure to be delayed, along with the follow-on missions to the ISS—the first without crew in 2023 and the first piloted flight in 2024.

On the Centennial of Apollo 11

In his new book, NASA historian Roger Launius writes that in another 50 years, Apollo may be celebrated as something wonderful that had no lasting impact. Noted historian Arthur M. Schlesinger, Jr. struck a far different chord in 1999, when he said Moon landings were the most important event of the 20th century. What does the future hold? In the following pages, our guest columnists share their views.


Tory Bruno

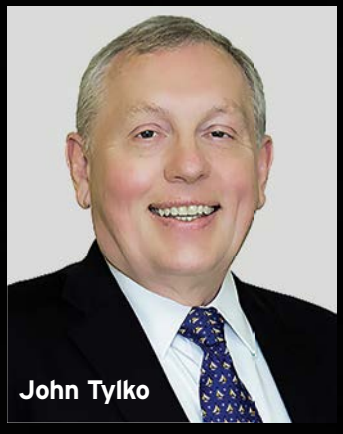

Ellen Stofan


Daniel S. Goldin


Frank Morring, Jr.


Mark Sirangelo


Lance Bush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Preparing FOR Life Among THE Stars

By **Daniel S. Goldin**

I stand in awe of the Apollo team as the world celebrates the 50th anniversary of the Apollo 11 mission. Fifty years later, we are finally preparing to leave our home planet again and open Earth's nearby neighborhood to human exploration and, hopefully, significant commercial, societal and scientific opportunities.

As we take these next steps into the vastness of space, we must pursue a number of challenging developments to assure crew safety and mission success. Such developments must be aggressively undertaken along with the pursuit of heavy-lift launch systems.

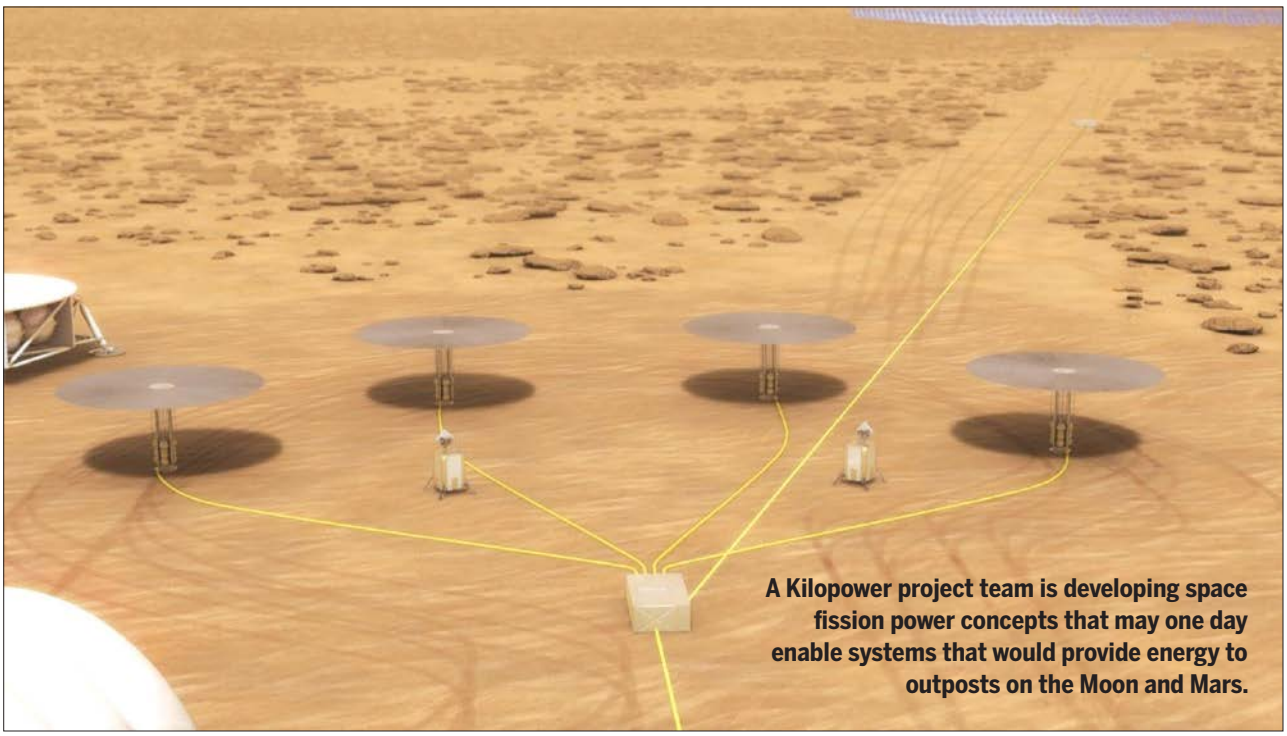
These developments might include procedures to assure the long-term health of astronauts exposed to hostile environments such as processes and equipment to generate nutritious food, ensure habitable atmospheres, maintain proper hygiene and generate rocket propellants for planetary surface escape. Other advancements might include high specific and total impulse propulsion to minimize interplanetary orbit-to-orbit transit time and radiation exposure; compact megawatt-class power systems; and techniques for prospecting, extracting, refining and product finishing of planetary resources. As these tasks are accomplished, we should have a responsible planetary protection system in place.

The tasks are formidable but no more so than those required by the Apollo program. Start with the Moon, as the president has proposed, because it is operationally desirable to begin this journey. Travel time back to Earth from the Moon is only a few days, water seems readily available at the lunar south pole, and there are locations offering the promise of natural resource extraction for use by the crew. The principle objective we should set to assure a strong system architecture for future space exploration is to have a goal of minimizing connection with the Earth and utilizing the resources found initially in our near-Earth neighborhood and then as far as our minds and capacities can take us.

Based on observations from approximately 80 interplanetary probes and five Apollo missions, it appears there is an abundance of natural resources on near-Earth bodies with a potential to support long-term human habitation and robust commercial activities. Carbonaceous C-Type asteroids are estimated to contain about 600 million km^3 (144 million $mi.^3$) of water, a little less than half that of Earth, and copious amounts of carbon.

Mars has large quantities of water ice at its south pole and, about a mile below the ice cap, what appears to be a liquid water lake. Frozen water ice has also been observed on Mars' surface. Robotic orbiters on our Moon have identified frozen ice in the craters of its south pole. Siliceous and metallic near-Earth asteroids contain vast quantities of iron, nickel, platinum, gold, silver and high-tech industry materials such as rare-earths, osmium, iridium, palladium, rhodium and ruthenium. Just one of the 1,000 near-Earth asteroids of about 1 km in diameter is estimated to contain 7,500 tons of platinum in addition to rare-earth materials required for high-tech manufacturing. The Moon and Mars have large impact craters from the same types of asteroids carrying high-value resources.

The question for us earthlings is: Do we have the vision, technology and tenacity to build commercial operations to use these natural resources in our



NASA CONCEPT

A Kilopower project team is developing space fission power concepts that may one day enable systems that would provide energy to outposts on the Moon and Mars.

neighborhood, or are we living in a field of dreams?

Availability of compact, safe, efficient, lightweight, megawatt-class nuclear power technology will be crucial to enable highly productive, long-term human exploration. This technology will help establish an economically productive permanent human presence in space. Although the early exploratory missions to the Moon will be very well served by the Kilowatt Fission System, the tens of kilowatts produced will be inadequate for the important and highly aggressive missions to come.

Most important, megawatt power levels will enable the start of natural resource exploration and exploitation, essential in building strong resource companies and assuring a permanent human presence in our Solar System. Megawatt power levels will allow faster surface transportation vehicles capable of carrying heavier loads as well as more robust and safer habitation and laboratories for improved productivity. Megawatt power levels could make economical the heavy-duty additive manufacturing of large objects such as extraction tools.

There would be adequate power for a team of robots to perform time-consuming maintenance tasks presently demanding one-third of the astronauts' time on the International Space Station (ISS), and it could also make available real-time high-bandwidth streaming of scientific findings to a world hungry to share the journey. Technologies like the high-temperature gas-cooled reactor are ready for development.

Although the space biomedical community has performed meritoriously in protecting the health and lives of hundreds of astronauts on ISS, state-of-the-art health countermeasures appear to be insufficient to prevent the development of clinical and physiological problems when long-term missions will be conducted beyond planet Earth.

Present technology may not be adequate to protect crews from the combined environmental stresses caused by energetic space radiation, low levels of gravity, close and confined quarters and chronic disease on an expedition that does not return to Earth for years. Although there are limited physical and chemical means to minimize some of these environmental stresses—such as fast interplanetary trajectories, body-fitting suits made of radiation-shielding and smart materials and perhaps living underground on a planetary body to avoid surface radiation and extreme climate conditions—they will probably not be effective enough.

To provide the best care for the astronauts, the highly creative biology community is becoming an important resource to spaceflight. Gene editing and synthetic biology will hopefully be able to build human resistance to space-induced environmental stresses and to prevent viral and bacterial outbreaks without the need to contact Earth. It may be possible to use new biological tools to assure microalgae can be relied on to provide food production, oxygen and waste management.

George Church, a Harvard geneticist and leading synthetic biologist, was recently quoted in *Wired* magazine as saying: "One likely path for risk reduction in space does seem to involve biological engineering of adult, would-be astronauts." He went on to say: "Quite a bit is already known about resistance to radiation, osteoporosis, cancer and senescence in mice."

There are ethical issues that must be understood, but given the possibility to protect life, modern biology should be given a very close look.

I started my career at NASA Glenn Research Center in Cleveland, Ohio, when America was highly confident about its future. At the time, we knew no limits to the capacity of the human mind to overcome the most difficult challenges. During the buildup of the Apollo program, under the brilliant leadership of Abe Silverstein, director of what was then NASA Lewis Research Center, we were developing megawatt-class fission reactors to power either ion or plasma thrusters to propel interplanetary spacecraft on exceptionally high-speed missions. The effort died with the downsizing of NASA in the late 1960s due to the economic pressures of the Vietnam War.

Today, a new generation is leading the charge to open our Solar System to human exploration. I have had the privilege to interact with many of these exciting new leaders, engineers and scientists. The newly forming commercial space industry, built on significant private investment, is providing thought leadership and high energy to help define new directions for America's space program. Its partnerships with the U.S. government and established space industry should accelerate progress and bring more focus and stability. I am once again comfortable that in my lifetime we will finally leave Earth orbit and open the space frontier for economic opportunity, democracy and new possibilities for all who are willing to venture forth into the unknown ocean of space. What a time to be alive. *Ad Astra*.

NASA

NASA's Glenn Research Center, Marshall Space Flight Center and the Los Alamos National Laboratory have conducted tests on a prototype fission reactor core.

Daniel S. Goldin served as the NASA administrator from 1992 to 2001, longer than any other person who has held the office.

Apollo's Legacy

By **Tory Bruno**

Fifty years ago, Neil Armstrong became the first person to set foot on the Moon. That night—July 20, 1969—Walter Cronkite came on air to deliver breaking news that would leave generations of Americans awestruck and inspired.

Looking back, it is astounding to consider that then-President John F. Kennedy spoke in 1962 about a plan to put an American on the Moon, less than a generation from the Wright brothers' first tentative and brief venture into flight. It was a bold statement, and yet that vision became a reality by the end of the decade. With a prescient vision of the future, Kennedy knew space would be an important frontier for America and that the nation must be able to rise to the occasion.

As Kennedy stated in his address at Rice Stadium: "The vows of this nation can only be fulfilled if we in this nation are first and therefore we intend to be first. In short, our leadership in science and in industry, our hopes for peace and security, our obligations to ourselves as well as others, all require us to make this effort, to solve these mysteries, to solve them for the good of all men, and to become the world's leading space-faring nation."

Americans had a new mission, and I knew I wanted to be a part of it. When I was a young boy, I realized space and all of its untapped mysteries were actually within reach. From that moment on, I knew my purpose was outside our atmosphere in order to advance and protect those within it.

I was part of a generation that would be inspired to enter the fields of science, technology, engineering and math. And our generation used innovations that started in space to change everyday life. For example, the CT scan has revolutionized medical diagnostics, but the technology was first used to find imperfections in space components. Home insulation now uses reflective materials originally designed to protect spacecraft from radiation. Our glasses are now 10 times more scratch resistant thanks to the visor coating developed for astronauts' helmets. The list goes on.

Stemming from that pivotal moment, my interest in science and engineering compelled me to begin experimenting with rockets in my own backyard. My passion for these would ultimately grow, and my training as a rocket scientist has allowed me to develop ballistic missile defense systems and many other rockets. And now, my team at United Launch Alliance (ULA) is working to lead the country's charge back to space.

Like Spirit and Opportunity, NASA's Curiosity rover, which launched on an Atlas V rocket, is helping the U.S. explore Mars.

ULA

At ULA, we have more than 100 years of combined Atlas and Delta launch history behind our boosters, with a proud 100% mission success rate. Our rocket families have been the backbone of U.S. exploratory and defense missions, launching NASA's Spirit and Opportunity Rovers, the Mars Phoenix Lander and critical GPS satellites— to name just a few.

With the renewed focus from President Donald Trump's administration on space exploration and defense, we are proud to bring our long-standing heritage of engineering excellence into the future as we craft America's next ride to space. The Vulcan Centaur will provide the launch reliability ULA is known for, partnered with innovative technologies in materials, design and manufacturing. Most important, we are helping a new wave of astronauts return to space on American rockets.

But our sights are set beyond returning Americans to the Moon, as my much younger self once thought. We now know that there is a wealth of resources in cislunar space. Two trillion kilograms of industrial and precious metals lie outside our atmosphere but conceivably within our reach. If harnessed, materials such as aluminum, titanium, iron, nickel, platinum and many more can provide the resources for roughly 1,000 years of Earth's total production. These resources will pave the way to improve life here on Earth, extend our presence to Mars, and eventually carry us to a post-scarcity human future.

Fifty years after man first landed on the Moon, we are once again at a critical juncture. Charged with challenges to meet greater goals by the Trump administration, and driven by our own needs here on Earth, we at ULA continue to press forward toward the future of space.

As we combine technology, innovation, expertise, ingenuity and a commitment to achieve new heights, we are excited about the next generation that has been inspired by the nation's new commitment to space. We stand on the threshold of a new era in space. Let us take the first step together, toward this bright new future.

Tory Bruno is the president and CEO of United Launch Alliance.

Earning the U.S. a Place in History

By Mark N. Sirangelo

NASA

NASA

This month we celebrate the 50 years since a U.S. astronaut made the famous first footprint on the Moon and 47 years since our last footprint there. The time has come to again expand the human experience to another world.

I have been fortunate to lead teams that took part in missions to planets, asteroids, the Sun and, of course, the Moon. I often am asked about the spacecraft and hardware that my teams have built. It is easy to talk about those things. But I want to put technology aside and discuss the why.

Why the Moon? Why now? Why America?

Our space program has sparked countless dreams. Just as the Apollo Moon missions motivated previous generations, we are positioned to inspire new minds with feats of science and exploration. Exploration is in humankind's DNA—the desire to discover and inhabit distant places, whether across and under our oceans or into the vastness of space. It is critical to the psychological and physical continuation of our species. It fuels our souls.

Genuine progress toward advancing human exploration will show young people around the world the power of dreaming big. Together, we will create an unparalleled example of how humankind can achieve an uncommon goal for the common good. The next generations watching may not apply the power of this lesson to space, but they will take it into their careers and change the world when they do. It has happened before. The true legacy of Apollo lay not in the Moon rocks but in its ability to motivate millions of people to pursue discoveries that have improved all aspects of our lives.

Generations past moved our society to another level through the industrial, transportation and technology revolutions, all of which helped make the U.S. the global leader it is today. The next great revolution will happen in space. We are on the precipice of a true space economy that will power and empower all generations as it creates new jobs and industries. Our decisions today either will propel us to the lead or make us miss this revolution.

There is more to life than tangible assets. Reflect on those in our military who have given their lives for us and those who continue to stand watch. If you ask these service members why they risk their lives, they likely will say it is to protect their country, families and homes—and the American way of life. A core part of it is to have both the opportunity to dream the impossible and the freedom to make dreams come true. I know. I had this chance, and it led me to the realization of a boyhood dream to touch the stars.

The true legacy of Apollo lay in its ability to motivate millions of people to pursue discoveries that have improved all aspects of our lives.

Even now, 50 years later, people around the world point to Apollo as one of the most recognized and respected of all American achievements. It is now time we honor all those who built the U.S. space program and the memory of those who sacrificed for our country by earning our own places in history. The best way to do this is to add our own high-definition record of humankind's first true effort to live in another world to the pictures and gritty videos of the 1960s' effort, to be watched anew in another 50 years with the same pride we feel for Apollo this July 20.

The world is sending the U.S. a harsh competitive wake-up call on the state of our space program. We need to respond with inspired, selfless leadership, tough change where needed and purposeful risk when justified. We cannot respond with business as usual. No major achievement happens without sacrifice, but America has been willing to sacrifice for the right cause and always has produced its finest achievements under pressure.

Space exploration is not a NASA domain alone nor that of any one political administration. It is a legacy attributed to all Americans. Therefore, we must offer our best and ask the support of all of the U.S. to help us return Americans to exploring our Solar System. By doing so, this era may be defined as one of memorable leadership and vision worthy of an Apollo comparison.

Our newsfeeds bombard us with stories of society being emotionally and divisively debated. The U.S. today, more than ever, needs something positive to unite behind. As in 1969 and throughout the nation's history, a great exploration effort can provide that experience. We owe it to those before who sacrificed, and to our future generations, to accept the challenge and show we are worthy of the gifts that we have received.

Mark Sirangelo, scholar-in-residence at the University of Colorado, serves on the U.S. Defense secretary's Defense Innovation Board and is chairman of the Center for Space Entrepreneurship. He previously was special assistant to the NASA administrator and executive vice president of Sierra Nevada Corp.'s Space Systems.

Lessons From Engineering Apollo

By **John Tylko**

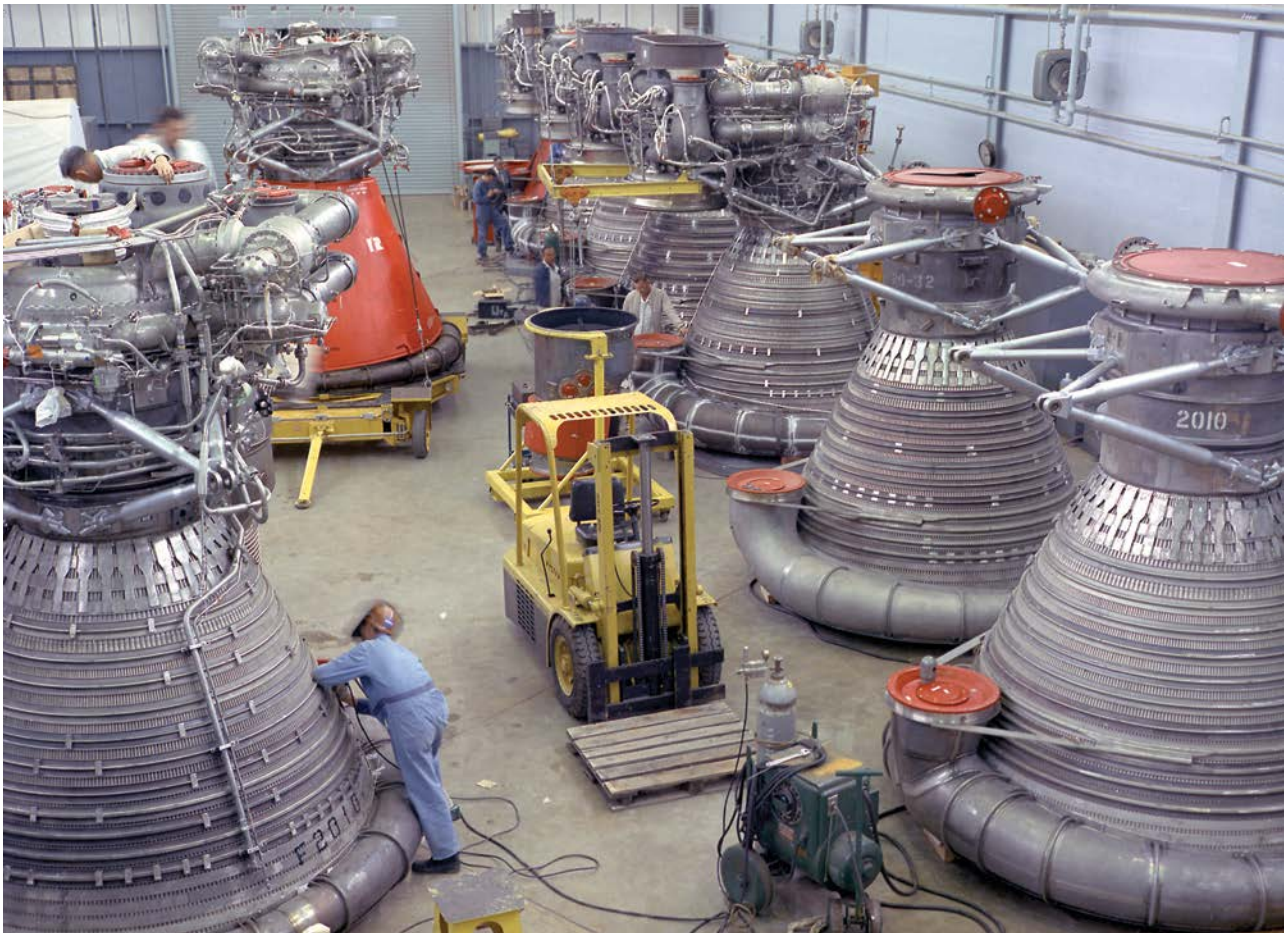
Apollo's 50th anniversary presents an opportunity to reflect on the tremendous technological challenges required to get to the Moon and to celebrate the engineers who overcame them.

Apollo required bold engineering decisions. When Eldon Hall was faced with the challenge of building Apollo's guidance computer, he recommended using newly developed integrated circuits from startup company Fairchild Semiconductor for the computer's logic. NASA concurred in late 1962, leading an effort to assure the new technology could meet Apollo's ambitious reliability goals. Not a single guidance computer failed during the entire Apollo flight program, proving that integrated circuits were indeed reliable for a wide range of applications. When Gordon Moore published Moore's Law in 1965, he relied on three years of integrated-circuit production data used primarily for the Apollo and Minuteman programs.

Engineers at North American Aviation developed a special technique to overcome combustion instability on the Saturn F-1 engine.

Engineering excellence often required elegance to reduce the complexity of Apollo's many systems and subsystems. After reviewing a complex thermal management system that had been proposed to cool the Apollo spacecraft, program manager Joe Shea suggested an alternative—passive thermal control—to rotate the spacecraft slowly to mitigate the effects of solar heating during the lunar voyage, eliminating cost, weight and complexity.

Apollo required ingenuity to overcome insurmountable challenges. When serious combustion instability problems plagued development of the Saturn F-1 engine, engineers at North American Aviation's Rocketdyne division developed a technique using explosive detonation of small "bombs" inside the rocket chamber to evaluate how the combustion process responded to pressure instabilities while the engine was test-fired. This technique allowed the propulsion engineers to evaluate sever-



NASA MARSHALL SPACE FLIGHT CENTER

al coaxial fuel-injector designs, refining them to overcome the challenging combustion instability problem.

At the Massachusetts Institute of Technology (MIT) Instrumentation Laboratory, innovative engineers including George Cherry and Bill Widnall applied Russian mathematician Lev Pontryagin's recently published maximum principle to design the lunar module digital autopilot. Yes, the Russians really did help us get to the Moon!

Don Fraser's initial design of a digital control algorithm for the spacecraft's thrust-vector control system led to the decision to use the Apollo guidance computer to perform the inner flight-control loops, eliminating most of the bulky analog flight control hardware of an earlier design.

Taking MIT's first class on optimal control theory during the fall of 1964, these engineers were the first to apply modern control theory to any flight vehicle. After Apollo's success with this technology, this team utilized an Apollo guidance computer to control an aircraft in the first demonstration of digital fly-by-wire at the then-NASA Dryden Flight Research Center in the early 1970s.

As Apollo 11 astronaut Michael Collins wrote, simulation was "the heart and soul of the NASA system." Real-time flight simulation enabled by analog, hybrid and digital computing was used across the industry as an engineering tool to develop and validate Apollo's complex systems. A team of engineers at Link Aviation developed realistic mission simulators using arrays of computers and optical display technologies to replicate every detail of the spacecraft faithfully in order to train the Apollo astronauts. When integrated with Mission Control, these simulations realistically could be used to train not only the flight crews but also the flight controllers, flight directors and mission support teams, to solve a wide range of complex malfunctions in real time.

Apollo's engineers lacked personal computers. E-mail had not been invented. Slide rules, spirules, Frieden calculators and typewriters were the norm. To speed up communication at NASA's Mission Control Center, a 2-mi.-long pneumatic-tube system was used to transfer time-sensitive documents to and from the adjacent mission support rooms. Yet the same building also housed the Real-Time Computer Complex, an array of newly developed IBM System 360 mainframe computers, to plan and validate Apollo's trajectory to the Moon. In many ways, Apollo creatively mixed state-of-the-art technology with time-proven mechanical methods.

Achieving Apollo's success required a strong leadership team—primarily engineers who had become managers—who not only conceived of a rapid program to get to the Moon but established the confidence of equally ambitious political leaders toward achieving a common goal. Headquartered at the Dolley Madison House just a block from the White House, NASA's leadership team responded quickly when the political opportunity presented itself in the spring of 1961. In an effort to reboot his presidency after the failed Bay of Pigs invasion and the Soviet Union's launch of cosmonaut Yuri Gagarin, President John F. Kennedy leveraged a willing team of NASA engineers who rapidly committed to win the geopolitical space race of the 1960s by beating the Soviets to the Moon.

Yes, the Russians really did help us get to the Moon!

Kennedy's succinct goal—landing a man on the Moon and returning him safely to Earth within the decade—required a massive mobilization that echoed the effort to prepare for World War II two decades earlier. James Webb's masterful political skills were necessary to drive a tenfold increase in NASA's budget within just five years. To win the support of the influential chairman of the House Appropriations subcommittee responsible for NASA's budget, Webb made a pivotal decision to locate the Manned Spacecraft Center in Albert Thomas' congressional district near Houston.

Selecting lunar-orbit rendezvous as the architecture for Apollo was another bold step, enabling the lunar landing to be achieved with a single Saturn V launch vehicle. NASA Langley Research Center engineer John Houbolt relentlessly championed this radical concept, putting his career at risk and bypassing several layers of management to get the attention of NASA Deputy Administrator Robert Seamans. Houbolt's perseverance prevailed, and the lunar-orbit rendezvous decision, coupled with the bold decision to do "all-up" testing of the three stages of the Saturn V in a single launch, enabled achievement of Apollo's ambitious deadline.

Agility extended to the acquisition process. NASA's first major contract to MIT for the Apollo guidance computer was a sole-source award made just 10 weeks after the lunar landing decision. Four months after the lunar-orbit rendezvous choice was announced, NASA competitively selected Grumman to build the lunar module. Rapid contracting proved essential to achieving Kennedy's goal.

One of NASA's biggest challenges was managing the three distinct cultures within the Apollo program: the Space Task Group under Bob Gilruth, which became the Manned Spacecraft Center in Houston; the German rocket team under Wernher Von Braun and Kurt Debus, which became the Marshall Space Flight Center in Huntsville, Alabama, and the Cape Canaveral Missile Test Annex in Florida (renamed the Kennedy Space Center); and the systems engineering team with ballistic-missile development experience under the leadership of George Mueller and Sam Phillips. NASA functioned as the systems integrator, managing a complex industrial enterprise extending to hundreds of companies across the nation.

Apollo's success demonstrated America's excellence in science, technology and engineering. But perhaps Apollo's greatest legacy is the inspiration it provided for an entire generation of engineers and scientists, myself included, to pursue careers in technological fields. Apollo captured our imagination. Today's aerospace engineering enterprises, from startups to aerospace giants, are led by engineers who were motivated by the audacious accomplishments of the Apollo engineers who overcame the seemingly impossible challenge of landing a man on the Moon.

John Tylko is the chief innovation officer at Aurora Flight Sciences, a Boeing company, and teaches "Engineering Apollo" at MIT.

Why Space Exploration Is Worth the Effort

By **Ellen Stofan**

The buildup was long. The pressure was intense. The risk was extreme. The accomplishment was breathtaking. Yet the public enthusiasm that followed humanity's highest achievement—landing on the Moon—was almost as remarkable for how rapidly it faded away as it was for how it inspired a generation of future innovators and explorers.

Just four months after U.S. astronauts Neil Armstrong and Buzz Aldrin set foot on the Moon, *The New York Times* reported that Apollo 12 seemed anticlimactic and that the unenthusiastic response was "perhaps predictable considering the intense national emotion spent on the first Moon landing." In a nation governed by "we the people," political will all too quickly followed that drop in public engagement. From a peak in 1966, NASA funding dropped by two-thirds in constant dollars over the next decade.

I had a front-row seat to the cutbacks as they unfolded in the middle of my father's 30-year NASA career. He witnessed the layoffs, the scaling back of projects, the unending postponement of getting to Mars. But through it all, with robotic probes such as Viking and Voyager and missions such as Apollo-Soyuz and Skylab, NASA kept the fire of exploration smoldering.

The space shuttle's first flight brought back a taste of the Apollo excitement, but it, too, faded into routine. Working at NASA during the shuttle era, I saw the peaks and valleys of public interest and how they led to the budgets that bounced around a narrow range for about three decades. The amounts have been insufficient for the bold human exploration that can be our next giant leap, with Mars as the goal.

So how do we get the public to back this effort as it did Apollo under the Soviet threat? It is a problem that needs to be addressed with the kind of teamwork that made Apollo possible. NASA, and increasingly private companies, still can thrill the public with everything from rovers exploring Mars to the images sent back from the edge of the Solar System to boosters that land back on Earth for reuse to, soon, launching humans from U.S. soil again. But it is important to remember that it was the leadership of President John F. Kennedy that literally called for the public to back "the most hazardous and dangerous and greatest adventure."

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President Kennedy called on the U.S. to undertake "the most hazardous and dangerous and greatest adventure."

JFK supported that call with dollars. Bipartisan support sustained it until we got there. Despite coming in second to the Soviets in reaching space, orbiting Earth and taking a spacewalk, U.S. leadership remained steadfast. That determination ultimately brought success.

I also feel a personal responsibility, as do all my colleagues at the National Air and Space Museum, to play my part in moving humanity along our space exploration journey. We have the opportunity to bring to life and share the exciting stories of these truly marvelous achievements with post-Apollo and now post-shuttle generations.

Robert Goddard once said, "Every vision is a joke until the first [person] accomplishes it: Once realized, it becomes commonplace." So we know that we must always refresh how we tell the stories of the miraculous history of aviation and spaceflight.

That is at the heart of our planning for new space galleries as we completely renovate the museum on the National Mall. As stewards of the nation's space history, we must adopt new technologies and techniques to inspire the girl who will grow up to be the first person to set foot on Mars.

Reaching the red planet, after first returning to the Moon, will require that inspiration. To reach that goal, leaders in government and industry must explain the value and importance of pushing boundaries. We can and must help the public understand the benefit that exploration brings to all of us back on Earth. And it is possible. I see the excitement in the reactions of audiences and the questions they ask whenever I talk about Mars and the potential for finding signs of life there.

Like the first person who set out on a voyage of exploration, we have taken on these expeditions, as JFK said, "not because they are easy, but because they are hard." Central to our hard work at the museum, in industry and among government leaders is making sure the public always understands the wondrous discoveries that will make it worth the effort.

Ellen Stofan is the John and Adrienne Mars director of the Smithsonian Institution's National Air and Space Museum.

The Future OF Space Exploration

By **Lance Bush**

Apollo inspired generations, including people who are now the explorers working to take us back to the Moon, on to Mars and beyond. They are designing vehicles, planning for challenges and charting major milestones. Their work is taking space exploration to new heights. But who will actually put new footprints on the Moon and take the first step on Mars? Who will take us beyond that goal? Who is responsible for the future of space exploration?

Over the last 30 years, more than 5 million students have participated in the Challenger Center's virtual space missions.

Students. Today's students are that future—and it is our job to inspire them and help them see themselves as those leaders.

At the Challenger Center, we inspire more than 250,000 students from around the globe every year. They are transported to space when they come to our centers. They become science, technology, engineering, and math (STEM) professionals leading futuristic missions. During one simulation called Expedition Mars, we set the stage by telling the students a handful of facilities are established on Mars and that a shuttle ferries them between a base on the moon Phobos and the Martian surface. To these students, this is not hard to imagine, it is not a dreamworld or something from a storybook. Setting foot on Mars, going back to the Moon and exploring beyond is not just an idea, it is their reality.

Today's students have a "no limits, anything is possible" mindset—the type needed for space exploration. They have an indomitable spirit and are less risk-averse than any previous generation. While adults talk about technology as a thing, students simply experience it as part of their lives. They are digital natives who expect technology to expand and evolve. Students are growing up in a world with experiences that would have been impossible a decade ago—and unimaginable before that. This mindset and adaptability are traits that could transform the space industry in the next 20, 30 or 40 years. It is our role to help equip students with the necessary skills and provide inspirational experiences that lead them down the path to pursue STEM careers.

Complex issues such as space exploration require communication and collaboration skills. Every industry, especially the space industry, needs talented individuals who can work together on a unified goal. But how do we show today's students the importance of these 21st-century skills? How do we prepare them to be collaborative problem solvers? At the Challenger Center, we provide visiting students with an experience that demands those qualities, and without hesitation the students work together to complete tasks and reach their goals. If you put them in a situation where these skills are required, they understand why it is important and witness positive effects as a result.

The Challenger Center has sent more than 5 million students on virtual space missions over the last 30 years. We give students around the world the chance to play a part in reaching a collective goal, to feel the anxiety of the risks, understand the impact of their decisions and enjoy the satisfaction of success.

CHALLENGER CENTER

I know this happens because I've seen it happen. I've watched students arrive uninterested and disengaged, silent and intimidated. When they realize their classmates are counting on them, I see a shift. They work hard to complete their tasks and help their teammates. When the mission is complete, they high-five their teachers before walking out the door with confidence and a can-do attitude. I know these moments happen because I hear from former students who are now young professionals working on incredible programs such as Lockheed Martin's Orion and Blue Origin's Blue Moon.

Space exploration, by virtue of its visionary perspectives and necessarily lengthy project timelines, is one of the few ventures that so heavily relies on the next generation. Knowing this also means understanding how critical it is to have a talented and motivated future workforce.

From volunteering and mentoring to supporting STEM programs, I challenge everyone in the space community to consider how, in your own way, you can inspire the next generation. Today's students have the mindset to transform the future of space exploration into something we cannot even imagine. Let's be role models and work together to inspire them to take on that challenge, just as Apollo inspired us.

Lance Bush is president and CEO of the Challenger Center, a nonprofit formed by the families of the crewmembers who perished when the space shuttle Challenger broke apart.

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Hot Topics on the Agenda!

Industry Scorecard: Key Challenges for UAM in the Urban Environment

Get an ecosystem level assessment of the substantive challenges that must be addressed to get to UAM operations. This session will provide an overall, integrated look at the necessary benchmarks for implementation and a fully-realized UAM ecosystem, including autonomy, noise and airspace scalability.

Industry Forecast

Hear the current status and trends that experts are seeing in the emerging Urban Air Mobility market. What are the enablers moving this market forward and why is it happening now? This session will lay-out a realistic timeline for what the market will look like 5, 10, and 15 years in the future.

The Race Is On: eVTOL Vehicles Take Flight

The world's leading eVTOL flying car and flying taxi manufacturers reveal their unique plans and current vehicle status for the future of flight. With Ehang and Volocopter.

Battery Power & Propulsion Technologies

Hybrid electric propulsion systems and all electric technologies are enabling the emergence of eVTOL vehicles and a new era in aviation. Our panel of industry experts provide an overview of the progress, power and reliability of distributed electric propulsion system designs and what the future holds.

Transforming Mobility: Safety, Regulation, and Certification

The Asia-Pacific region has established itself as a pioneer when it comes to regulatory acceptance and encouragement of urban flight tests for eVTOL vehicles. This session will dive into the regulatory path to market for the region, including potential challenges ahead and opportunities for collaboration between industry and government.

From the Ground Up: UAM Infrastructure Planning and Development

As we try to navigate and understand a new urban environment and the evolving and ever-present role of smart city applications, we discuss what strategies, testing and validation needs to be undertaken to get the buy-in of local officials, airports, businesses, developers and urban planners.

Conference will conclude with a
Networking Reception

Aviation Week's UAM series brings together manufacturers, regulators, technology innovators, disruptors, municipal leaders, and the infrastructure & investment community; all working together to create on-demand aviation for smart cities and a new future for manned and unmanned air transportation.

Hot Topics on the Agenda!

Industry Forecast

In this scene-setting session, engage holistically with the UAM ecosystem, consider the timeline and expectations for this market and what might impact it. What are the key trends and opportunities for stakeholders? As the UAM market continues to evolve, what individuals and organizations will be involved and what can they expect?

Infrastructure and Investment Panel Discussion

Attend this discussion to assess the infrastructure requirements: What collaboration has there been that is driving/facilitating progress and what further support is needed? What can we learn from the cities that have launched UAM projects under the European Smart City Initiative? How do current and new investors develop strategies for this market and understand future demand and requirements?

Battery and Propulsion: Quick Fire Technologies

Regulatory and Certification: Critical Challenges

How can existing barriers be overcome and what regulators are working on making this happen? When we have progressed beyond initial test flights, how do we go about building and beginning to certify electric VTOLs? As the urban air mobility revolution takes place, how do governmental and regulatory bodies support and create a safe and effective framework for manufacturers, stakeholders and the public.

Who are the Players in the Game? Airframers Panel Discussion

Hear the airframers perspective on the outlook for UAM vehicles and how they will differentiate themselves in the market. What are the anticipated integration challenges? What are their plans for market access and how are they increasing public acceptance? Are there ongoing concerns about liability and responsibility and how are they mitigating safety fears?

Deliveries and the Operating Environment

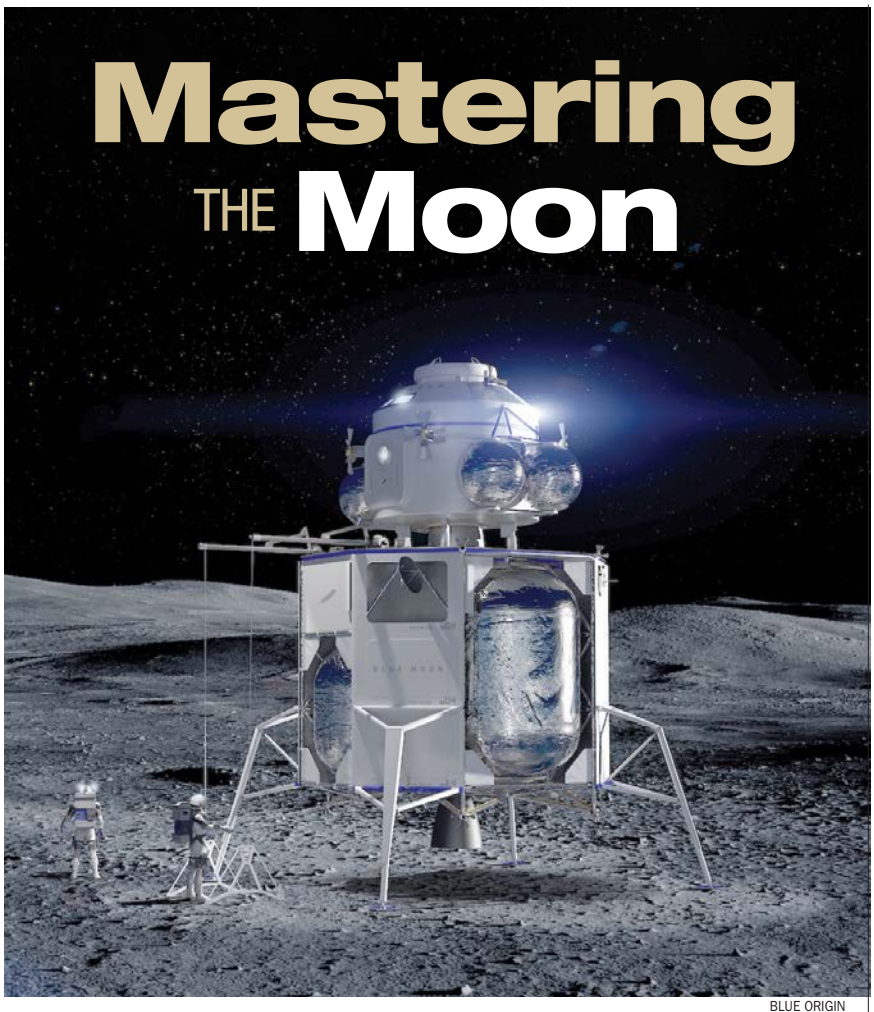
What is the operational environment of the future when we reach mass deployment? What capacity of deliveries of eVTOLs do we expect to see in the next 5, 10 and 20 years? What supply chain will be required for the anticipated production including associated equipment and ground management? How do we expect the vehicles to integrate with the other modes of urban transport and avoid conflicts and congestion?

Reaching Commencement of Operations: What Challenges Must be Overcome?

Considering passenger and public perception: What are the FAQs? Can media support enhance social acceptance? How will eVTOL work around traditional airlines, airports and other competition? Efficiency, congestion, fuel, cost, testing and validation: What issues still need to be addressed? Who are the biggest supporters and who wants a stake in it?

Conference will conclude with a
Networking Reception

Mastering THE Moon



BLUE ORIGIN

By **Frank Morring, Jr.**

After he went to Mars, Andy Weir went to the Moon. The acclaimed science fiction author followed up *The Martian*, a novel of human exploration on the red planet, with a high-concept tale of men and women living and working on Earth's huge natural satellite. It is no coincidence that NASA chose his title—*Artemis*—as the name for its new effort to return humans to the lunar surface 50 years after Apollo 11.

In Greek mythology, Artemis was Apollo's twin sister, a huntress associated with wildlife, the wilderness and the Moon itself. As China, India and a host of private companies target the Moon for exploration and exploitation, the U.S. space agency is pitching a 37-mission effort to put the first woman on the surface by 2024. NASA's bosses in the White House want to plant the American flag on the rim of a deep polar crater at the Moon's south pole, potentially staking a claim to the frozen reservoir of water believed to lie in its permanently shadowed depths.

The concept remains unfunded by the currently dysfunctional U.S. government and probably will not happen—at least not as outlined and certainly not in five years. Like military organizations preparing to fight the last war, NASA's Artemis program is a throwback to the superpower space race of the 1960s. Then, competing teams of U.S. and Soviet engineers enjoyed almost unlimited access to public resources in the hope their side would cross the lunar finish line first.

Soon after Apollo crossed that line 50 years ago, geopolitics forced human explorers to abandon the Moon. The visionary master engineers who spearheaded the human spaceflight competition—Sergei Korolev of the Soviet Union and NASA's Wernher Von Braun—faded into history.

Today, humankind's return to the Moon is likely to require a very different kind of leadership. The job of planting a colony there will be too big for any one nation to develop and fund and too complex for a single master designer to oversee. The evolution of a Moon base will be much more organic, and evolutionary, than a one-off engineering feat on the model of Apollo. Weir's fictional vision is more likely a foreshadowing of what comes next than a rehash of what has been.

In the novel, Artemis is the name given to a 2,000-strong commercial settlement in the Sea of Tranquility. A hypercapitalist outpost of competing interests, in an economy based on mining and space tourism, the colony is located a short, pressurized train ride from the historic Apollo 11 landing site. With a multinational population and a currency valued on the cost of getting a gram of mass from Earth to the lunar surface, Weir's vision owes more to the "Moon Village" proposed in 2016 by Jan Woerner, the director general of the European Space Agency, than to anything Von Braun, Korolev or their colleagues conceived.

Blue Origin's concept of the Blue Moon lunar lander with a crew/ascent module.

Those men—and they were almost all men—considered themselves staunch nationalists, working to advance the interests of their competing nations by demonstrating through peaceful means that they had superior technology for making war. The space-launch technology they developed separately had a common root in Nazi Germany's V-2 rocket, a weapon Adolf Hitler hoped would turn the tide of World War II in his favor. Von Braun, a serial nationalist, led that development, too. The Soviets also used rocket engineers from Germany's development center at Peenemunde, some of them personally recruited by Korolev as the war ended.

The space race was an exercise in what today is called soft power: A nonviolent competition played out before a rapidly changing world. It soon evolved into collaboration, beginning with the "handshake in space" of the Apollo-Soyuz Test Project in 1976. After the Soviet Union collapsed, Russian cosmonauts began flying aboard NASA space shuttles to the old Soviet Mir orbital outpost.

Ultimately, the former opponents, and some of their Cold War partners, collaborated to build the International

Space Station (ISS). NASA astronauts have been riding Russian Soyuz capsules to the ISS on a pay-as-you-go basis since the shuttle was retired in 2011, a victim of its technical complexity.

The way back to the Moon will be shaped by the lessons learned on the ISS, starting with international cooperation among national governments and expanding to include the private space sector. The new crew vehicles NASA is developing with commercial partners owe more to the Soyuz technical approach—separate launchers and landers—than to the winged shuttle. The private owner/operator business arrangements NASA has with Boeing and SpaceX point the way to future lunar operations while holding promise for more efficient launcher reusability than the shuttle ever could provide.

China remains a wild card in this emerging era. The technology it is developing for its orbital and lunar operations follows the same lessons, albeit with much richer resources than the ISS partners are applying today.

Funding continues to be a much more important propellant for space exploration than anything available at the Moon's pole. Developing a permanent lunar colony will cost big money. Significant investment from all sectors, public and private, will be necessary.

It is not yet clear what the return on that investment will be. Lunar ice can be processed into rocket fuel and oxidizer for further exploration, but a pot of gold is elusive. Michael Griffin, the former NASA administrator who oversaw early attempts to bring private investment into the U.S. spaceflight endeavor, calculated in 2011 that there is up-front money to be made in lunar transportation—provided the nations of the world are willing to buy it.

"Development of an international lunar base provides the best near-term option for such a program," he wrote in a paper prepared for the International Astronautical Congress in Cape Town, South Africa. "To be effective, public policymakers must heed the old investment advice—go big or stay home."

SpaceX has made the recovery and reuse of its Falcon 9 orbital launchers seem almost routine. Blue Origin and Virgin Galactic are nearing suborbital adventure-tourism spaceflight with reusable vehicles, and Blue Origin has unveiled a commercial robotic lunar lander that may be powerful enough to accommodate a crew.

Public policymakers are beginning to go big, too. China is operating one of its Chang'e robotic lander/rover combos on the lunar far side, India has an ambitious Chandrayaan lander in the works, and NASA's Artemis has drawn interest from Europe, Japan and other potential international partners.

From Bangalore to Berlin, the engines are running, and the thrust level is rising for a permanent return to the Moon. This time the bird is too much for one nation, and one leader, to fly.

Frank Morring, Jr., was Aviation Week's senior space editor when he retired in 2017. His journalism career spanned more than four decades.

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Candidate materials may be submitted online by applying to requisition #190373 at http://careers.erau.edu.

Any questions should be directed to the University's Associate Provost for Research, Dr. Remzi Seker at sekerr@erau.edu or 386.226.7409.

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Aerospace Calendar

To submit Aerospace Calendar Listings
email: aero.calendar@aviationweek.com

July 25-Oct. 4—RTCA Plenary Sessions. Various locations. See rtca.org/content/upcoming-committee-meetings

July 29-31—International Fighter USA 2019. Sheraton Pentagon City Hotel. Washington. See internationalfighterusa.iqpc.com

July 30—2019 Hypersonics Capabilities Conference. Purdue University. West Lafayette, Indiana. See ndia.org/events/2019/7/30/2019-hypersonics-capabilities-conference

July 30-Aug. 1—IEEE International Conference on Space Mission Challenges for Information Technology. California Institute of Technology. Pasadena, California. See smcit.ecs.baylor.edu

Aug. 3-8—AIAA/USU Conference on Small Satellites. Utah State University. Logan, Utah. See smallsat.org

Aug. 3-Oct. 19—AOPA Flight Instructor Refresher Course. Various locations. See aopa.org/forms/event-calendar/firc_onsite

Aug. 19-22—AIAA Propulsion and Energy Forum. JW Marriott Indianapolis. Indianapolis. See propulsionenergy.aiaa.org

Aug. 20-21—Association for Unmanned Vehicle Systems International Unmanned Systems (AUVSI)—Defense. Protection. Security (USDPS). Marriott Wardman Park. Washington. See auvsi.org/events/unmanned-systems-defense/auvsi-unmanned-systems—defense-protection-security-2019

Aug. 20-22—Counter UAS USA. Sheraton Pentagon City Hotel. Washington. See counteruas.iqpc.com

Aviation Week Network Events

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Aug. 7-8—CAPA Australia Pacific Aviation Summit. Sydney.

Sept. 9-10—CAPA Canada Aviation Summit. Winnipeg, Manitoba.

Sept. 9-10—CAPA Latin America Aviation & LCCs Summit. Curacao.

Sept. 11-12—Aero-Engines Europe. Istanbul.

Sept. 16-18—Aviation Industry Suppliers Conference in Toulouse (ATC). Toulouse.

Sept. 21-24—World Routes 2019. Adelaide, Australia.

Sept. 24-26—MRO Asia-Pacific. Singapore.

Sept. 25—Urban Air Mobility Asia-Pacific. Singapore.

Sept. 25-26—Aero-Engines Asia-Pacific. Singapore.

Oct. 2—Business & General Aviation Conference (BGA). Los Angeles.

Oct. 9-10—CAPA Low-Cost Long-Haul Global Summit. Hamburg.

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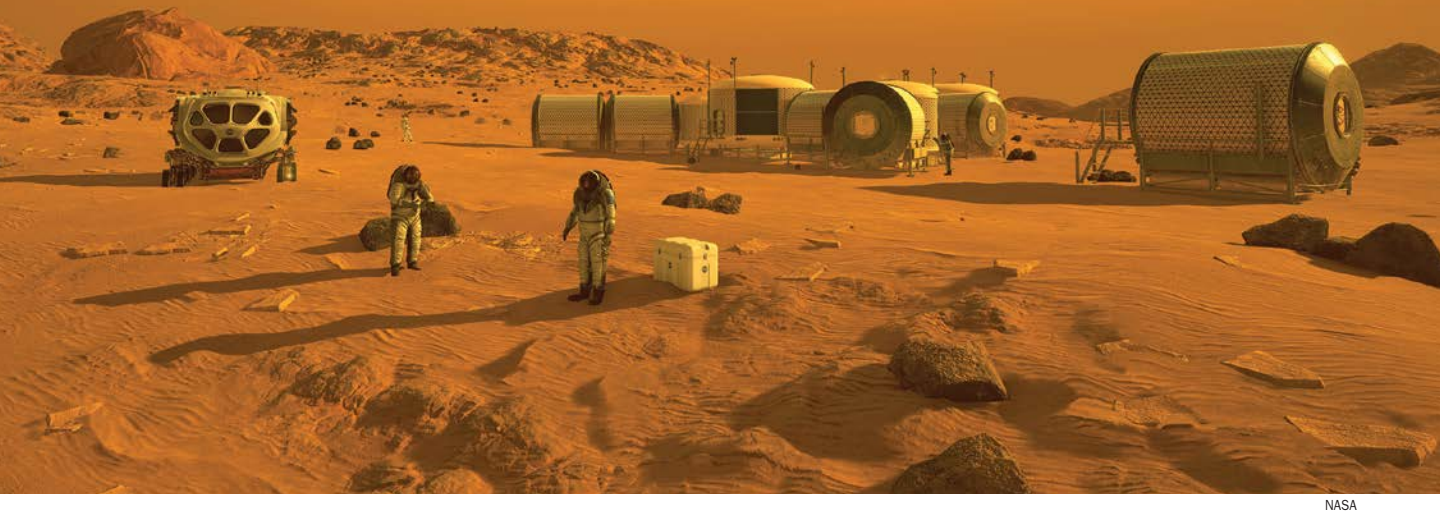
EDITORIAL

The Price of Awe



NASA

Fifty years after Neil Armstrong and Buzz Aldrin stepped onto the Moon, no astronauts are in deep space, and none are expected to travel there until 2022 or 2023 at the earliest. The U.S. is still working to restore its ability to fly astronauts to and from low Earth orbit, let alone set foot on the Moon or Mars. So, half a century after Apollo 11, what is the program's most lasting impact?

For starters, the experience of awe. The achievement of setting foot on the Moon has yet to be equaled by any other human feat to date. It was not just the knowledge that humans could land there, it was also the ability to harness the brainpower of a nation for so singular a purpose. It was a president declaring an audacious goal and his successors completing it. It was multiple bureaucratic agencies devising new technologies in the pursuit of that goal and learning from their mistakes along the way until they flawlessly achieved it.

To do these things, the nation paid heavily. The total lunar effort from 1960 to 1973 cost $28 billion; in today's money, that comes out to $288 billion (see page 27). NASA currently receives about $20 billion a year, approximately half of which it spends on its human spaceflight activities.

The world benefited from that focus on the Moon, not simply from learning about our closest celestial neighbor but also from the technologies it spawned. Al Gross, an Apollo engineer, used Moonboot technologies to improve athletic footwear. The fatal 1967 Apollo 1 fire drove NASA to look for ways to protect crew and develop a fabric that does not burn—the roof of Houston's Reliant Stadium was derived from the material of Apollo spacesuits. Cordless power tools, necessary in the cramped conditions of a space capsule, translated into a godsend for the do-it-yourself home improvement set.

Apollo was not an accomplishment for the U.S. alone. It drew the world together in pursuit of civil space exploration in a way that has continued through decades of cooperation on the International Space Station. It also helped the U.S. meet its strategic aim of beating the Russians to the Moon. That boosted the nation's international credibility so much, according to NASA Administrator Jim Bridenstine, that when the U.S. pursued the Strategic Defense Initiative missile defense concept in the 1980s, Russia had to invest heavily in offsetting that technology. The achievement of Apollo left it no other choice.

NASA points to its 31.8 million Twitter followers and says it still has the right stuff, but it is not the only shining star, nor does it want to be. Elon Musk's launch of his Tesla roadster on the Falcon Heavy's first flight last year may have been a masterful stroke of marketing, but it also delighted a generation of people who were not alive during the Apollo program.

For the children of the Apollo generation and those watching NASA and private industry wrestle with plans for revisiting the Moon, the questions remain: Can we do it again, and why haven't we?

As the golden anniversary of the first Moon landing approached, the Senate Commerce, Science and Transportation Committee queried a panel of experts, including Apollo 11 Flight Director Gene Kranz, on that very topic. Kranz, never one to mince words, said that despite current plans to build a lunar Gateway and land on the Moon as a way to get to Mars, the U.S. lacks vision, unity and leadership.

"There is infinitely more technological capability than in the early programs, but there is a lack of focus and prioritization," Kranz says. "We have to reestablish the passion, the energy, the imagination in our organizations, and this starts right at the top with our leadership.

"We have to reconstitute what our nation stands for and what we expect from our people, for all employees at NASA and the federal government, right on down the line. We have to establish some shared values that we're all working toward."

Without unity, Kranz adds, general support for space activities and the desire to explore will continue, but the space exploration program will be grounded.

Whether Apollo's mantle proves too heavy for the next generation to carry remains to be seen. Fifty years after the first Moon landing, however, it continues to inspire.

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AVIATION WEEK NETWORK

THE FIRST WATCH WORN ON THE MOON

On the 50th anniversary of the first lunar landing, OMEGA is reflecting on the golden moments that defined that iconic day. As a tribute to the occasion OMEGA has produced a timepiece that's truly lunar-inspired: the Speedmaster Apollo 11 in 18K Moonshine™ Gold.
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