JUNE 2018

Aerospace TESTING INTERNATIONAL

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Inside this issue

// Fear of change

There have been a few times recently when I have been reminded of the difficulty of managing change in business and industry. The first was a session on space industry startups at a conference in London. The conference's organizers had packed the session with presentations by several earnest entrepreneurs. Some were developing small satellites; others were developing low-cost rockets, balloons and spaceplanes. The ideas were bold and ambitious.

During the session it was easy to detect a hint of fear, perhaps even derision, from the conference audience toward the new entrants to the market. Innovation was welcome, it seemed, as long as it was on the incumbents' terms.

In contrast, the launch of Rolls-Royce's Pearl 15 engine at the European Business Aviation Conference and Exhibition in Geneva in May (see page 10), was met by all with open arms. The company had successfully kept the Pearl 15's development and testing secret for six years. Commentators applauded the secrecy as much as the technology itself. Rolls-Royce is one of the few companies that can develop an aero-engine on its own, in secret. Nevertheless, shortly after the Pearl 15 reveal the company announced 4,600 job losses.

Wind tunnels arguably play a less important role in aircraft development today, because of the growth in the use of computer simulation. Georg Eitelberg, the recently retired director of DNW, German-Dutch Wind Tunnels, has managed the impact of this change on his organization (see page 56). He still sees a future for wind tunnels in helping to develop new ideas. If you are looking for innovation, it is evident in the flight testing of the flexible wings on Bombardier's Global 6000 business jet (see page 16). To quantify cabin comfort, engineers used 3D laser scanners to measure the movement of the wing, plus accelerometers to measure vibration, then combined the data to quantify how the wing's flexibility would contribute to a smoother ride. It's a fascinating example of how test engineers measure and quantify an aspect of flight that many would be satisfied with just 'knowing' is right.

Elsewhere we look at some really big projects. The examination of the test program for NASA's Space Launch System (see page 24) provides an opportunity to gawk at the massive infrastructure and engineering effort involved in ensuring the world's biggest rocket is mission-ready by June 2020.

The Space Launch System is a project that is taken seriously, and is being run by a single organization that knows that years of testing are needed to launch a manned spacecraft. But that isn't stopping companies backed by individuals, such as Elon Musk's SpaceX, Jeff Bezos's Blue Origin and Richard Branson's Virgin Galactic, from building rockets and spaceplanes.

These individuals are taken seriously because they are powerful and rich. But their endeavors also inspire the small companies entering the space market. A plurality of companies encourages competition, which in turn creates innovation. Perhaps change shouldn't be feared by the industry, but welcomed and supported as the lifeblood of technological advancement.

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WORLD *test update*

// 'FLYING CAR' MADE AVAILABLE FOR TEST FLIGHTS

Kitty Hawk, a company backed by Google co-founder Larry Page, is making its all-electric 'flying car' available for potential buyers to flight test at its facility in Las Vegas, Nevada.

Kitty Hawk's Flyer is a personal aircraft that is widely being called a flying car. It is powered by 10 lithium-ion battery-powered lift-fans, has a top speed limited to 20mph (32km/h), and is designed to be flown without a pilot's license over water and uncongested land areas.

In a major step forward for the project, the first aircraft, which can fly at an altitude of 10ft for up to 20 minutes, can now be pre-ordered and test flights applied for at the website flyer.aero. The first journalist, a reporter from CNN, has also taken a flight in the Flyer.

READ MORE ONLINE

A prototype of the Flyer was tested in New Zealand, where Kitty Hawk is also testing an autonomous, electrically powered vertical take-off and landing aircraft named Cora.

Las Vegas, Nevada

// VSS UNITY SPACEPLANE REACHES NEW HEIGHTS

Virgin Galactic and The Spaceship Company's VSS Unity has successfully achieved supersonic, rocket-powered flight during two tests.

During the second test flight, the spaceplane, which launches from the WhiteKnightTwo carrier aircraft, reached an altitude of 114,500ft and a speed of Mach 1.9.

WATCH THE VIDEO ON OUR WEBSITE

The VSS Unity's return to test flying marks almost four years since the tragic loss of its predecessor VSS Enterprise during a test flight.

The hybrid rocket motor on VSS Unity runs on a nitrous oxide/hydroxyl-terminated polybutadiene compound and was designed, built and tested by The Spaceship Company, which is owned by Richard Branson's Virgin Galactic.

"It was great to see our beautiful spaceship back in the air," said Branson after the successful test.

The test flight follows two years of extensive ground and atmospheric testing. It generated data on flight, motor and vehicle performance, which engineers will review.

Mojave Air and Space Port, California

// G500 CLOSING IN ON FAA TYPE CERTIFICATION

The Gulfstream G500 business jet is close to achieving FAA type certification. The aircraft, which is nearing completion of its function and reliability testing, completed the 300 hours of flight testing required by the FAA for aircraft with new engines after a six-month world tour that ended in June in Paris, France.

The certification tests for flying into known icing and high-elevation conditions have already been completed.

The five G500 test aircraft have accumulated more than 4,955 flight hours over more than 1,355 flights.

Mark Burns, Gulfstream president, said, "The rigor and discipline of our program, which began with lab work years before our first flight, gives us complete confidence that the aircraft we deliver to customers this year will surpass their exacting standards."

The G600 is currently undergoing mechanical systems certification testing. The five G600 test aircraft have logged more than 9,500 flight hours and 510 flights.

Paris, France

// SEA VENOM PASSES FLIGHT TEST

MBDA has successfully completed the second development firing of its Sea Venom/ANL anti-surface missile from a French Defence Procurement Agency Panther test helicopter.

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The firing, during April, demonstrated the missile's lock on after launch capabilities. It also validated its low-altitude, sea-skimming flight; the data link between the missile and helicopter; and its autonomous guidance capability, using images from its infrared seeker.

Sea Venom/ANL is part of an Anglo-French program linked to the Lancaster House treaty agreed between the UK and France in November 2010. The missile system has a 'fire and forget' mode alongside an 'operator above the loop' capability, to maintain control over the entire missile trajectory.

The missile will be used on the UK's AW159 Wildcat helicopter and France's future light joint helicopter.

Île du Levant, France

// LONG-RANGE A350 XWB COMPLETES MAIDEN FLIGHT

The ultra-long-range version of the Airbus A350 XWB has successfully completed its first flight. The aircraft will be able to fly further than any other commercial airliner and is expected to enter service with launch operator Singapore Airlines later this year.

It has a range of 9,700 nautical miles, meaning it can stay in the air for up to 20 hours, and a maximum take-off weight of 280t.

The aircraft, which is powered by Rolls-Royce Trent XWB engines, is completing a short flight test program to certify the changes to the ULR version over the standard A350-900. The modifications include changes to the fuel system computer and the air venting, and inert gas distribution piping in the wings.

The current test phase is also measuring the enhanced performance from aerodynamic improvements, including the aircraft's extended winglets.

Toulouse, France

// AGNI-V BALLISTIC MISSILE PASSES SIXTH TEST-FIRING

India's Agni-V, an indigenously developed, nuclear-capable surface-to-surface ballistic missile, was successfully flight tested during June.

After the successful launch, which took place at the integrated test range on Abdul Kalam Island, off the coast of the east Indian state of Odisha, the intermediate-range missile flew 5,000km (3,100 miles) before hitting its target. The missile was successfully tracked by radar, electro-optical tracking stations and telemetry stations, said the Indian government and "all mission objectives were achieved".

This is the sixth test flight for India's intercontinental ballistic missile, which was first flight tested in April 2012. The Agni-V's range means it can reach potential targets in China.

The Agni-V is a three-stage, solid-fueled missile that uses composites throughout its design to reduce weight. The missile is transported and launched by a mobile launcher.

Odisha, India

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// PRODUCTION OF XAT-5 TRAINER PROTOTYPE STARTS

Engineers at the Aerospace Industrial Development Corporation (AIDC) of Taiwan have started to build a prototype for its XAT-5 'Blue Magpie' advanced jet trainer aircraft.

The prototype is planned to be completed by September 2019. The XAT-5 will replace the country's aging fleet of AT-3 trainers, which were supplied by the Republic of China Air Force, and have been in service in Taiwan since 1984.

AIDC is contracted to produce 66 XAT-5 aircraft by 2026 – it is based on the AIDC F-CK-1 Ching Kuo multirole Indigenous Defense Fighter, which entered service in China in the mid-1990s.

The XAT-5 will be powered by the F124 turbofan engine, which is being produced in Taiwan by the International Turbine Engine Company – a Honeywell and AIDC joint venture.

Taichung City, Taiwan

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BELUGAXL PASSES GROUND VIBRATION TEST

The first Airbus BelugaXL has passed its ground vibration test (GVT), a requirement for certification of the aircraft before its maiden flight within the next three months. The objective of the test is to measure the dynamic behavior of the aircraft and confirm the theoretical models of various flight conditions, such as maneuvering, flying in gusty conditions and landing. The test data also helps clear the aircraft's flight envelope.

The vibration test was performed by ONERA and the German Aerospace Center over eight days, using several hundred external accelerometers on the airframe's external surfaces, while the aircraft was stimulated by external shakers or seismic exciters on platforms.

The GVT technology is well-known and provides reliable results. However, this GVT was special because, after having completed the 'classic' aircraft empty GVT, the test was repeated, but with a representative payload inside the aircraft. This is the first time that Airbus has conducted a GVT in this way, according to the company.

In addition, the auxiliary fins fitted at the tips of the horizontal tailplane required the design and manufacture of specific tools to perform vibration excitations at the top extremity of these components. A dedicated and synchronized testing process with two cranes was implemented to perform the testing sequences on those components that are non-conventional for an Airbus aircraft.

"The approach for all testing is generally that this is a derivative of the regular A330 aircraft, against which we measure the changes. In terms of this GVT, there was a focus on the significantly modified rear-end, especially in the auxiliary fin structure," said Airbus.

The BelugaXL was launched in November 2014 to address the transportation and ramp-up capacity requirements for Airbus beyond 2019. The new oversize air transporters are based on the A330-200 Freighter, with extensive reuse of existing components and equipment. The first of five BelugaXLs are expected to fly this summer and enter into service during 2019. \\

// Vibration tests of the BelugaXL focused on the modified rear-end of the aircraft and its auxiliary fin

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// The Natilus seaplane drone started taxi tests in February

SEAPLANE CARGO DRONE ON COURSE FOR FIRST FLIGHT

Startup Natilus, which is developing 13-ton capacity transoceanic drones that will take off and land on the sea, is taking its 30ft-long (9m) prototype through high-speed taxi tests and expects to conduct its first test flight soon.

Natilus is testing its blended-wing cargo seaplane/drone in San Pablo Bay, about 15 miles (24km) northeast of San Francisco, California. The technology demonstrator will be able to carry 700 lb (320kg) of cargo for up to 2,500 nautical miles and is intended to be the precursor to 2-, 60- and 130-ton capacity freighters for use by companies such as UPS and Fedex, and medium freight forwarders such as Costco.

The company plans to have a larger capacity version of the cargo drone in the air by 2020. The initial versions of the drones will operate from sea, with their cargo loaded and unloaded at ports.

The seaborne prototype has no landing gear, which, according to Natilus CEO Aleksey Matyushev, has made testing easier. "We chose to start with that to make sure that we don't have to go to a test range in Oregon or Nevada – we could do it in our backyard in San Francisco. The FAA opened up 24 square miles [$62km^2$] of aerospace for us in San Pablo Bay as a result of this decision."

The prototype is also unmanned, a move which Matyushev said has created challenges. "There is a higher risk of aircraft loss in having a remote pilot and trying to do gains tuning. I think having a pilot in the cockpit is a huge asset to start with – once the gains are tuned, you can take him out." \\

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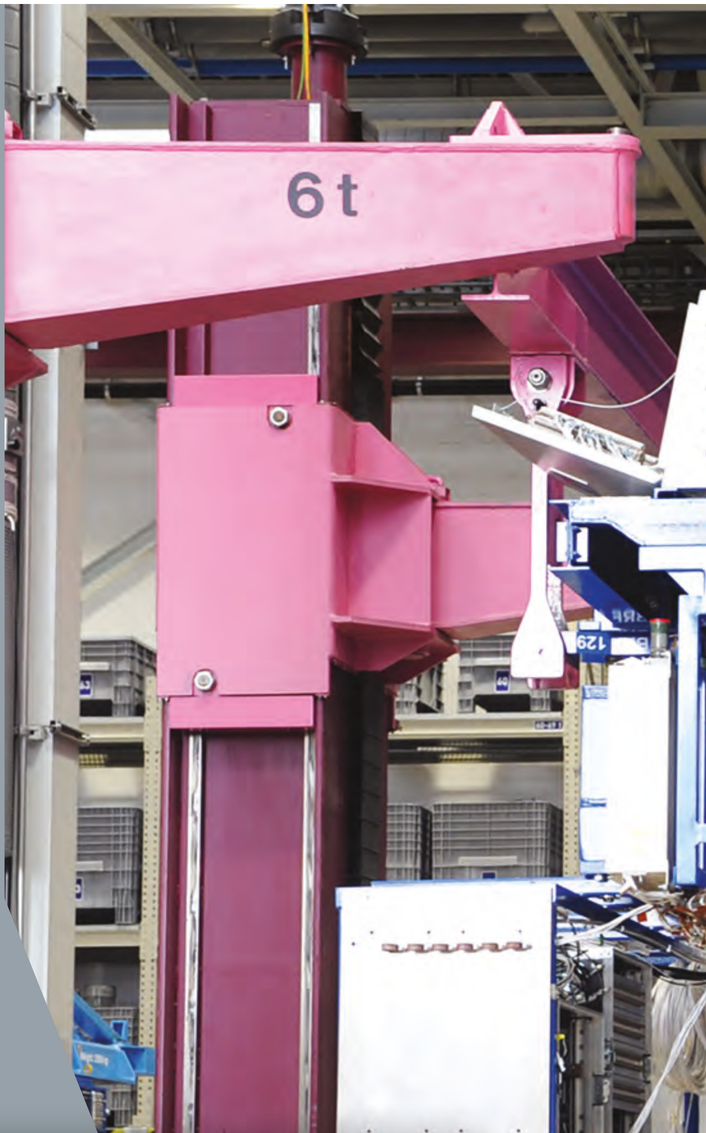


Rolls-Royce has surprised the industry by announcing it has been secretly developing a new business jet engine that will enter into service before the end of 2019.

The Pearl 15 engine was announced at the European Business Aviation Convention & Exhibition (EBACE) in May. Engineers at the company's Dahlewitz facility in Germany had kept the engine secret for six years during its development and testing.

Ground testing of the engine began at Dahlewitz in 2015. The European Aviation Safety Agency (EASA) certified the engine in February 2018, shortly before the EBACE event, but did not publicize the certification.

The Pearl 15 is currently being flight tested in the USA by Bombardier, with specific tests such as water ingestion, cold start and icing being conducted. Ground testing of the engine for reliability is also ongoing at the Dahlewitz facility, using a sea-level testbed.

"So far, we've completed 2,000 hours, 6,000 cycles, with six different Pearl engines. By the time it's operational the engines will have done 10,000 cycles," said Rolls-Royce.

The Pearl 15 is designed for use by long-range business jets and is an updated version of its predecessor, the BR725, benefiting from technology developed under the company's Advance 2 technology demonstrator. The updates include improved fan and core technology with a 10-stage blisk high-pressure compressor, two-stage high-pressure turbine, titanium fan-blisk, a lightweight containment system and high efficiency and a low-noise low-pressure turbine.

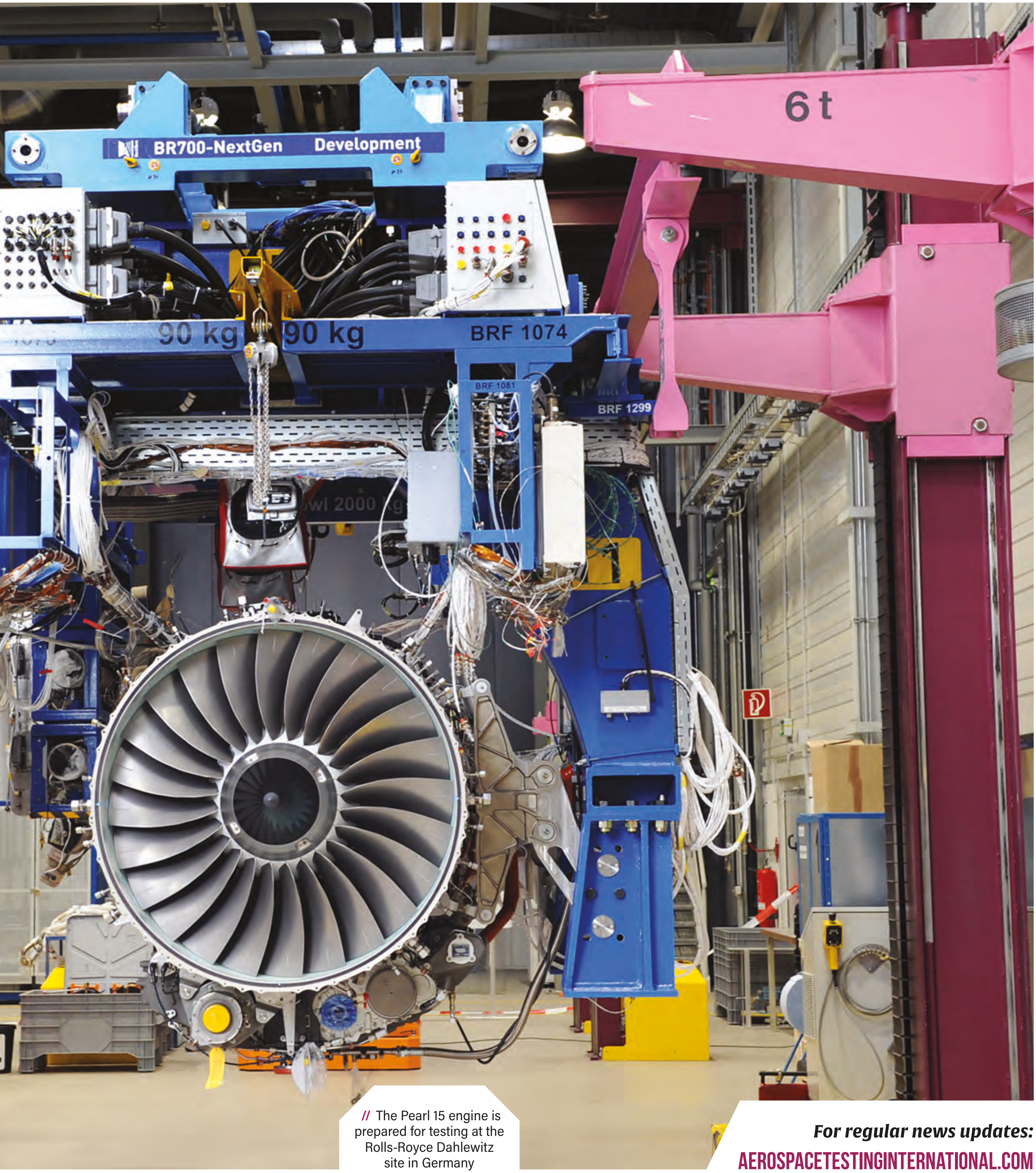
The Pearl has a take-off thrust of 15,125 lb, together with a 7% increase in thrust-specific fuel consumption compared to the BR725. The engine is also 2dB quieter, with reduced NO_x emissions, Rolls-Royce claims.

It features an Engine Health Monitoring (EHM) system which tracks 9,000 datapoints in the engine at a rate of 1Hz or 1 datapoint per second, so that changes can be seen in the engine. The hardware and software were developed and tested in-house by Rolls-Royce engineers because of their importance to the engine.

"It's a completely new level of quality, quantity and data. It's about making the best decisions with the best data," said Rolls-Royce. "The EHM system's hardware and software were rigorously tested because they're so important and have to operate at temperatures between -50°and 40°C [-58° and 104°F]."

The engine is named after the Pearl rivers in southeast China and the USA. \\

ROLLS-ROYCE REVEALS SECRET ENGINE PROJECT



// The Pearl 15 engine is prepared for testing at the Rolls-Royce Dahlewitz site in Germany

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// The folding wingtips must include multiple warning systems and failsafes

FAA SETS RULES FOR BOEING'S FOLDING WINGS

The FAA has set a number of special certification rules to cover the folding wingtips that are set to feature on Boeing's 777X long-range wide-body aircraft. The wingspans of the 777-9 and 777-8 will measure 235ft (72m) when extended in the air and 213ft (65m) with the tips retracted. This is so that the new airplane can use the same airports and gates as Boeing's current popular long-range aircraft, the 777-300ER.

Boeing has developed a hinge mechanism to achieve the folding. It will activate shortly after landing and is similar to that used by some carrier-borne military aircraft.

Certification criteria under Part 25 of Federal Aviation Regulations do not cover folding wingtips, so the FAA has devised 10 special conditions for them.

According to a rule published by the FAA in May, these extra safety standards include having multiple alerts for the wingtip position that operate before take-off, and a redundancy system to prevent take-off if the wingtips are in the wrong position, as well as several rules associated with aeroelastic stability, durability, reliability, inertial loads, performance in crosswinds and the position of lights.

The folding system is being designed and tested by Germany's Liebherr Aerospace.

The 777-9 is expected to start flight testing in early 2019 and to enter service in 2020, with the 777-8 scheduled to enter service two years later. \\

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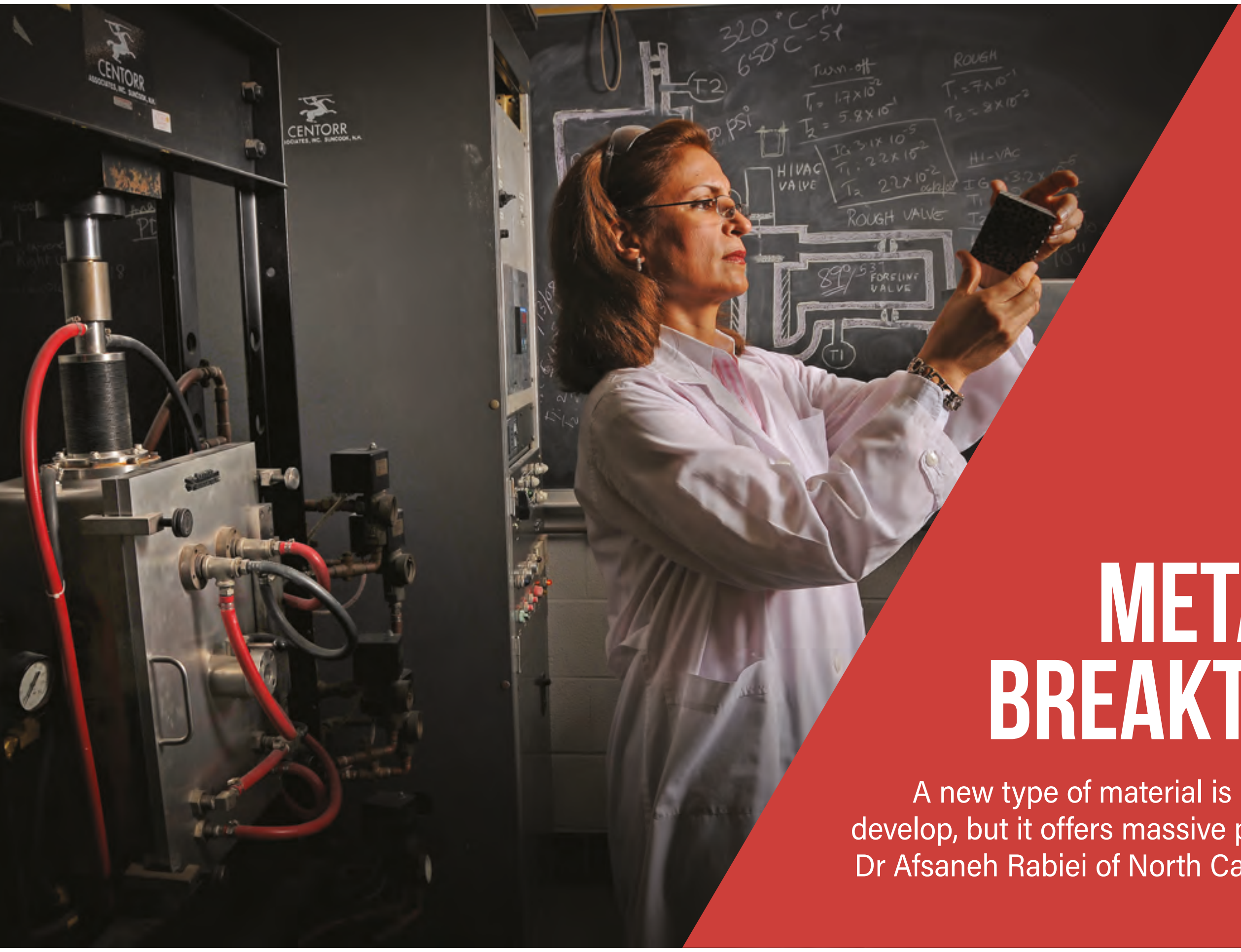

METAL FOAM BREAKTHROUGH

A new type of material is proving challenging to develop, but it offers massive potential benefits, says Dr Afsaneh Rabiei of North Carolina State University

Development and testing of composite metal foam (CMF) has been taking place since 2003, but it wasn't really until the Iraq War when we recognized the need to develop this material to save lives. Since then it's been a challenging journey to get the technology to where it is today.

Metal foams are a relatively new class of material. They can be up to 95% less dense than regular bulk metals. In most metal foams, premature failure under load is caused by variation in cell size and the thickness of the cells' walls. In CMF, hollow spheres are used to create cells that are uniform in shape and size. These cells (porosities) are reinforced by a metal matrix, which is formed around the hollow spheres using casting or a powdered metallurgy technique.

As such, CMF is a stronger metal foam. It is an ultra-high-strength metal matrix composite foam and has a much higher strength-to-density ratio than any other metal foam or bulk metal. The metals we have used so far to produce CMF are mostly aluminum and steel based, due to their low cost, availability and ease of production. But we can make CMF from any mix of metals and alloys.

Under load, the porosities in CMF collapse to give a cushioning effect, like bubble wrap or Styrofoam. Thanks to this phenomenon, although the density of the steel-CMF is a third that of bulk steel, its capability to absorb energy is about two orders of magnitude greater. As such, when used in many structures, CMF offers the same performance with lower weight than the bulk materials, or better performance when used in equal weight.

The key is air. We take air for granted, but it has many purposes for engineers. It helps protect us against radiation in the atmosphere. Bubble wrap and Styrofoam use air to give structure and protection from impact and heat. By using air inside steel, we can offer better protection against impact, heat, radiation, noise and vibration, all of which are important in aerospace. For example, it could be very useful for crash-energy absorption in hard landings of helicopters or to protect against bird strikes.

The most recent experiment conducted at North Carolina State University looked at blasts and the resulting fragments. Researchers fired high-explosive incendiary (HEI) rounds, the type that are used against helicopters, at panels of CMF. The experiment showed that the material can absorb the fragments as well as the blast wave. High-speed cameras were used to record the experiment, and when the results came back it was surprising to see that CMF could stop fragments moving at up to 5,000ft/s (1,500m/s)).

Using computer modeling, we simulated a similar weight of aluminum with the same HEI rounds. The simulation showed how CMF offers more protection against fragments and blast waves than the same weight of aluminum.

The biggest panels we have so far produced are about 1 x 1ft (30 x 30cm). Our next aim is to increase the size of the panels we can make and then start mass production.

There is more work to be done testing and developing the material. We are confident that CMF will be used in many structural applications. It will be used in biomedical devices, trains, automotive, aircraft and spacecraft, as well as in defense applications. It may need additional testing for certain new uses, but we are confident that it will be in every household in the near future. \\


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// PAUL E EDEN

Flexing their wings

Customers appreciate the Global 6000's smooth ride, but it wasn't until Bombardier conducted a series of innovative tests that there was quantifiable data to support their claims

S

1 // The Global 6000 is the mid-sized option in Bombardier's popular family of large-cabin, ultra-long range business jets


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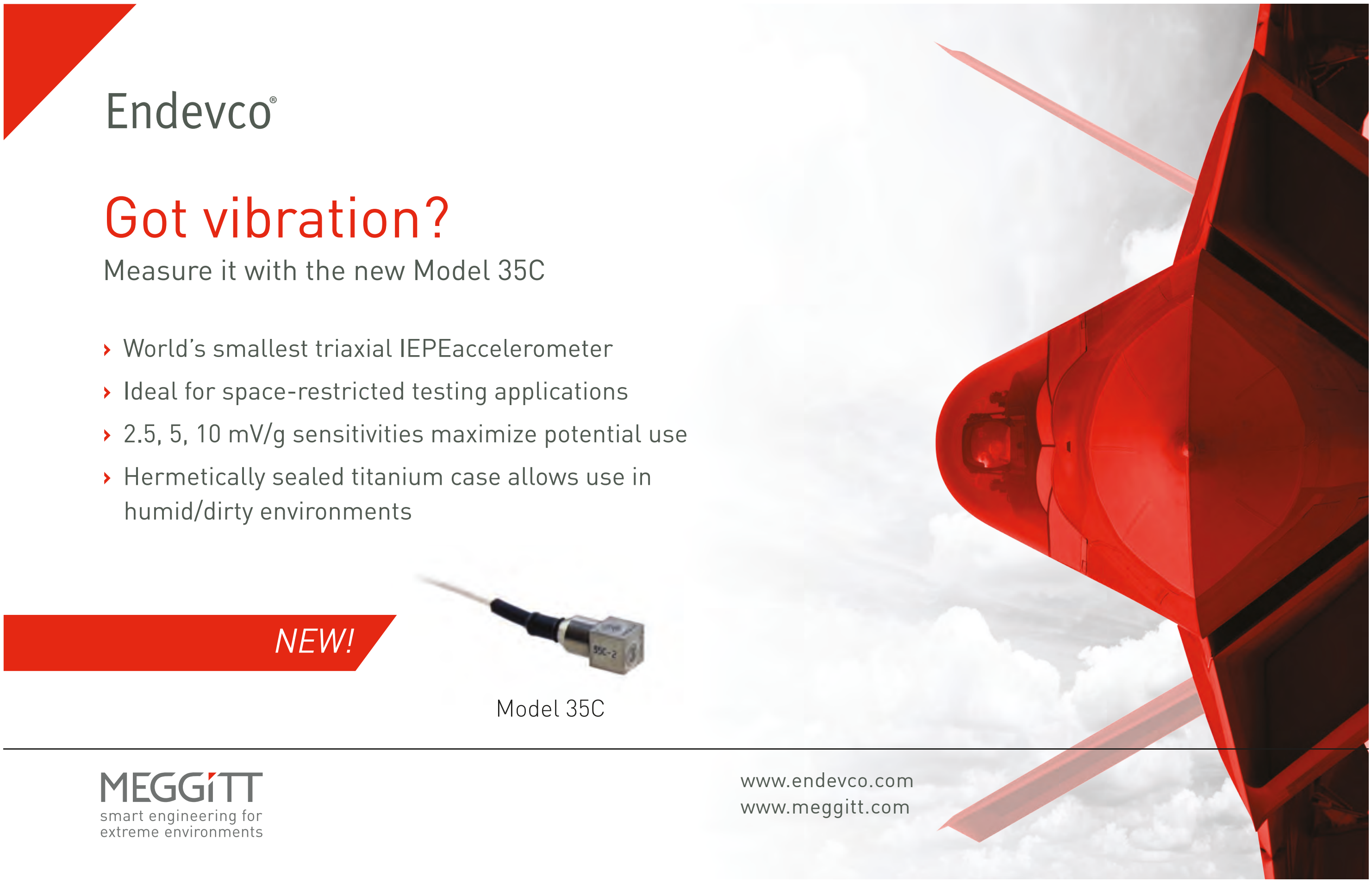
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2

2 // The Global 6000's flexible wing structure is designed to compensate for turbulence

"We know aircraft weight and wing area, so wing loading is easy to calculate, but wing flexibility is less easily quantified"

Visitors braving the baking desert sun to visit Bombardier's National Business Aviation Association (NBAA) static display at Henderson Executive Airfield, Las Vegas, last October, were treated to the kind of opportunity seldom granted. The Canadian manufacturer's team was on hand, inviting attendees onto a pedestal, from which they could not only reach the wingtip of the Global 6000 demonstrator, but were actively encouraged to see just how much they could move it up and down.

Your correspondent is happy to confirm that the trial of strength versus Global 6000 wing, as measured in real time by Bombardier's Flex-O-Meter, a huge transparent protractor, was a joyous thing indeed. 'Flexible wing = Smooth ride' and '#IFlexedTheWing', writ large on the Flex-O-Meter, hinted at the serious purpose of the setup, demonstrating a particular quality of the Global 6000 wing and complemented by a model simulation nearby.

Striking in its simplicity, being more Airfix than PlayStation, the simulation featured a pair of semi-anonymous aircraft models 'flying' one behind the other, each atop a post. The posts moved up and down, the amplitude of their motion replicating exactly the movement of a Global 6000 and competitor aircraft as they flew through the same air mass. The Global's movement was noticeably less pronounced, although both aircraft at times moved when the other didn't, but just how faithfully did the simulation match reality and where had Bombardier acquired the data?

That question prompted a conversation with the man who led the test, Mathieu St-Cyr, manager of engineering at Bombardier.

THE GLOBAL EXPRESS FAMILY

The Global 6000 is the mid-size option of the three large-cabin, long-range business jets Bombardier has in production. The line began with the Global Express, which entered service in 1999, followed by the Global XRS in 2005. The current-production Global 6000 superseded the XRS in 2012, joining the contemporary Global 5000, first delivered in 2005.

Longer than the Global 5000, the Global 6000 delivers a 6,000 nautical mile maximum range compared with the smaller jet's 5,200 nautical miles. Bombardier built 45 Global 5000 and 6000 aircraft in 2017, then chose May's EBACE show in Geneva for the dramatic unveiling of new Global 5500 and 6500 jets, powered by the Rolls-Royce Pearl turbofan.

Prior to EBACE, the third member of the current Global line-up, the larger-still Global 7000, was scheduled for first delivery later this year. It remains on track, but is now designated the Global 7500.

"We've always designed our aircraft for a smooth ride and we get a lot of customer testimonials confirming how smoothly they fly, as well as press reviews from journalists who have flown on them. But it's always been qualitative information, with no quantitative data to back it up," says St-Cyr.

WING FLEXIBILITY AND LOADING

The secret to a smooth ride is a combination of wing flexibility and wing loading, explains St-Cyr. "Wing loading is a simple relationship between wing area and aircraft weight; the analogy we like to use for it is walking in a storm with a small umbrella, compared with a golfing umbrella, where the large one is more likely to offset your balance because the wind has more surface to catch. If two aircraft weigh the same, the one with the larger wing has more chance of being offset by turbulence.

"Meanwhile, a flexible wing absorbs some turbulence, but at the same time offsets the angle of attack, with the result that while the wing moves, the cabin moves less. We know aircraft weight and wing area, so wing loading is easy to calculate, but wing flexibility is less easily quantified.

3

3 // GPS and flight recorder information was combined with vibration data

4 & 5 // The 3D laser scanner was used on the ground and in the air

6 // Test results were compared to a competitor's aircraft to quantify the benefits of the flexible wing


4


5

"We wanted to compare our wing flexibility with that of competitor aircraft and measure the end vibrations that would put quantitative data to the ride quality, while making the comparison as fair as possible. We used laser scanners to measure wing flexibility on the ground and in the air, with accelerometers mounted in the cabins to measure vibration.

"The laser scanners measure a point in space with micrometer accuracy. We scanned on the ground to get accurate data on wing position from outside and inside the airplanes; we knew the windows would make the measurements slightly less precise and now we could asses the deformation the scanners saw as they looked out at the wing in flight."

Bombardier custom-designed tables for mounting a laser scanner inside each aircraft without the requirement for permanent cabin modification or damage. St-Cyr explains, "The three-ply bamboo tables were mounted on tripods in the aft cabin, positioned so that the scanner looked out of a cabin window. We used the aircraft seatbelts to secure the platforms so solidly that they didn't move at all. The seats are certified for 16*g* impact, so with the tables effectively connected to the seat tracks, the table movement was less than 0.1mm.

"The laser scanners produced a 3D scan of each wing so that we knew the deflection at each point and we used that data to produce a CFD model. It showed that at 1*g*, our wing was 15% more flexible than the competitor's." The model also helped generate the data that translated into the physical movements of the pole-mounted models at NBAA.

In order to quantify wing loading, St-Cyr's team measured cabin vibration via identical accelerometers to those used in the Global 7000 flight test program. "They're extremely precise and pick up any vibration," he says. "We mounted them in four identical locations in each aircraft cabin – one in the left-hand forward-facing seat track, another immediately behind the cockpit seats, a third at another cabin seat, and the final one in the back of the aircraft."

FLYING THE TEST

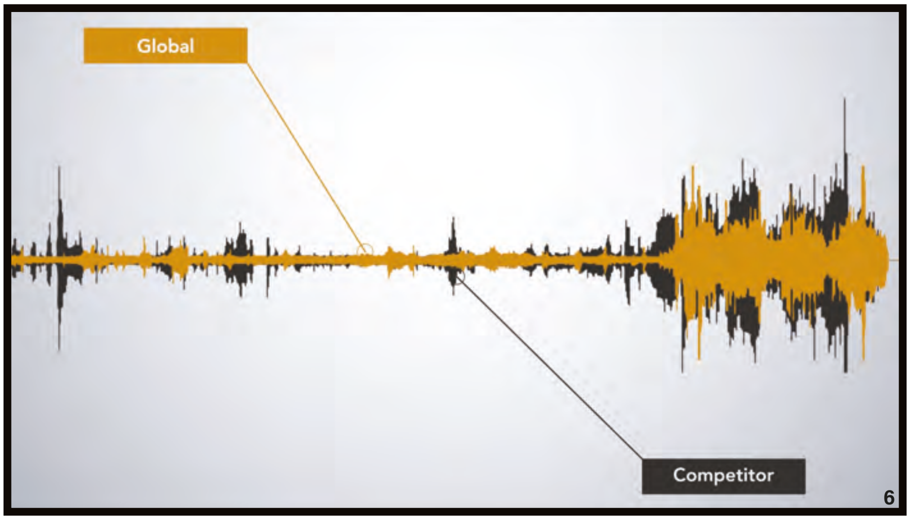
"We performed the same laser scan on both aircraft while pulling 1*g* turns, measuring the wing deflection of each. It was important for us to get exactly the same air, so we flew them one right after the other, as close as was achievable with regular crews and aircraft, rather than test pilots and test aircraft. We flew them five minutes apart from take-off to the test point, with our aircraft initially taking the lead.

"It needed a lot of coordination. The two crews were in constant contact to ensure they were following accurately and, to be as fair as possible, midway through the test we swapped the positions. We wanted to know if wake had an effect; we didn't think it did, but we made the swap to see – the data proved we were correct and we were able

2
Aircraft flown

5
Minutes between flights

8
Flight test crew in each cabin



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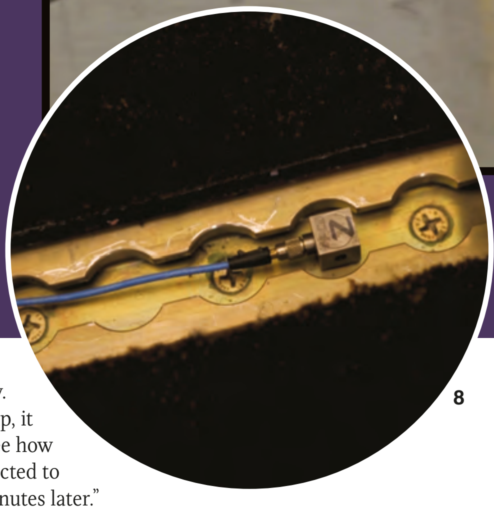
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7 // Tape being fitted to the Global 6000's wing for the 3D laser scanners

8 // Accelerometers were fitted in the seat track

9 // The Global 6000 has a wingspan of 94ft (2.75m)

to repeat the variability. When it showed a bump, it was quite striking to see how the trailing aircraft reacted to the same bump five minutes later."

Since wing loading varies with aircraft weight, Bombardier was also careful to design a fair comparison in terms of fuel and payload. "We didn't load them to the same weight, because the two aircraft don't necessarily fly the same distance. Instead, we loaded them for the same mission – a 3,000 nautical mile trip with eight passengers, landing with NBAA reserves. Our assessments after fueling the aircraft showed we were 0.3% off our calculated figure for the Global and 0.6% on the competitor aircraft."

St-Cyr quickly dispels the assumption that the eight passengers actually comprised ballast for simplicity, "They were real people! Flight test engineers were on board monitoring the accelerometers and running the scans, all sitting in the same positions on each aircraft, plus someone in each aircraft's jump seat coordinating communication between the pilots." St-Cyr himself flew on the competitor aircraft, and not entirely as ballast – he noted and time-stamped movement as he felt it, for post-flight correlation with the measured data.

"We measured vibration throughout the flight, although we didn't fly a full 3,000 nautical mile mission. Instead we flew for around two hours, but we knew the loading at take-off was the same, so at the end the change in weight was the same for both."

Autopilot was engaged as the majority of the measurements were made, eliminating variations in piloting style. Although St-Cyr acknowledges variations may exist in the way that autopilots behave, the focus of the tests was on ride quality, and because aircraft of this type perform the majority of their missions on autopilot, any variation from the autopilot systems ultimately had no effect on the results.

"The smoothness of the ride is really down to wing flexibility and wing loading. Does the autopilot have a part to play? Maybe a little, but not enough to be a major consideration in the overall results."

SMOOTH RESULTS

The test complete, Bombardier spent around a month analyzing data. "We have software that links the vibration data to the flight data recorder information, including GPS. It's super-refined, but it takes some time to process. Also, the accelerometers pick up all vibration, so we filtered out anything that wasn't turbulence.

"At 60Hz we found a vibration that was more prominent on the competitor, but we identified it as engine vibration and it, along with some other data, was filtered out. We only kept vibrations that were under 20Hz, although the major vibrations were less than 1Hz – something you can really feel."

St-Cyr says the process of measurement was in itself important, because it transformed a poorly understood parameter into something tangible. "The amplitude of vibration – how far the aircraft is pushed up and down by turbulence – was between 1.6 and 2.5 times greater on the competitor aircraft than on the Global," he says. "It's quite significant and enables us to quantify what customers tell us – that the Global is more comfortable." \\

1.6-2.5
Times less amplitude of movement on the Global compared with competitor aircraft

3,000NM
Mission load for test flights

1G
Turn sustained for wing flexibility scans


9

One giant leap for mankind

The Space Launch System is the largest rocket ever built, and it's currently being tested using infrastructure on the same scale as its massive structure before it sends astronauts to the moon

During December 2019 at NASA's Kennedy Space Center, the world's largest rocket, the Space Launch System (SLS), will fire its four RS-25 engines and two solid rocket boosters to provide the 37,365kN of thrust required to lift the 321ft-tall (98m) launcher for its maiden flight. Atop the SLS will be an uncrewed Orion multipurpose crew vehicle, which will be sent around the moon.

The launch will be the culmination of several years of carefully planned and executed tests, during which engineers will have used the latest technologies and built infrastructure as tall as an office block to check the performance of the SLS's structure.

The prime contractor for the SLS core stage since 2014 is Boeing. "After the Constellation program and Ares I were canceled, Boeing proposed what is now called the SLS," says Paul Wright, Boeing Test & Evaluation senior test manager. "The test team was involved from early on, to determine the scope of the development, qualification and acceptance tests."

The Constellation program and Ares I, which was originally the rocket to launch the Orion spacecraft, were canceled by President Barack Obama (see *A short history of the Space Launch System*, page 29). "Our involvement in Constellation led to an early determination of the facility needed for the large structural qualification tests of the SLS, as well as for the hot-fire tests prior to integration and launch," Wright explains.

The SLS core stage is the largest part of the rocket at more than 197ft (60m) tall. It contains the forward skirt, the liquid oxygen (LO_X) tank, the interstage tank, the liquid hydrogen (LH_2) fuel tank, and the engine section that hosts the four space shuttle-era Aerojet Rocketdyne

1 // Artist's impression of the Space Launch System launching the multi-purpose crew vehicle from the Kennedy Space Center *(Photo: NASA)*

> **"During testing, instrumentation will capture more than 3,500 strain and detection measurements"**

RS-25 engines. The interstage tank is not a tank, but a cylinder connecting the LO_X and LH_2 tanks. The forward skirt contains the SLS flight computers and connects the core stage to the launch vehicle stage adaptor (LVSA), the upper part of the SLS.

LOAD TESTING

At NASA's Marshall Space Flight Center (MSFC) in Huntsville, Alabama, Structural Test Stand 4693 consists of two 221ft-high (67m) towers, each 48ft (15m) wide on a 17ft (5m) reinforced concrete floor. The stand is built on top of the foundations of the stand that was used to test the Saturn V moon rocket's F-1 engines in the 1960s.

More than 50 years on, Test Stand 4693, which took 2.5 years to build and was finished in December 2016, will be used this summer to subject the SLS core stage's 2,032,766-liter LH_2 tank to the same stresses and pressures it must endure at launch and in flight.

"We will not apply loads to 4693 before the SLS core stage LH_2 tank is integrated. The first loads 4693 will ever experience will be during the LH_2 tank test," says Mike Roberts, one of the engineers serving as an acting director of Marshall's Structural Engineering Test Branch. "The test stand is much stronger than the test article and built with well-understood materials and manufacturing methods."

A total of 38 hydraulic cylinders, each weighing from 500-3,300 lb (230-1,500kg) are being fitted with custom-built test cells to send and receive instructions and data around the tank. At the base, 24 of the 3,300 lb (1,500kg) cylinders will simulate the thrust produced by the RS-25 engines. During testing, the cylinders extend and retract, applying millions of newtons of pulling and crushing force and up to 1.5 million newtons of shearing or sideways force in different combinations against the test article, the test stand base and towers. During 30 or more test scenarios, instrumentation will capture more than 3,500 strain and detection measurements, temperatures, pressures and high-definition images.

The LO_X tank is put through the same tremendous forces in test stand 4697. It is an L-shaped structure that is 29.5m tall.

126 SECS
Length of time the booster rockets will fire

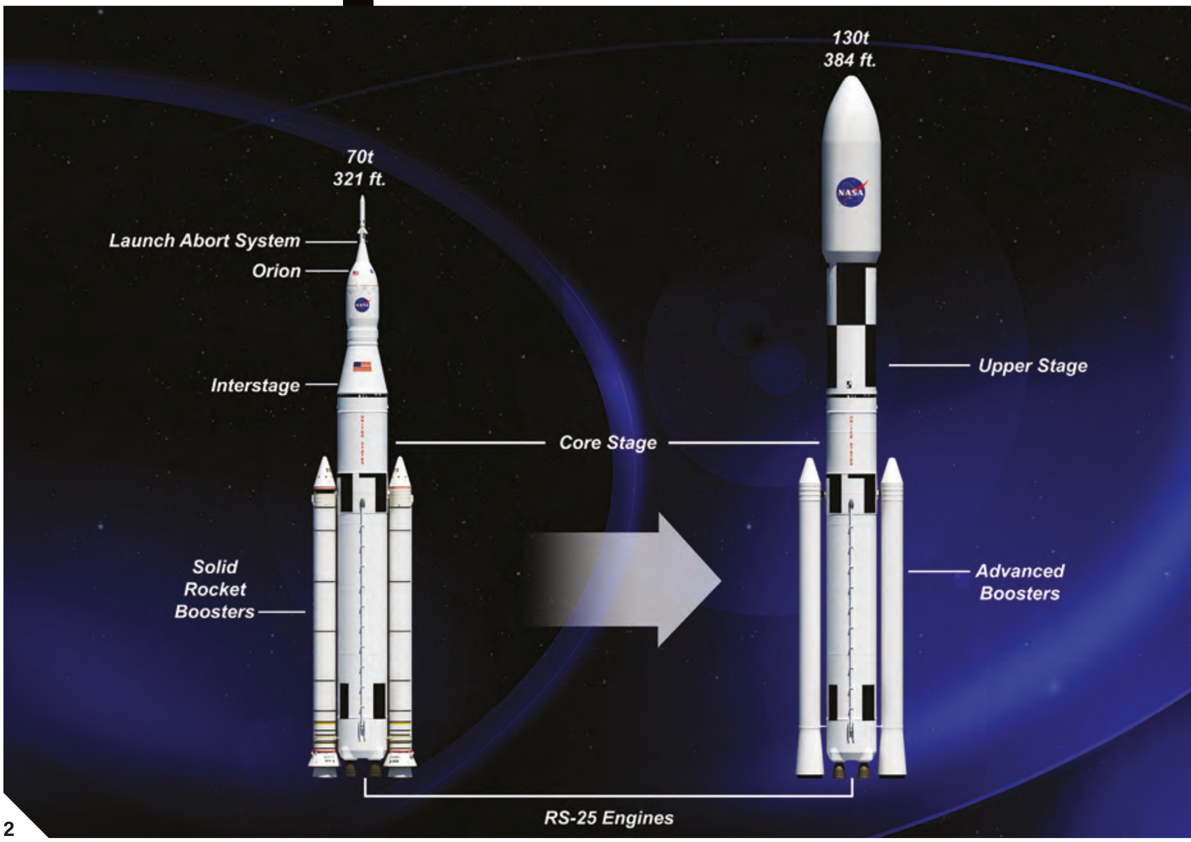
5 TONS
Propellant burned every second by each booster

Sharing the test stand's 3,500ft²-tall (324m²), 6.5ft-deep (2m) concrete foundation is a ring of what NASA calls cage-like pedestals. The LO_X tank test article is surrounded by these pedestals, which the agency also refers to as an 185,000 lb (83,900kg) steel reaction ring. At the bottom of these pedestals, and on their top, are what NASA describes as 'spiders and rings'. These fix the LO_X tank in place for the substantial mechanical loading that it will experience. During the tests, the tank will be subjected to up to 40,000kN of compressive loads and up to 1,334kN of shear loads. Instead of liquid oxygen, the tank will be pumped full of nitrogen. It took about eight weeks to install all the sensors, gauges, systems, cameras and test equipment for the stand. It also has fluid transfer and pressurization systems, hydraulic and electrical control and data systems, and fiber-optic cables.

CRYOGENIC TANKS

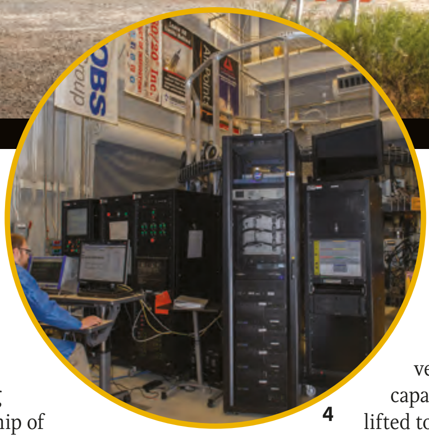
While 4697 and 4693 are, along with all the other major structural test infrastructure, located at MSFC, the LO_X and LH_2 tanks are being fabricated and quality tested at NASA's Michoud Assembly Facility, in New Orleans, Louisiana. Both tanks are made of welded sections. After the circumferential weld in MAF's Vertical Assembly Center, the LO_X tank undergoes a phased-array ultrasonic testing (PAUT) scan.

"If there are areas of interest, x-rays can be done while the tank is in the welding tool," says Ben Birkenstock, NASA SLS Stages Office cryogenic tank



2

2 // The larger SLS rocket has an upper stage to help send payloads beyond low Earth orbit *(Photo: NASA)*



manager. If the tank passes the in-tool, and an additional off-tool, PAUT, the LO_X tank undergoes a hydrostatic proof test. "The hydrostatic proof test fills the [LO_X] tank and an additional standpipe with liquid to simulate the pressures seen during flight and to check the workmanship of all the welds. Post-proof, the PAUT technique is used again to ensure that no defects opened up past the acceptable limit during the test," he explains.

The LH_2 tank, after welding, also has a PAUT test, but its hydrostatic proof is a pneumatic test using gas and actuators. Birkenstock says, "Post-weld and initial PAUT, the [LH_2] tank is taken to a separate building. Pressurized gas puts different loading conditions into the tank. The area is cleared as this is a hazardous operation with safety concerns." The LH_2 tank then follows the same post-proof inspection process as the LO_X tank. The LO_X and LH_2 tanks for the first 2019 SLS flight have completed these tests.

There is more testing conducted at this early stage while NASA establishes its design and manufacturing processes for the SLS. "There is an initial surge in testing and facilities to execute the qualification program and establish the production acceptance test program," Boeing's Wright explains. "Once initial qualification is done, there will be acceptance testing performed on successive builds of the existing design per the engineering specifications, primarily at MAF as the stages are built there."

The 2019 flight will be the 70-ton payload capacity SLS, but the rocket also has a cargo version with a 130-ton payload capability. This extra 60t will be lifted to orbit with a more powerful upper stage, but the core stage is also expected to evolve, requiring more testing. Wright says, "As the design evolves, additional qualification and new acceptance testing will be needed for new or modified hardware."

Further testing of these large structural test articles will provide NASA and Boeing with data for qualifying future evolutions of the core stage to increase its lift capacity.

8 MINS
Length of time the SLS four RS-25 engines will operate during ascent

6,000°F
Maximum operating temperature of the RS-25 rocket engine

HOT FIRINGS

The engines that will propel the core stage are tested at NASA's Stennis Space Center. In January 2018, NASA and the RS-25 engine provider, Aerojet Rocketdyne, hot-fired an RS-25 for a 365-second test. This was to qualify a lighter avionics controller for one of the RS-25 engines that will propel the SLS during its second flight in 2021. The RS-25 was the space shuttle's engine. Aerojet has 16 RS-25 engines left over from the Space Shuttle program, leaving enough for four SLS launches, including the first in 2019 and second in 2021. After those four missions, Aerojet will build a new version of the RS-25.

The RS-25 engines are contained within the core stage's engine section. At MSFC, the 27ft-diameter (8m),

A SHORT HISTORY OF THE SPACE LAUNCH SYSTEM

SLS was announced eight years ago, but its roots lie in President George W Bush's Constellation program, which started in 2005. Abandoned by President Barack Obama in 2010, Constellation envisaged a huge rocket called the Ares V that would send material and astronauts to a moon base at the lunar south pole. Ares V was to have five space shuttle engines for its first stage, along with two SRBs, which were longer versions of the space shuttle's SRBs.

While SLS is very similar to Ares V, it will launch the Orion multipurpose crew vehicle, which Ares V was never intended to do. Under the earlier Constellation program, the crew exploration vehicle would have carried four astronauts to the moon, while under Obama's plans, the multipurpose crew vehicle would have transported the crew to rendezvous with an asteroid. Under President Donald Trump, SLS and Orion will send astronauts to a moon-orbiting space station, called the Deep Space Gateway, as part of a longer-term plan to reach Mars – very similar to Constellation's goals.

3 // Test Stand 4697 will subject the LO_X tank test article to extreme forces

4 // The solid rocket booster system's avionics cleared system-level qualification in October 2017 *(Photo: NASA)*

9m-tall (29.5ft) engine section has hydraulic forces applied to it by what NASA calls structural test equipment. These forces simulate the power generated by the four rocket engines. The build-up for the engine section test began in 2016, when 680t of steel was assembled into the structural test equipment.

"We tested the engine section between September 2017 and February 2018," MSFC's Roberts says. "Regarding applying forces from the hydraulics, the main engine section forces are from the four engines, total around 3,800,000 lbf [16,000kN] and the SRB [solid rocket booster] attachment, total about 1,000,000 lbf [4,448kN] at each SRB point, in opposite directions."

NASA recorded more than 100GB of data from the test. The data will primarily be used for verifying finite element modeling.

NASA fitted 55 load cell sensors, most of which were for strain, to the engine section. Cell sensors were also fitted for displacement, temperature, humidity and pressure. "We use a National Instruments PC-based data acquisition system with in-house software," Roberts explains. "This software is configuration controlled and checked out using standard NASA software checkout processes." MSFC's calibration laboratory performs checks on all of the load cells, displacement gauges and pressure gauges.

5 // Mark White, lead test engineer for the SLS core stage engine section

> ***"There are so many complex parts. Everything has to work for a flight to be a success"***

5

SPACE LAUNCH SYSTEM IN BRIEF

Height:	Orion version 321ft (98m) Cargo version 384ft (117m) Core stage 197ft (60m)
Diameter:	Both versions 27ft (8.3m)
Payload capacity:	Orion version 70t Cargo version 130t
SLS weight:	Orion version 249t Cargo version: 294t
Total thrust:	Orion version 37,365kN Cargo version 40,923kN
Upper stage:	Orion version – Interim Cryogenic Propulsion Stage Cargo version – Two J-2X cryogenic fuel engines developed from Saturn V rocket's J-2 engine
Engines:	Four Aerojet Rocketdyne RS-25 engines providing 2,200kN thrust each Two Orbital ATK solid rocket boosters with 16,000kN thrust each

While the RS-25 engines are important, 80% of the thrust for the first two minutes of the ascent is provided by the SRBs. Longer than the space shuttle's SRBs, upon which their design is based, they provide 32,000kN of thrust in total. The boosters' avionics receive their commands from the SLS flight computers that are located in the forward skirt. Qualification testing for the SRB avionics includes the ability to initiate ignition, controlling the booster during ascent, terminating the flight if something goes wrong, and triggering separation from the core stage. NASA engineers carried out system-level qualification testing for the boosters' avionics in an MSFC systems integration lab last year.

ORION MODULE CONNECTIONS

Lockheed Martin is the prime contractor for the Orion crew module, which consists of the command module, the capsule in which the astronauts work and the service module, which is a propulsion and electrical power unit supplied by the European Space Agency. The defense company is testing the Orion stage adaptor as part of its larger test campaign for the Orion crew and service module.

At the top of the rocket, the LVSA connects the 27ft-wide (8m) core stage's forward skirt with the

6 // Marshall Space Flight Center staff at their desks in the structural loads testing control room *(NASA)*

6

18ft-diameter (5.4m) of Orion's interim cryogenic propulsion stage (ICPS). Last year, the LVSA test article, which was produced by Teledyne Brown Engineering, was stacked at MSFC with the other upper parts of the SLS. NASA began testing the LVSA in August 2017.

The ICPS is the rocket engine that will blast Orion out of Earth's orbit and to the moon. "The ICPS was tested in the MSFC west test area in an existing test stand and primarily executed by NASA with support from Boeing," says Wright.

After the moon-shot engine burn, the ICPS separates from the crew vehicle and is lost in space. The ICPS is connected to the Orion spacecraft by another stage adaptor.

There are so many complex parts and everything has to work for a flight to be a success. The first 2019 launch may be without a crew, but still needs to prove that the rocket and spacecraft works. After the x-rays, hydrostatic, pneumatic and hydraulic testing, the final trial will be the flights themselves. The first crewed flight of Orion is the SLS's 2021 second flight. Called Exploration Mission 2, it will send four astronauts beyond the moon to a distance from Earth no human has gone to before, a bold step for the human race and the culmination of one of the most rigorously tested space missions ever. \\

// BEN SAMPSON

Extreme measu

1 // Polar researchers take off from the British Antarctic research station Rothera for a measuring flight *(Photo: Michael Fischer)*

ures

Scientists are using aircraft laden with instrumentation and are braving extreme weather conditions to gather data about melting glaciers in the Arctic and Antarctica

One of the biggest polar research projects ever will be conducted over the next five years. Scientists from the USA and the UK are to study the massive Thwaites Glacier in Antarctica to assess whether it is likely to collapse.

The glacier, which is in the west of the continent and is about the size of the UK, is melting at an increasing rate. The melt from Thwaites accounts for about 4% of the rise in sea levels around the world, a proportion that has doubled since 1995. If Thwaites does collapse, it would cause global sea levels to rise by more than 80cm(32in) – although this will occur over centuries.

The £20m (US$27m) International Thwaites Glacier Collaboration (ITGC) project is being funded by the UK's Natural Environment Research Council and the US National Science Foundation. The project is the largest one to be carried out in the Antarctic since the region was first mapped in the late 1940s and involves around 60 researchers and several aircraft.

POST-WAR AIRPLANES

Surprisingly, some of the aircraft likely to be used for the ITGC project are almost identical to those that would have been used in mapping expeditions 70 years ago. Polar researchers from organizations such as the British Antarctic Survey (BAS), which will participate in the ITGC, depend on sturdy turboprop designs that date back to the late 1960s. The BAS fleet consists of a DHC Dash 7 and four DHC-6 300 series Twin Otters. The Twin Otters celebrate their 50th anniversary of Antarctic service this year.

3TB
Data generated by the most advanced radars on board a typical airborne survey of the Antarctic

24
Channels used by radar to penetrate snow and ice and measure their structure

The BAS uses two of the Twin Otters for transporting cargo and two heavily modified ones for conducting geophysics, meteorology and remote sensing research. Some of the sensors and instruments used for surveys are acquired off-the-shelf, but many, such as the radar, are developed bespoke to observe snow, ice and other polar phenomena.

Carl Robinson, head of airborne survey technology for BAS, says, "Common to our systems is a need to keep the signal and data as raw and unprocessed as possible. This way, scientists can process it in the best way and future scientists can use new processing techniques to analyze the data, without the hindrance of past down-sampling, compression or averaging."

Although the interfaces and equipment fitted to the aircraft are certified and flight tested, the scientific data acquisition systems are not. This allows for the latest

VALUABLE SCIENTIFIC DATA

The data from the Twin Otters has "fundamentally changed" our knowledge of Antarctica, says British Antarctic Survey geophysicist Dr Tom Jordan.

"Airborne radar has revealed a landscape of valleys and mountains below the ice. This is the information needed to understand the first order control that landscape has on ice flow.

"We've discovered vast basins over 4.6km [2.9 miles] below sea level, buried beneath the ice sheet. Such regions are predicted to be the most vulnerable to rapid retreat, as warming ocean water can melt the ice sheet.

"Using magnetic and gravity sensors, we have also learned about the geology and tectonics of Antarctica. As less than 1% of the surface of Antarctica is exposed rock, these techniques, sensing the properties of the rocks beneath the ice, is the only way we have of understanding the past history, and therefore possible future evolution of the continental interior."

2

3

2 // The low altitude flying needed to take measurements is grueling for pilots

3 // The BT-67 aircraft used by AWI are fitted with retractable skis *(Photo: Michael Fischer)*

4 // BAS's Twin Otter. The aircraft celebrate 50 years of service this year

advances in technology to be used without burdening the science community with the delay and costs associated with the certification of avionics equipment.

The data acquired is stored for processing and physically handed over instead of being transmitted. "Storage has tracked the evolution of analog and digital electronics over time," says Robinson. "Scientists always require more capacity to store higher-resolution data and data measured at increased sample rates. High capacity solid state hard drives are used to store sometimes over 3TB of data per flight for the latest radars."

ELECTROMAGNETIC BIRDS

Dr Daniel Steinhage, senior scientist at Germany's Alfred Wegener Institute (AWI) for Polar and Marine Research, manages the institute's fleet of aircraft. AWI's Polar 5 and 6 are Basler Turbos (BT-67s), converted DC-3s (see sidebar, *Ice-modded airplanes*) that carry a similar range of instrumentation to the BAS aircraft: radar for measuring ice sheets and glaciers, gravity meters, magnetometers, lidar systems, radiation sensors and spectrometers.

The aircraft are flown to measure the thickness of ice, its movement and structure, in places such as the Canadian Arctic, Greenland and Antarctica. Steinhage says, "From the satellites, you get the distribution and width of the ice. But it's harder to measure the thickness with satellites. Scientists use the data to monitor the ice for variation and in climate and ocean modeling to validate the models and increase their accuracy."

One of AWI's most intriguing instruments is the EM-Bird. This torpedo-shaped sensor detects electromagnetic reflections and measures the thickness of sea ice by detecting the boundary between the ice and the sea. The EM-Bird is deployed at altitudes of around 100ft and is towed from the belly of the aircraft. It is deployed for 45 minutes at a time because the sensor has to be recalibrated at higher altitudes and low-altitude flying is demanding on the pilots. The data collected is transmitted to the aircraft both wirelessly and wired.

10,000
Pulses per second from the laser altimeter used on NASA's Operation IceBridge aircraft

ICE-MODDED AIRPLANES

Basler Turbo Conversions in Oshkosh, Wisconsin, converts old Douglas DC-3s into BT-67s for various uses, including polar expeditions and scientific surveys.

The company has supplied aircraft to Germany's Alfred Wegener Institute, NASA, and most recently the Polar Research Institute of China. Randy Myers, president of Basler Turbo Conversions, says, "The DC3 is just such a great platform for operations in the Arctic, Antarctic or Greenland. You can put them on retractable skis, and they have high payloads and a long range. They can carry enough fuel for 12 hours.

"They beat newer aircraft hands down in terms of performance and reliability for that environment. You would pay up to US$30m for a new aircraft with similar capabilities. A BT-67 is one-third of the cost and they leave our shop brand new."

When Basler receives DC-3s to convert, the aircraft are in a variety of disrepair, from corrosion to bullet holes. Engineers carry out a complete structural overhaul. The remanufacturing process takes around six months. There is a baseline 'polar package' with skis, heaters and a suite of scientific equipment. Instrumentation is also fitted out according to customers' requirements.

Modifications to carry scientific equipment can be substantial. Lidar systems require large holes to be made in the belly of the aircraft with a roller door. Ice-surveying radar equipment requires a 12 x 3ft-wide hole to be made in the aircraft. Hard points, racks and power distribution are installed. "The instruments and equipment on these airplanes change from year to year – we're constantly updating the sensing equipment," says Myers.

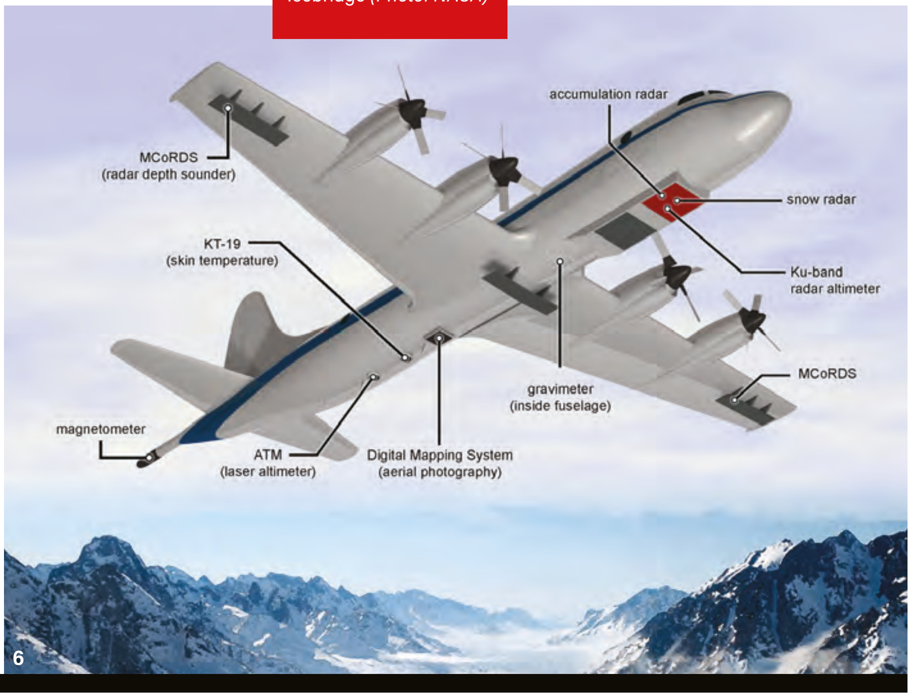
Flight testing and cold weather certification takes around 30 days for each aircraft and is done in-country. "The aircraft we supply now will keep going for another 75 years," says Myers. "I fully expect my grandkids to be working on them."

The BT-67s are favored by polar researchers for several reasons. Dr Daniel Steinhage of the AWI says, "With a Basler, you know in advance where your mounting points will be. With a new aircraft, you have to cut and work around components.

"Modern aircraft are designed to be lightweight and fly fast. We want aircraft that fly slowly and have a high payload capacity. Baslers are the only aircraft that can be supplied with retractable skis already fitted."

5 // NASA's P3 refueling before a science flight *(Photo: NASA/Jeremy Harbeck)*

6 // Equipment fitted to NASA's P3 for Icebridge *(Photo: NASA)*



However, the instruments used the most on AWI's aircraft are the laser scanners. "We use them to quickly check anomalies in the radiation data," says Steinhage.

A laser scanner at 2,000ft will record around 2GB of data in 45 minutes. The instrument with the highest data production rate is the radar, which produces around 40GB every 45 minutes.

"Everything and anything can go wrong," says Steinhage. "The operator can forget to switch on the instrument or press record. The hard drives can break. We can run into icing clouds that cause ice to accumulate on the airframe and there can be visibility problems, especially in the Antarctic."

The next technology upgrade AWI is looking to install on Polar 5 and 6 is an improved camera system. Existing commercial systems are too heavy to install, so a lightweight version for polar missions is being developed by DLR researchers. It will be used for the first time in Canada this summer.

NASA ICEBRIDGE

While AWI operates on a regional scale, NASA's Operation IceBridge has been surveying polar ice across all of the Arctic and Antarctica for the last 10 years. The project was started to provide data on polar ice in the interim between the US space agency's ICESat satellite, which was active between 2003 and 2009, and ICESat-2, which is expected to launch in September 2018.

US$100,000
Cost of a 12-hour flight in NASA's DC-8 jet used for Operation IceBridge

IceBridge typically operates two aircraft, a P-3B turbo in the Arctic from Thule Air Base in Greenland and a DC-8 jet out of South America. The aircraft undertake flights of up to 12 hours, six days in a row, with two crews to survey ice. These long-distance flights avoid the complications that are normally associated with having to base in the Antarctic.

IceBridge's main instrument is a laser altimeter, which measures the elevation of the surface of the ice. Recently upgraded, it transmits 10,000 pulses every second – three times more than the previous versions and with a shorter pulse duration. The upgrade will enable the mission to measure ice elevation more precisely, as well as try out new uses on land ice.

This measurement is also more accurate than most satellite altimeters. The use of aircraft also has the benefit of being able to carry instruments for other monitoring tasks. However, the speed of the survey and the extent of measurements is limited in comparison to satellites.

Joe MacGregor, project scientist for NASA's Operation IceBridge, says, "The DC-8 is called the Airborne Science Laboratory and that's a helpful reference point – the aircraft is our lab.

"The laser altimeters alternate between red and green light. This has value because ICESat used lasers that were red, whereas ICESat-2 will use lasers that are green. There could be a penetration bias between red and green, which we are trying to work out and compensate for."

The aircraft carry sounding radar and gravity meters for most missions. The data is used to work out geological anomalies. The P-3 also has a magnetometer in the tail boom, which is used to work out the location of sub-glacial volcanoes. In addition, the aircraft are equipped with cameras for high-resolution photography, an infrared camera and hyperspectral imaging cameras.

MacGregor says data integrity is a concern, alongside the weather, logistics and flying the aircraft safely: "We verify operations at every step during a mission. We only fly when there is low turbulence and in mild conditions. When you are flying 1,500ft above rock formations and glaciers, it's spectacular, but there is no room for error, the bank angle is limited to 15º to prevent GPS signal loss.

"Also, when you are spending US$50,000 per flight in the P-3 and up to US$100,000 in the DC-8, you need to know that it's money well spent. The system has to back all that data up."

"Some of the instruments will be valuable for ICESat 2's calibration and validation. An overlap between IceBridge and ICESat-2 will help tie these time series together," says MacGregor.

With the many secrets that the polar regions still hold, it looks likely polar aircraft and their innovative data acquisition systems will remain a useful research tool for some years to come. \\

// Unlike the STOVL F-35B, the F-35C has been tested against the catapult and arresting requirements of a conventional carrier *(Photo: US Navy)*

F-35 checks out

The completion in April of the system development and demonstration phase of the F-35 Lightning II program provides an opportunity to look back at more than a decade of intense testing

1 // October 3, 2011 saw the first F-35B vertical landing on a ship at sea *(Photo: US Navy/ Natasha R Chalk)*

BAE Systems test pilot Peter Wilson completed the developmental flight test of the Joint Strike Fighter's (JSF) system development and demonstration (SDD) component with an F-35C external loads sortie on April 11, 2018.

Comprising more than 1,000 personnel, among them pilots, flight test engineers, ground crew and support specialists, the SDD team performed six detachments at sea and in excess of 1,500 vertical landing tests with the complex F-35B variant. Developmental flight test team sorties included missions with as many as eight F-35s, flying against advanced threats, among them 183 weapon separation, 46 weapon delivery accuracy and 33 mission effectiveness tests.

From the outset the F-35 test program was planned on a scale and complexity never before attempted. A retrospective of the 12 years since F-35A AA-1 completed the type's first flight in 2006 reveals design shortcomings, cost overruns and delays. The process of readying the most technologically challenging military aircraft system ever created for multi-variant international service has been long and challenging. Never before had an aircraft with the F-35's degree of sensor fusion, intelligence-gathering and warfighting capability been combined in a tactical fighter, especially one designed in three very distinct variants and for stealthy, or low-observable, operations.

In its 2004 F-35 annual report, the office of the Director, Operational Test and Evaluation (DOT&E) exhibited notable prescience in identifying software development as a particular challenge: "The JSF requires an unprecedented amount of software. Block 3 delivers the majority of the capability. The slope of the learning curve and efficiencies required to execute Block 3 software development exceeds previous software development programs." At the completion of developmental flight test, the Block 3F software, which was intended to support basic combat capability, had yet to reach the required full standard.

The report also identified that the weight reduction required to create a useful operational fighter out of the STOVL F-35B would complicate the future test program, as it would inevitable erode the much vaunted commonality between the 'conventional' F-35A, F-35B and carrier-capable F-35C.

A test and evaluation masterplan was under review by late 2005 and an examination of trial resources had noted shortfalls in "instrumentation and adequate opposing forces/threats", requiring further planning and investment to solve. The F-35 was presenting challenges not only from industrial and operational perspectives, but for its testers. A decision had also been made to align the test program with software capability blocks, enabling a focus on the enhancements introduced with each standard, rather than attempting to begin a test program on a near-operational configuration. The requirement for a "data collection and range interface capability that enables precise mission replay and data capture to evaluate mission-level effectiveness and suitability" had also been recognized at this early stage.

Further challenges to existing test processes were identified in 2006, when the DOT&E recognized that neither the US Air Force nor the US Navy had programs in place to create a full-scale aerial target sufficiently capable of supporting the full range of F-35 weapons integration trials. Nonetheless, AA-1's F135 engine was run

65,000
Test points by engineers during F-35's development

2 // The F-35B's door design has proved challenging *(Photo: Lockheed Martin)*

"The F-35 program was planned on a scale never before attempted"

for the first time and taken into full afterburner during ground running, before its first flight in December 2006.

INTEGRATED TASK FORCE AT PATUXENT RIVER

BF-1, the first of the F-35B aircraft, completed its maiden flight 18 months later, in June 2008, followed by the initial F-35C in June 2010. Breaking the mold for previous US fighters, the JSF program progressed from the original X-35 designation, where 'X' denotes 'Experimental', to F-35 (Fighter), without the developmental 'Y' stage, exemplified by the YF-16. Instead low-rate production machines, delivered in various lots to different software standards, supported the developmental flight test program.

An Integrated Test Force (ITF), comprising contractor and customer representatives, was established at Patuxent River, Maryland, in 2009, with the objective of completing 168 of the planned 5,000 flights required to complete SDD. Instead, with only three of 13 SDD airframes delivered and the remaining 10 delayed, only 16 sorties were flown in that first year. Among these, one was planned to include the first F-35B vertical landing, but it was postponed to 2010.

That initial touchdown occurred in March, the first of 10 such landings during the year. While engineering and software issues continued to challenge the program, however, overall the test pace increased such that for FY2010 the number of flights achieved exceeded those planned, with 2,948 test points completed compared with 2,496.

By June the F-35C had also joined the SDD effort, with the ITF increasing its resources, adding engineering support to its existing F-35B cadre, ready to begin flying the carrier variant later in the year. The F-35 fleet operated Block 0.5 software through most of 2010, with the first Block 1-equipped aircraft, an F-35A, arriving at Edwards AFB, California, in December. Considered adequate for initial training, Block 1 fixed bugs found in Block 0.5.

Into 2011, software work focused on completing Block 0.5 test points, with Block 1 assessment split into Block 1A and Block 1B segments. F-35A and B testing remained 11% and 9% behind schedule, respectively, even after the test program was reordered to take into account ongoing SDD difficulties. But there was better news for the US Navy – its F-35C was already 32% ahead.

Perhaps most significantly, the F-35 went to sea for the first time in October 2011, with the B-model completing initial amphibious ship trials. Two additional aircraft joined the F-35B SDD trio as the ITF worked to catch up and expand its understanding of the jet's capability. Rapid F-35C progress included the identification and completion of new test points, while a particular focus of the F-35A effort was in readying the type for initial pilot training.

By November 2012, 34% of SDD test points had been completed, and while the F-35A remained slightly behind the overall test schedule, the B and C models were ahead. However, these figures hid underlying software-related issues and several test points had been deferred until suitable software became available, while other points were added to assess software fixes. Block 1 was finally verified and some trials toward Block 2 development completed, but even this was some way from delivering combat capability.

Highlights for the year included flight envelope expansion, with the F-35A reaching a speed of Mach 1.6 and its 50,000ft maximum altitude, but all variants continued to face structural

3

3 // AIM-120 missile launch for AF-1 *(Photo: Matt Short/ Lockheed Martin)*

17,000
Flight hours flown by the F-35 to test its systems during development

9,200
Sorties made by the F-35 aircraft during its developmental testing

4

4 // In hovering and STOVL flight, the F-35B gains lift from its vectored exhaust nozzle and forward lift fan *(Photo: US Navy/ Michael D Jackson)*

STOVL SDD CONTRIBUTION

As one of Lockheed Martin's major industrial partners on the F-35 and representing the program's most important overseas contributor, BAE Systems focused its SDD test flying on the F-35B.

When the type took its first flight, from Lockheed Martin's Fort Worth, Texas, facility in June 2008, BAE Systems test pilot, Graham 'GT' Tomlinson was at the controls. The company remained at the forefront of F-35B flight test as the Integrated Task Force was established at Patuxent River in 2009. The first STOVL test aircraft, BF-1, was ferried to the station during November and undertook its first test flight from there on December 23.

Through the subsequent SDD effort, BAE Systems supported 4,041 hours of test flying with a fleet of five F-35Bs, covering 20,137 points. With SDD complete, attention is turning to the UK-specific effort to complete the jet's integration with the Royal Navy's Queen Elizabeth-class (QEC) aircraft carriers.

The flight trials will involve the BAE Systems team at Patuxent River and its UK-based engineering teams, elements of which will be on board HMS Queen Elizabeth when it sails for fixed-wing sea trials later this year. The company's F-35/QEC integration simulator facility at Warton, Lancashire, continues to play a key role, with RAF and Royal Navy pilots using it to develop a flight trials plan.

5 // AF-1 and AF-2 during a 2010 test flight *(Photo: David Drais/ Lockheed Martin)*

challenges, with the F-35B's complex door systems proving particularly difficult for engineers to perfect.

With 18 aircraft assigned by year end, 2013 saw flight test again achieving rates close to those scheduled. Software trials continued toward the completion of Block 2B work, which was intimately connected with the F-35's Autonomic Logistics Information System. The ultimate 2B goal was to inform Block 3F, considered the service-entry combat-capable standard. The trials included 10 days of the F-35B flying off USS Wasp, while all three variants continued weapons and performance trials.

With the US Marine Corps (USMC) declaring its wish for F-35B initial operating capability (IOC) in 2015, 2014's work pushed for the completion of Block 2B testing, while addressing Block 3i (limited combat capability) test points on the way to 3F. Elsewhere, while overall test point completion rates remained high, weapons and systems integration presented challenges that slowed progress in the IOC's key areas. An F-35A engine failure in June added to the program's woes, with consequent engine modifications introducing further delay.

13
F-35s used for testing during its developmental testing

"The Lightning II heralds a new era in air power"

6 // An F-35C returning from a flutter trial in 2011 *(Photo: US Navy/Phaedra Loftis)*

Block 2B testing was terminated in May 2015, leaving deficiencies in the standard but offering a limited combat capability sufficient for the USMC to declare IOC in July. Block 3i and 3F trials continued in earnest to produce truly combat capable aircraft, the Block 2B machines being incapable of autonomous operations in contested airspace. While the complexities of the program as a whole still required attention across a gamut of test points, the primary effort now focused on completing Block 3F, a task then considered achievable by May 2017.

SDD CONCLUSION

In 2016 the JPO considered August 2017 a realistic date for the conclusion of SDD, yet DOT&E had revised its earlier estimate and now believed Block 3F trials would continue until July 2018. Although structural and systems challenges continued to emerge through 2016, the F-35C embarked on the USS George Washington in August and the F-35B went to sea again in November. Further weapons trials, including external carriage, expanded the F-35's warfighting capability, but without Block 3F its frontline suitability remained questionable.

With time and funds running out for SDD, in 2017 the JPO devised a Continuous Capability Development and Delivery (C2D2) program. Beginning in 2018, C2D2 is a means of addressing Block 3F deficiencies and working toward Block 4. While the final elements of SDD testing elsewhere in the program ended with various levels of completion, C2D2 might also be seen as a tacit acknowledgement that the F-35's software requirements were simply too great for development and test to be achieved within even the revised SDD timeline. Initial service aircraft have therefore inevitably joined their squadrons with intermediate software standards.

The C2D2 initiative will continue alongside initial operational test and evaluation (IOT&E), the next originally scheduled phase of F-35 trials. Further complication arises for nations wishing to operate or equip their Lightnings differently from the US services. The UK, for example, will fly its F-35Bs off a unique carrier design while employing UK-specific weapons, systems and tactics. The country's Lightning Force is prepared to maintain a small, permanent F-35 test facility in the USA throughout most of the type's service career.

As F-35 developmental flight test came to an end, Greg Ulmer, Lockheed Martin vice president and general manager of the F-35 program, said, "The F-35 flight test program represents the most comprehensive, rigorous and safest developmental flight test program in aviation history." In line with a similar message from the US Navy's Vice Admiral Winter, he went on to describe the transformational capability the aircraft introduces to its operators and there's no doubting that the Lightning II heralds a new era in air power.

What neither man mentioned was that thanks to its design concept, the F-35 will never leave flight test. The jet was conceived for constant development through staged improvement to its sensors and weapons systems, much of it software driven and almost all requiring an element of flight test. The developmental flight test program may be over and the IOT&E phase about to begin, but in many ways the F-35's flight test career is only just beginning. \\

Future Spino

1 // The Bell V-280 Valor converting to airplane mode during recent flight tests in Amarillo, Texas

ff

An innovative and broad technology demonstration program in the USA is helping to determine the design and specification of the next generation of military helicopters

2 // The Bell V-280 flew for the first time last December at the Bell Military Aircraft Assembly and Delivery Center in Amarillo, Texas *(Photo: Bell Helicopter)*

The ultimate shape of the US military's next generation of helicopter is being determined by data from today's Joint Multi-Role Technology Demonstration (JMR-TD) program. There are four main prototype development projects.

Since its first flight under the JMR-TD program last December, the Bell V-280 tiltrotor has attained 190kts and converted from helicopter to airplane mode. The Sikorsky-Boeing SB>1 compound helicopter should fly later this year after ground testing. Each squad-sized demonstrator is to generate 120-140 hours of flight test data.

Under parallel technology investment agreements, Karem Aircraft will ground-test a full-sized optimum-speed tiltrotor nacelle in 2019, and AVX Aircraft will apply results from coaxial compound helicopter wind tunnel tests and piloted simulations to smaller Future Vertical Lift (FVL) scout concepts.

All four JMR contractors are feeding data to the US Army Aviation Development Directorate (ADD) so that it can make informed decisions on FVL. According to Army JMR/FVL program director Dan Bailey at Redstone Arsenal, Alabama, "As they learn, we want to learn what Future Vertical Lift looks like."

The FVL plan envisions a family of aircraft with greater speed and range than today's helicopters. For example, US Army analyses have pegged the desired cruise speed for a practical Black Hawk replacement at 230kts (425km/h), with a range of around 229 nautical miles with 12 troops and four crew. An FVL platform twice as fast as today's helicopters would double the number of troop lifts possible under cover of night. A Black Hawk replacement also has to hover for 30 minutes at 6,000ft and 95°F (1.8km and 35°C) to insert and immediately extract troops at mountainous landing zones.

The FLV plans call for one or more of the innovative JMR configurations to result in an aircraft that remedies "capability gaps" in today's vertical lift fleet. Five capability sets have been devised to characterize the aircraft to be developed.

Capability Set 3 (CS-3) describes a mid-sized FVL assault squad carrier expected in development around 2030 to initially augment and then replace today's 22,000 lb (10,000kg) Black Hawk helicopter, the biggest part of the US vertical lift fleet. The Bell V-280 Valor tiltrotor and Sikorsky Boeing SB>1 Defiant compound helicopter are sized around 30,000 lb (13,600kg) gross weight to allow for new, heavier technologies in a faster, longer-range FVL. Significantly, neither JMR demonstrator is an FVL prototype. Systems are borrowed from existing aircraft to save time and money, and structures lack the ballistic tolerance and crashworthiness of a combat aircraft. The fuel-efficient 5,000shp turboshaft needed to achieve FVL range is itself a science and technology demonstrator years from production. This means that the Valor and Defiant are flying with proven, but thirsty, engines.

230KTS
The cruise speed that enables Future Vertical Lift concepts to double the productivity of conventional helicopters

The JMR Valor and Defiant remain contractor-owned aircraft, flying with a FAA experimental certification. They will nevertheless explore flight envelopes for new military vertical lift concepts. Bailey explains, "We don't have key performance parameters. That's a very doctrinal

3 // The Sikorsky-Boeing SB>1 Defiant compound helicopter is sized to replace the UH-60 Black Hawk assault aircraft *(Photo: Sikorsky)*

term related to a capabilities document we don't yet have. What we set were key technical measures. There's endurance, hover efficiency and forward flight efficiency – lift-over-drag types of things.

"It's not just about how far you go or how long you can stay in the air – it's more about efficiency."

ANALYZING ALTERNATIVES

FVL is also considering a smaller, light attack/reconnaissance aircraft to work with an advanced UAS and the CS-3 assault aircraft. The schedule of FVL developments is yet to be determined. US Army leadership may launch upgrades for the Black Hawk and other helicopters pending FVL. An analysis of alternatives is expected to be reported in 2019 before a development decision is made on the Black Hawk replacement.

5

Future Vertical Lift Capability Sets will identify aircraft from unmanned air vehicles to ultra-heavy cargo lifters

The US Army leads the JMR-TD. The US Navy is meanwhile conducting its own analysis of alternatives for a notional Seahawk replacement. Preliminary industry data feeds FVL simulations. According to training and doctrine command and FVL director Col. Erskine Bentley at Fort Rucker, "We develop these modeling simulations and use a program called Helios [Helicopter Overset Software Simulations] for aircraft modeling. We put all that in the simulation, and it enables us to predict the design capabilities of FVL aircraft."

Helios also models aircraft lifetime costs and pits concept aircraft against projected threats to judge the survivability of different aircraft.

Industry and government are sharing the cost of the JMR-TD throughout the program, including the test campaigns. The army, for example, contributes experimental test pilots – two primary and one backup – and two flight test engineers each to the Valor and Defiant teams. In February, a pilot from US Army Special Operations Aviation Command became the first army pilot to fly the Valor. US industry, government and academia representatives share technical insight and resources in a Vertical Lift Consortium (VLC).

VLC managing director Gerry Graves says, "One of the most exciting things I've seen in the VLC is the collaboration we've had with the FVL requirements Integrated Product Team. The leader of that, Col. Bentley, met with the VLC several times on Cap Sets, gaining feedback on those and learning a little bit about what is achievable."

TILTROTOR ANEW

Late in 2017, Bell flew the V-280 Valor third-generation tiltrotor at its Military Aircraft Assembly and Delivery Center in Amarillo, Texas. The delivery center there has a new US$3m tiltrotor run stand to exercise the V-280 or V-22 with rotors turning through full tilt from helicopter to airplane mode, enabling the JMR team to measure the effect of differential cyclic control inputs. Still, V-280 testing is planned to move from Amarillo to Bell's Flight Research Center in Arlington, Texas, later this year.

Lower disk loading promises the V-280 Valor enhanced low-speed handling for air assaults, and the US government also wants to test it on the ADS-33 handling course at the Naval Air Warfare Center Aircraft Division in Patuxent River, Maryland.

By mid-May the V-280 had achieved a 190kts cruising speed. The demonstrator

"The FVL envisions aircraft with greater speed and range"

4 // Karem Aircraft expects ground runs of a full-scale Capability Set 3 Optimum Speed Tilt Rotor nacelle representative of its Maverick assault FVL in 2019 *(Photo: Karem Aircraft)*

uses twin General Electric T64-GE-419 turboshafts – the same 4,750shp engines that are now in the Marine Corps CH-53E Super Stallion helicopter. Tests at Amarillo have advanced from restrained and unrestrained ground runs, to first hover and vertical flight in helicopter mode. Meanwhile, drivetrain tests are continuing to be conducted at the Bell Drive Systems Center in Grand Prairie, Texas. Drive system test rigs measure tooth fatigue in tiltrotor gearboxes with increasing loads. Piloted simulations in the Arlington Systems Integration Laboratory (SIL) use flight control software to work aircraft hardware.

Valor flight test instrumentation borrows from that on the Bell 525 helicopter. "It's similar in terms of approach," acknowledges Bell vice president of advanced tiltrotor systems, Keith Flail. "However, given the helicopter versus the tiltrotor, you're going to instrument things differently. It's different in terms of what you have to monitor. You can't do an apples-to-apples comparison."

4
Technology investment agreements run through 2019 to explore joint multi-role technologies for Future Vertical Lift

ADVANCING THE BLADE CONCEPT

Sikorsky and Boeing are partnering on an advanced compound helicopter being assembled at the Sikorsky Development Test Center in West Palm Beach, Florida. The SB>1 Defiant improves on the coaxial rigid-rotor Advancing Blade Concept of the 1970s XH-59 demonstrator to attain FVL speed and efficiency. Lift-offset coaxial rotors with a pusher propeller and variable speed drive enabled the 6,000 lb (2,700kg) X2 demonstrator to achieve 262kts (463km/h). The 11,000 lb (5,000kg) S-97 Raider collected about 20 flight hours of flight test data before a hard landing. A second company-funded demonstrator will resume flight tests this spring and give the Sikorsky-Boeing team a risk-reduction asset pending first flight of the 30,000 lb (13,600kg) Defiant.

The SB>1 flight test fuselage underwent static load testing with a dummy transmission in the Boeing facility in Mesa, California. First flight of the big JMR demonstrator has been slowed by manufacturing challenges, but Sikorsky FVL business development director Rich Koucheravy explains, "We remain on track to fly in 2018, after successful completion of integration testing, ground test, DNE [do not exceed] establishment, and testing on the propulsion system testbed [PSTB] ground test stand.

"We are building this technology demonstrator differently from other rotorcraft platforms available today, and to do that requires time and incurs risk as we develop and evolve new processes and technology."

The Sikorsky-Boeing JMR demonstrator uses two Honeywell T55-GA-714A turboshafts like those found in the CH-47F Chinook, each rated 4,777shp at take-off. Major components of the Defiant hydraulic, electrical and flight control systems have been tested in various ground rigs. Dedicated simulators at Sikorsky in Stratford, Connecticut, and Boeing in Philadelphia, Pennsylvania, have tested flight controls, handling qualities and the vehicle management system. The propeller clutch was tested on a dynamometer at the supplier.

The SB>1 PSTB at West Palm Beach is due to run the Defiant transmission and rotor system in July 2018, following the JMR incremental test methodology and risk mitigation plan approved by the government. Koucheravy says, "The PSTB contains all of the major systems of the aircraft in their correct positions relative to each other and allows us to exercise the majority of the conditions that the

"The Defiant improves on the coaxial rotor concept"

5 // AVX Aircraft has completed wind tunnel and piloted simulations of its coaxial compound helicopter for FVL *(Photo: AVX)*

6 // Sikorsky's company-funded S-97 Raider demonstrator provides a risk reduction platform for the bigger Defiant FVL, and a pathway to a scout *(Photo: Sikorsky)*

7 // The tiltrotor test stand built at the Bell Amarillo facility is designed to exercise the Valor through its complete tilt cycle from helicopter to airplane mode *(Photo: Bell Helicopter)*

aircraft will experience before we get off the ground."

The PSTB measures installed engine performance, propeller performance, and electrical and control system operation. It tests the aircraft clutch, gearboxes and rotor system components and is instrumented to record more than 800 parameters including temperatures, pressures, torques, strain gauge information, inlet flow rates, blade pitch, cooling flows and accelerometer data.

The Defiant PSTB will also measure gear patterning and the interactions between the coaxial rotors and fuselage, and the rotors and auxiliary propeller.

Boeing FVL director Randy Rotte explains, "While certain aspects of high-speed flight cannot be simulated on this ground-based testbed, we will be applying cyclic and collective inputs to both the main rotors and prop that cover the full range of control system operation, the moments and loads expected, and the full power levels expected in flight." External instrumentation will be used to measure the Defiant's acoustics.

OPTIMIZING TILTROTOR TECHNOLOGY

While Bell refines the tiltrotor for FVL, Karem Aircraft is pursuing Optimum Speed Tilt Rotor (OSTR) technology to achieve FVL speed and range measures. Continuously variable speed and individual blade control (IBC) on tilting proprotors promise to optimize efficiency. Karem is preparing to test a 36ft (11m) OSTR proprotor with articulated engine nacelle on a ground test stand in Victorville, California, next year. The test article is sized to represent the Maverick tiltrotor that is proposed for FVL Capability Set 3.

Karem previously ran a full-scale OSTR hub with blade actuators at the company facility in Forest Lake, California. The new single rotor tiedown (SRT) rig incorporates all components that would be in the nacelle for flight, including the proprotor, IBC controls, drive system, powerplant, sensors, thermal management systems, and primary and secondary nacelle structure. The heavily instrumented SRT will measure vibrations and loads, temperatures, pressures and shaft speeds. It also includes strain gauges and accelerometers on all dynamic components and health monitoring sensors for the drive and subsystems.

While industry giants Boeing and Sikorsky integrate their compound helicopter, engineering house AVX Aircraft in Benbrook, Texas, remains under contract for further study and development of a coaxial compound helicopter that uses stacked rotors, ducted thrusters, and lifting canard and tail surfaces to attain FVL speed and range. The coaxial compound helicopter uses differential tail thrusters for both propulsion and directional control. Extensive computer modeling indicates that simplified controls on a rotor less rigid than that of the Sikorsky-Boeing SB>1 can reduce both drag and weight.

120-140HRS
Amount of test data that two joint multi-role flight demonstrators will each accumulate

AVX tested a 1/10 scale model of the CS-3 FVL assault aircraft in the Texas A&M university wind tunnels. The company is now waiting for revised FVL CS-1 requirements for unmanned reconnaissance air vehicles or manned scout aircraft with a 2,000 lb (900kg) payload. Sizing a scout rotor system to operate within 'urban canyon' clearings 40ft (12m) square poses fresh challenges for engineers seeking low disk loading. The company says, "The scalability of the design makes possible the quick development of CS-3 aircraft down to a future UAV design." \\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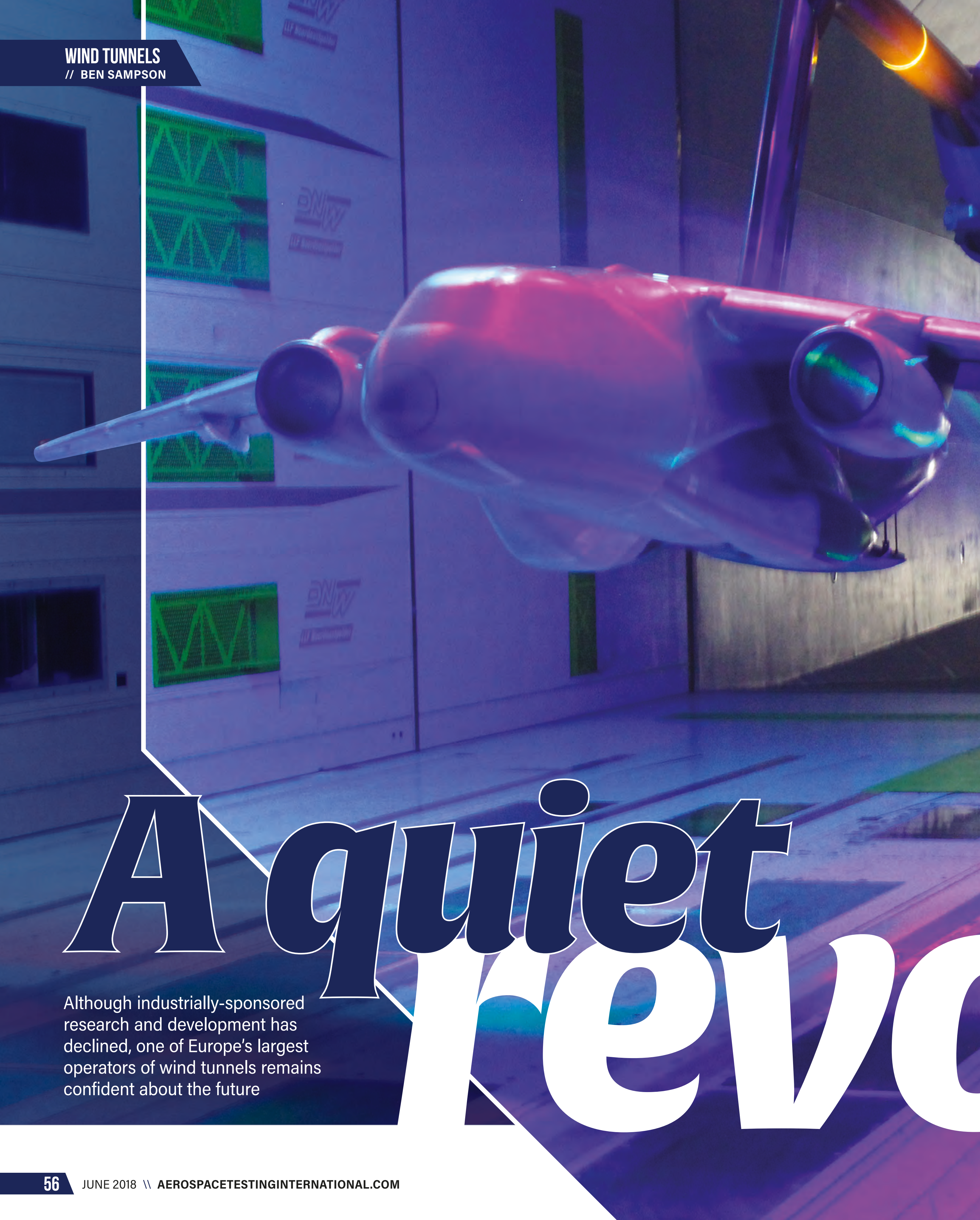

A quiet revo

Although industrially-sponsored research and development has declined, one of Europe's largest operators of wind tunnels remains confident about the future

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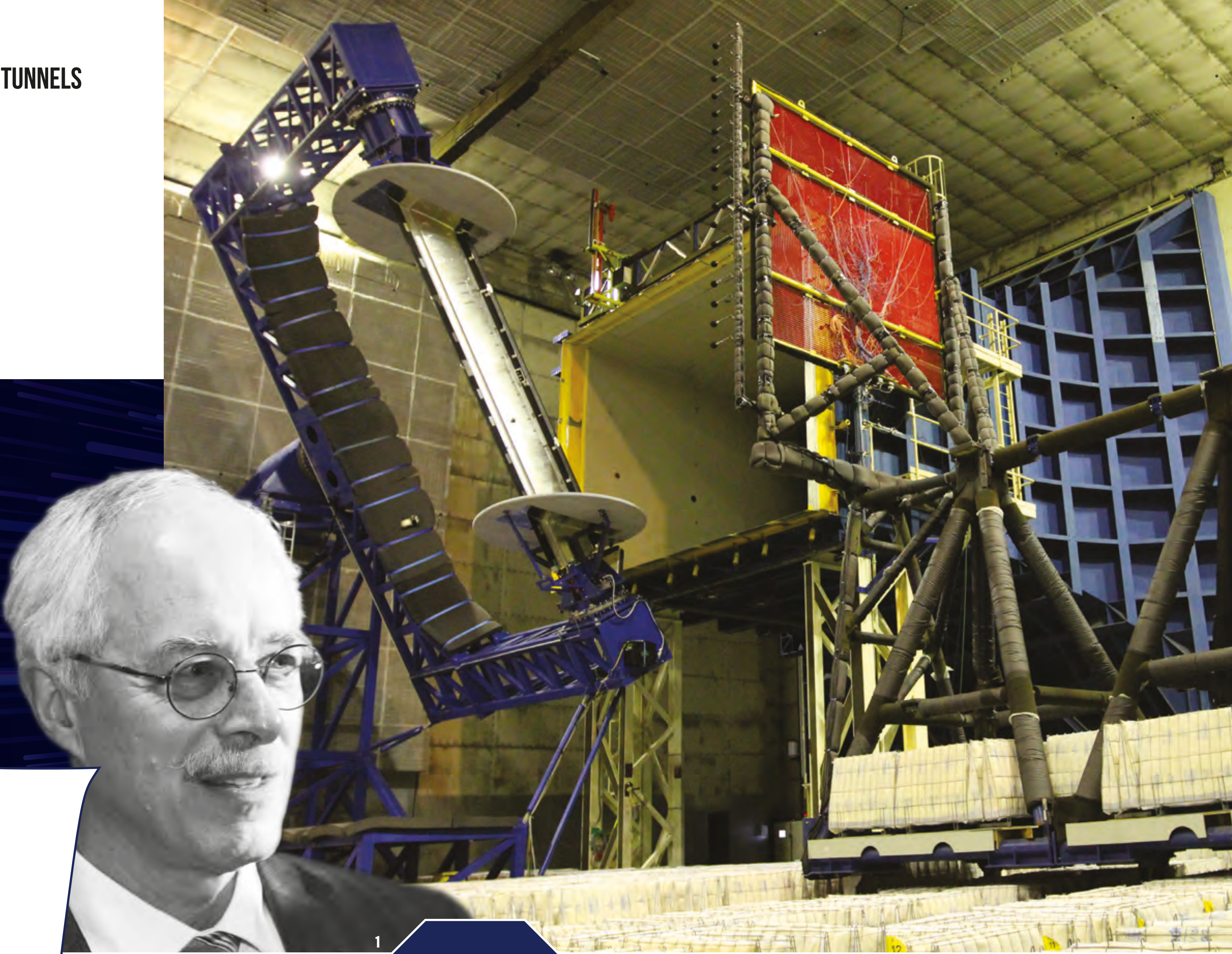


1

€3M
The cost of the most expensive model ever tested at DNW's low-speed wind tunnel (US$3.5m)

In his office Professor Georg Eitelberg is surrounded by models and pictures of the aircraft he and his engineers have tested. When we meet, he is about to step down as director of German-Dutch Wind Tunnels (Deutsch-Niederländische Windkanäle, DNW), a position he has held for 20 years, to take up a part-time professorship at the Delft University of Technology. The career change finds the industry veteran in a reflective mood. He is proud of the past achievements that surround him and sanguine about the future of aeronautical testing.

CONSOLIDATION

Marknesse, 31 miles (50km) northeast of Amsterdam, is DNW's largest test site and features the biggest low-speed wind tunnel in Europe, the 9.5m-wide (31ft) large low-speed facility (LLF). It was built almost 40 years ago and has been used to test dozens of aircraft. However, the number of staff working at Marknesse has steadily decreased over the last 20 years, from a peak of around 150 to its current level of around 100.

"There has been a reduction in staff because of a continual drive for efficiency and the consolidation in the aeronautical industry," says Eitelberg. "The industry is so successful, there are practically only two companies left in the world, Airbus and Boeing, both with full order books for the next 10 years. They are not in need of innovation and we've noticed that the industrial development part of our business is getting weaker."

The paucity of innovation Eitelberg perceives in aeronautics saddens him. "I think the fascination for aeronautical engineering for most people lies in seeing different configurations flying with different properties," he says. "Flight is still a fascinating area, but when you see the umpteenth version of an A320 or a Boeing 737, you realize that we have a mature product that doesn't need to be significantly changed."

He also believes the concentration of money in the duopoly restricts innovation. "Around 90% of the aeronautical industry's turnover is with Boeing and Airbus. There are smaller firms, but they cannot justify the complicated testing procedures we offer on the basis of their product range. The work is so concentrated, I don't know when the next innovation push will be."

PERFORMANCE CRITERIA

DNW manages 10 wind tunnels in Germany and the Netherlands, where the testing carried out can be split into two types. Research work is done mainly by academics and is mostly early-stage blue-sky R&D. Industrial development testing is performed later in a project, mainly by engineers at aerospace companies.

Academics use the wind tunnels to research issues around flight and aerodynamics. "We are still trying to help researchers understand phenomena like sound generation, drag reduction, control and stability, separation, transition and laminar wings," Eitelberg says. On the industrial development side the focus is on mitigating risk. "We test the extremes of flight conditions for aircraft manufacturers' latest designs using models. If the design doesn't work in terms of stability control, for example, they know they have a problem," he says.

3

2

1 // Georg Eitelberg, former LLF director

2 // The LLF set up in an open configuration for an acoustic test

3 // An experiment to test potential noise reduction in push propellers

"The amount of data we can produce makes the models very elaborate. We can provide 1,500 pressure points on a model and then the acoustic data, because we can accommodate models with a 6m span instead of the 2ft [0.6m] span models used in university tunnels.

The most expensive model ever in the LLF was worth €3m (US$3.5m) and was made for Northrop Grumman.

UPGRADES AND EXPERTISE

Acoustics, alongside engine integration testing, are fields where DNW is investing in equipment and facilities. Engineers at the LLF take pride in the tunnel's acoustic qualities and the fidelity of the aeroacoustic testing they can conduct.

144
Microphones in the LLW's array for out-of-flow acoustic measurement

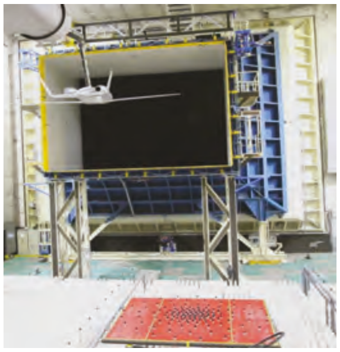
"The interaction between engine and airframe is difficult to quantify and predict. We have made it our specialty to quantify that interaction, by providing the best experimental simulation for landing, approach and take-off."

To achieve more accurate results in these phases of flight, the LLF's floor has a rolling road that moves with the air. DNW has also invested in areas such as engine simulators, which can be installed in the tunnel.

Shifting public opinion, particularly on environmental issues, is a major consideration for decisions about upgrades to wind tunnels. Although the organization's guiding principle is to provide what the industry wants, the decisions of aviation companies can be greatly influenced by short-term business and marketing concerns. An awareness of public opinion can often provide a more accurate guide as to how the industry will develop. "Public opinion is not like engineering analysis," says Eitelberg. "Engineers are most concerned with the cruise phase of flight. The public is concerned with noise and emissions at airports. So we've concentrated on maintaining and developing our acoustic testing and engine integration testing capabilities."

According to Eitelberg, improvements to the environmental performance of aircraft are gradually being made and aircraft manufacturers are being pushed in this direction. "Aircraft are getting quieter and emissions are reducing. But I don't think we'll see any bigger aircraft now."

U-TAIL TESTED AT LOW-SPEED WIND TUNNEL



A recent two-week test campaign at the LLF in Marknesse has helped to develop a new tail for aircraft to reduce the engine noise of business jets. The U-tail works by shielding the engine from the ground and reflecting the noise upward.

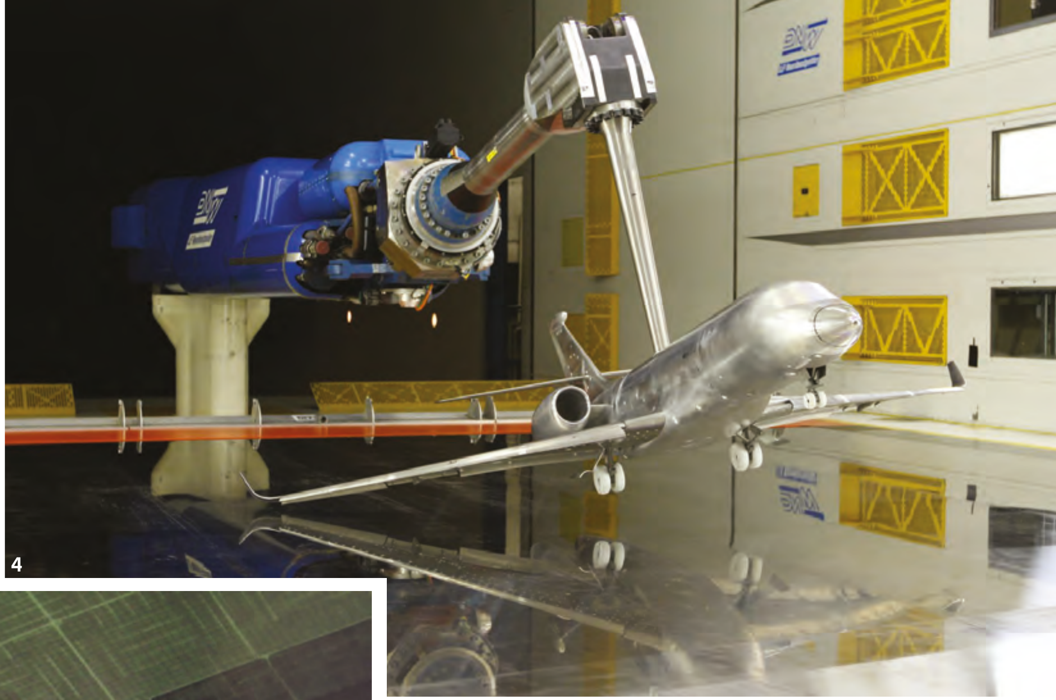
Funded under the EU's Clean Sky program, the main objective of the Shield research project, which started in 2015 and concluded last year, was to develop a prototype U-tail and demonstrate it in a simulated operational environment.

After the concept and detailed design phases, a model of Dassault's Low Sweep Business Jet (LSBJ) featuring the U-tail was tested inside the LLF, including with the moving belt to simulate ground effect and with the use of microphones for acoustics.

Aerodynamic testing resulted in the creation of a new turbulence model for the CFD models. Acoustic testing was carried out with pressure transducers, 39 microphones for far field noise and an array of 140 microphones to measure noise sources on the aircraft.

The next stage saw a full-size U-tail fitted to the rear of an LSBJ for ground tests at the Istres Flight Test Centre near Marseille in the south of France, where it successfully demonstrated the viability of the design.

Floriane Rey, acoustics engineer at Dassault Aviation, says, "It's the combination of testing and simulation that gives you the results. When we found different results from the wind tunnel, we developed a new turbulence model for CFD computations. That led to an accurate comparison with the test results. The wind tunnel data also enabled comparison with classic tail shapes. Thanks to the large size of this wind tunnel, we have been able to measure the noise sources of the landing gear and the nose. It's really important to have that data."



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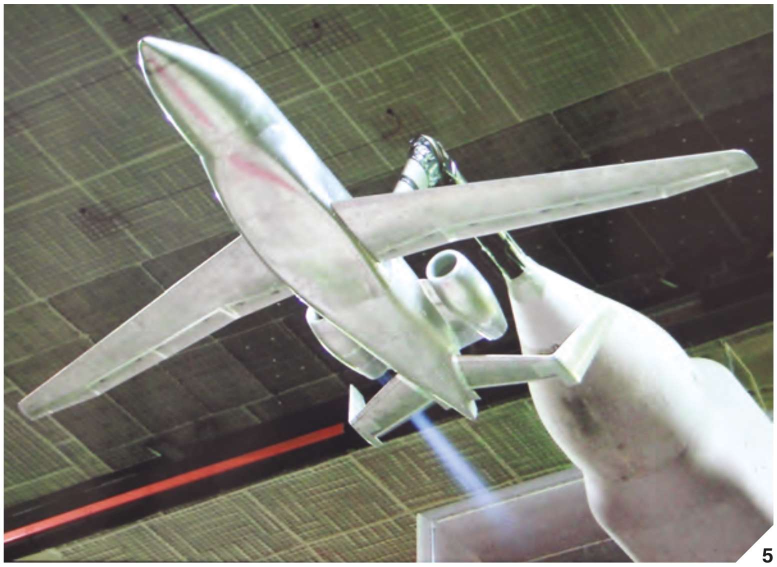

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4 // The LLF can simulate objects that move on or near the ground to address a number of phenomena

5 // Much recent research at the wind tunnel has focused on noise reduction using shielding

The most attention from the public the LLF has ever received was during the tests for the Joint Strike Fighter's STOVL variant in the early 2000s. Eitelberg says, "It was quite controversial at the time, with different countries debating whether to be involved in the program. We provided the customer with good data about the aircraft's performance.

Eitelberg says that, personally, he has enjoyed working on the projects that have tested propeller aircraft. "Most propeller aircraft are underrated. They are more efficient than jet engines especially on the majority of routes that are shorter than two hours – that's 80% of flights worldwide. Forty-eight of the most frequently used routes in the world are shorter than two hours in the air."

"I'm not an economist; I'm an engineer. But with the predicted continued growth in mobility and air travel, someone is eventually going to realize that we can do 80% of it more efficiently, with less fuel burned, by using aircraft with propellers."

Electric aircraft will not make much difference to DNW's simulation of flight using wind tunnels, but the organization is monitoring the development of the technology alongside propeller aircraft as a commercial proposition. "Although the power density of batteries and performance of electrical motors is improving, I think that electrical flight will remain a niche project because of the weight of the batteries," says Eitelberg. "Biofuels offer the only viable recharging method."

DATA AND WORKING PRACTICES

Even if there is an increase in electric aircraft being tested at the LLF, the type of aerodynamic measurements made hasn't changed much. Engineers are examining the same aspects of aircraft, such as noise sources, handling qualities and the interference between propulsion and drag. But IT has changed the way the tests are run. "Our tasks have not changed; the tools have developed," says Eitelberg.

1,500
The number of pressure points on a model from which the LLF can gather data

"The amount of data has increased and the results are available much sooner. No one waits two months for data anymore. They want it and can get it the next day. Also, some acoustic modeling has only become available because of increases in computing power. It takes less time to get the fancy colored pictures, but you still need the knowledge and experience to interpret that data. Maybe in some ways we are very traditional.

"In the future the quality of data will continue to improve in terms of better temporal and spatial resolutions and there will be more image-based data. We can measure the whole surface of the wing and how it bends and twists under loads. Information about the interaction of the wing's material or shape with airflow can be used to verify design procedures.

"Computing power now means we can identify and quantitatively analyze every pixel. In the future there will be more data and more image-based evaluation, which will improve the design tools. This is the same for all aspects of performance."

He adds that although aerospace companies are iterating on the same tube and wing configuration of aircraft, he does not discount that there will be a reason to radically change the design of aircraft, which should increase the amount of experimental prediction testing conducted in wind tunnels as opposed to validation testing. "There might be a radical new configuration to verify," he says. "The engines might go into the fuselage, for example, where there is no history of dependent predictions. Then verification of new designs will once more become important, until we again reach a stable design configuration." \\

Blade runner

MEET GUY CHRISTOPHE, PLANT MANAGER AT SAFRAN'S ISTRES TEST FACILITY


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1 // Snecma's TP400 during testing at Istres. The turboprop engine will power the A400M military transport, and can produce 11,000shp

"Experimental assets require an even higher level of awareness"

// TELL US ABOUT YOUR EARLY CAREER.

I am an autodidact, with a Bachelor of Science (Major: Engineering and Commercial), obtained in 1981, who discovered the aerospace industry a little by chance after a friend of mine informed me about an open position at Turbomeca some 33 years ago. I began in sales before moving to various customer support positions in the world of helicopters, starting with Safran Turbomeca back in 1984. After spending the largest part of my career in a customer support field, I wanted to explore the upstream part of the process, which led thus to my choice to move into the engineering field, and more specifically to engine development testing. A company like Safran offers such career path opportunities.

// SO YOUR AEROSPACE TESTING EXPERIENCE IS RELATIVELY NEW?

Yes! I first began in aerospace testing only recently, when I moved from the rotor-wing engine world to the fixed-wing engine business in late 2014. I was offered a job in San Antonio, Texas, where I took the business manager position at the site where Safran Aircraft Engines (SAE) conducts flight tests of its Silvercrest engines. At this location, we operate a Gulfstream GII modified to accommodate a Silvercrest engine on the right wing in place of one of the Rolls-Royce Spey engines, for flight testing, as part of an intense program (close to 1,000 flight test hours and 270 flights in three years).

// WHAT IS YOUR CURRENT POSITION AND WHAT DOES IT INVOLVE?

After my two years abroad in San Antonio, I returned to France, where I took up my current position overseeing the open air testbed and flight test center of SAE in Istres, which is close to Marseille in the south of France. This seemed a logical continuation of the position I had in San Antonio, as it is complementary in terms of activities covered, while also offering ground testing and different types of engines and aircraft.

// WHAT IS THE MOST IMPORTANT TESTING LESSON YOU HAVE LEARNED SO FAR?

With no hesitation, the most important lesson I have learnt is that in our industry, safety always comes first! The safety of the population overflown, the safety of the flight crew, the safety of any personnel. In aerospace testing, it has been my main concern to ensure that we were performing operations with a high level of control in terms of safety for our crew members first, while also protecting the assets under test. Safety is also absolutely critical during 'normal' service, from aircraft maintenance to flight operation. However, experimental assets require an even higher level of awareness because you are testing things that usually have not been tested before. To be able to do this, you have to ensure operational safety by implementing very stringent testing organization and procedures.

// PLEASE CAN YOU DESCRIBE A TYPICAL DAY.

After reaching the office I love going to the shop floor to meet with the teams and get the latest developments/updates about progress of the assets under test, directly from them. My managers, experts and team members do the job on-site – I am mainly there to ensure the overall coordination, relations with authorities, partners, etc, as needed. I see my main duty as ensuring we deliver the expected tests results to our customers in a timely manner, as a result of efficient planning, at committed costs and within a very safe environment. If I consider that all safety conditions are not fulfilled, I will ask the extra 'what if' question before we start!

2 // Guy Christophe oversees the Open Rotor demonstrator tests currently taking place at Safran's new 'IP2' open-air test rig in Istres, southern France

3

4

3 // The Open Rotor demonstrator is being developed through Europe's Clean Sky research program

4 // Safran and its Clean Sky program partners have received €65m (US$75m) in funding from the European Commission for the project

5 // The Open Rotor features two counter-rotating, unshrouded fans, enabling it to reduce fuel consumption and CO_2 emissions by 30% compared with Safran's current CFM56 engines

// WHAT ARE SOME OF THE MAJOR MILESTONES THAT YOU HAVE ALREADY OVERSEEN?

I am very proud of the Open Rotor campaign we have just successfully completed, reaching all key results expected while demonstrating the maturity of the key technologies. Our site was given the chance to work on the next generation of engines, providing a unique opportunity to project ourselves into the engine world of the 2030s and beyond.

In October 2017, we celebrated the first Open Rotor engine run and the opening of our new test bench (IP2) among all the main stakeholders of the aviation industry R&T community, representatives from the European Community, local authorities, our partners in the Clean Sky Joint Undertaking, including Airbus, and leading executives from Safran, such as our CEO, Philippe Petitcolin.

We are also continuing with our work on the Silvercrest test campaign for the Cessna Citation Hemisphere application.

Finally, we are about to start flight tests of the M88 (Rafale fighter engine).

// WHAT ARE THE UNIQUE FACILITIES FOR ENGINE TESTING YOU HAVE AT ISTRES?

IP2, the Open Air Test Bench (OATB) where we performed the Open Rotor tests, is quite unique. SAE commissioned IP2 in mid-2017, following an investment of €17m (US$19.7m) to be able to test different engine architectures in Istres, such as the Ultra High Bypass Ratio, open rotor or classic turbofan architecture.

This OATB is quite unique in Europe since it can accommodate both engine configurations (open air and classical fan architectures) on its impressive 18m-tall (60ft) pylon. It features a data acquisition system with about 1,200 measurement channels. The OATB makes it possible to conduct engine tests in similar conditions to the Flight Test Bed (FTB) and allows testing impacts of cross wind, for example.

We also benefit from a fairly unique ecosystem with the proximity of Dassault, Airbus, Thales, DGA-EV and good infrastructure, with the longest runway in all of Europe.

The Istres site was established in the mid-1960s and has flight tested all major SAE military engine programs, and now handles all commercial engine flight testing, too. This site is a critical asset in SAE's strategy to remain a major engine manufacturer.

// WHAT IS THE MOST IMPORTANT PIECE OF EQUIPMENT USED IN ENGINE TESTING?

The single most important piece of equipment used in engine testing, other than the engine itself, is the whole test bench. A test bench is a complex system with a lot of pieces of equipment that dialog between them to ensure multiple interconnected functions to achieve two main goals: safety and data acquisition.

// HOW IS ENGINE TESTING CHANGING?

The biggest change I have seen is the increasing amount of data acquired for engine development testing, and also the level of accuracy required by the engineering office. As I mentioned before, IP2 is capable of acquiring close to 1,200 different measurements (speed, vibration, airflow, temperature, etc) during a test.

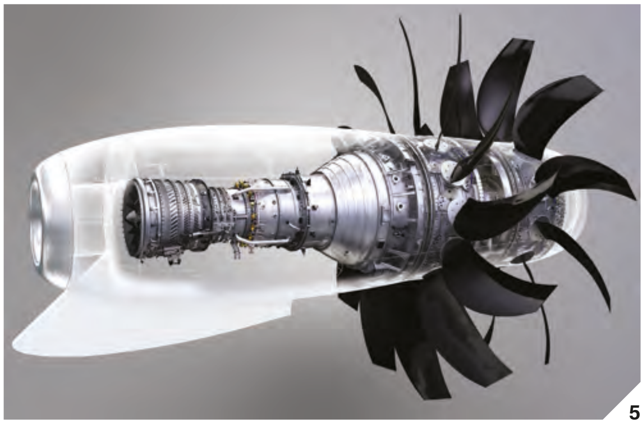
// ANY PARTICULAR TEST OR EXPERIENCE STICK IN THE MIND?

The most exciting experience so far has to be the Open Rotor inauguration ceremony, when more than 400 people visited our site to see this exceptional engine we have been given the chance to test in Istres. This is a once-in-a-lifetime experience!

// DO YOU ALWAYS FORESEE A NEED FOR ENGINE TESTING IN THE FUTURE?

Just as a cook who does not taste his dishes does not know if they're good, our creed is that what we do not test does not work. I do believe that physical testing will continue particularly in our business where product integrity is on top and is a given for all of our customers.

However, it's true that new electric and hybrid aerospace engine developments will cause us to change our methods. But I see this as a great opportunity to enhance synergies among the different entities of the Safran group, due to the need to have a higher integration of power management and distribution in the aircraft tomorrow to meet the aviation challenges that lie ahead. \\



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Southwest

Old *before their* time?

The recent engine explosion on a Southwest Airlines Boeing 737 calls into question the tools and techniques being used to test aircraft for fatigue

1 // A technician inspects engine blades on a Southwest Boeing 737

2 // All engine fan blades used in Southwest's fleet of Boeing 737s have undergone a detailed ultrasonic inspection

3 // The ultrasonic inspections are intended to detect and monitor fatigue

The engine explosion on the Southwest Airlines flight from New York's LaGuardia Airport to Dallas on April 17 shocked people around the world. It resulted in the death of Jennifer Riordan, a passenger who was nearly sucked out of the Boeing 737 after a window was shattered by debris from the engine.

Industry regulators soon discovered that the cause of the accident – a fan blade shearing off – was nearly identical to an incident two years ago. The 2016 blowout on a flight from New Orleans to Orlando led to a loss in cabin pressure and involved the same carrier, aircraft type and engine type – a CFM56-7B turbofan – but fortunately did not result in any deaths.

Though it has yet to release its final report on the 2016 incident, the US National Transportation Safety Board (NTSB) concluded that metal fatigue caused the fan blade to break off. The preliminary NTSB investigations of the latest incident also point to metal fatigue as the cause.

OVERUSE

Following the April 2018 incident, the NTSB conducted inspections of the Southwest fleet. John DeLisi, director of the Office of Aviation Safety at the NTSB, says, "The findings have so far proved inconclusive. This is not a rampant phenomenon. These appear to be the only two blades in the entire fleet where there were cracks."

Following the latest incident, attention focused on Southwest's heavy scheduling, with some experts suggesting that the fan blades had cracked with overuse. But according to DeLisi there is no evidence that either of the blades that broke off had higher than average use. "These appear to be two random blades from the population that have experienced fatigue failures within their expected lifetime," he says.

Nor was there any evidence of discrepancies in the inspection regime. In both incidents the engines were inspected within the required inspection intervals. "For all high-energy rotating parts, engineers will set up the inspection regime so that if a crack exists, but is too small to be detectable, the inspection intervals are frequent enough for it to be caught the next time, before it reaches a critical length," says DeLisi.

The investigation has looked at the materials used in the manufacturing of the blades as well as the lubricants used to grease them. The NTSB has also been looking at the hubs into which the blades were inserted.

The lack of a direct cause disturbs DeLisi because it raises the possibility that the blades failed randomly. The aviation industry works hard to avoid randomness in aircraft safety. "You don't want randomness," he says. "You want materials to behave similarly. You want to be able to proof test one sample to failure and expect that all other parts made with that same material exposed to the same stresses will fail at the same time. That's what gives confidence in fatigue life."

3,000
Cycles or 5,000 hours between inspections of CFM56-7B engine fan blades owned by Southwest

CRACK RESEARCH TEAM

Before the two Southwest incidents there had been almost no accidents attributed to metal fatigue for almost 30 years. That is because the aviation industry has conducted extensive research into the problem for at least half a century. This was forced on the industry because of several high-profile disasters in the early days of commercial aviation. "But now," says DeLisi, "the issue of metal fatigue is well understood."

One of the organizations that has contributed to this body of knowledge is the US National Institute for

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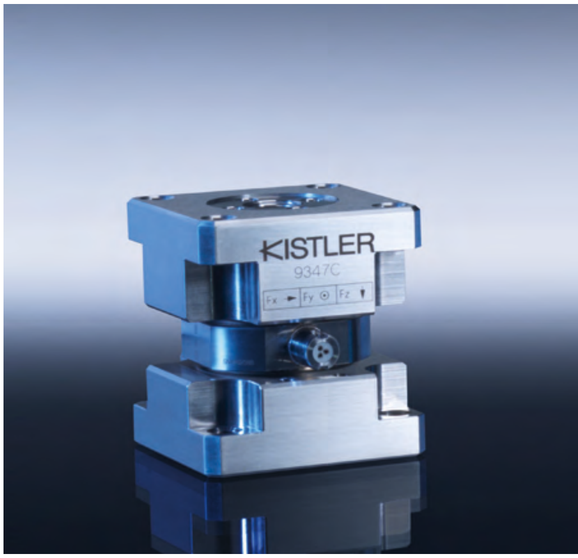

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AIRCRAFT REGULATIONS AND DAMAGE TOLERANCE

Increased level of use and longer operational lifetimes have created a need for regulators to ensure aircraft have a high level of structural integrity that is maintained.

Regulations that cover the inspection of aging aircraft in the USA were overhauled at the beginning of the decade by the FAA. Since December 2010, operator's aircraft structural maintenance programs must include damage-tolerance based inspections to comply with the Aging Airplane Safety Rule. The rule also covers inspections of repairs, alterations or modifications to fatigue-critical structures. The change affected around 4,000 US-registered airplanes and 240 operators.

The European Aviation Safety Agency has been developing the technical elements for an aging aircraft structure plan since 2003. Discussion are ongoing, but certification specifications will be amended to improve standards on structural aging and create guidelines to assess the damage tolerance of structural repairs. Similarly to when the FAA rule was introduced, the changes will require aircraft OEMs to review their existing designs to demonstrate compliance with the amended specifications and for operators to introduce modifications as required. The rule change would again affect around 4,000 aircraft and is planned to be introduced by 2022.

"Typically we find the most cracks in wing spars"

Aviation Research (NIAR) in Wichita, Kansas, which has a dedicated aging aircraft lab.

"We do structural tear downs," says NIAR research director Melinda Laubach-Hoch, who has worked at the lab for 16 years. "We take older aircraft and dismantle them, looking for anything that might be detrimental to the long-term health of the aircraft, such as cracks, corrosion and fretting. If we find any cracks we try to determine the cause."

The work is useful for the aircraft certification process. "We can corroborate whether the expectations about how an aircraft will age agree with reality," she says. "Typically we find the most cracks in wing spars. Usually the most vulnerable point on the spar is where it connects to the aircraft fuselage, because that's where you have the highest load. You also have to check the landing gear because of the impact of landing."

100,000
Flight hours needed before a Boeing 737 reaches the FAA's limit of validity for airworthiness

Vulnerabilities vary according to the aircraft model and manufacturer, although there are general trends. For example, larger aircraft are more subject to fuselage problems, "because it's a much bigger barrel that you're pressurizing", according to Laubach-Hoch.

The primary method used to inspect for cracks in metals is eddy current testing. If a crack is found, it must be repaired for the aircraft to be allowed back into service, since the FAA has a zero-cracks policy.

After the Southwest incident in 2016 engine manufacturer CFM International recommended that its engines in service undergo regular ultrasound inspections. Based on that recommendation, the FAA initiated a public comment period but no rule change was enacted before the latest incident. According to the FAA, the blade that failed in April was not in the population of blades that fall under the new inspection regime.

"The inspections that the FAA is mandating cover a broader population of blades than the initial proposed action," an FAA spokesperson says.

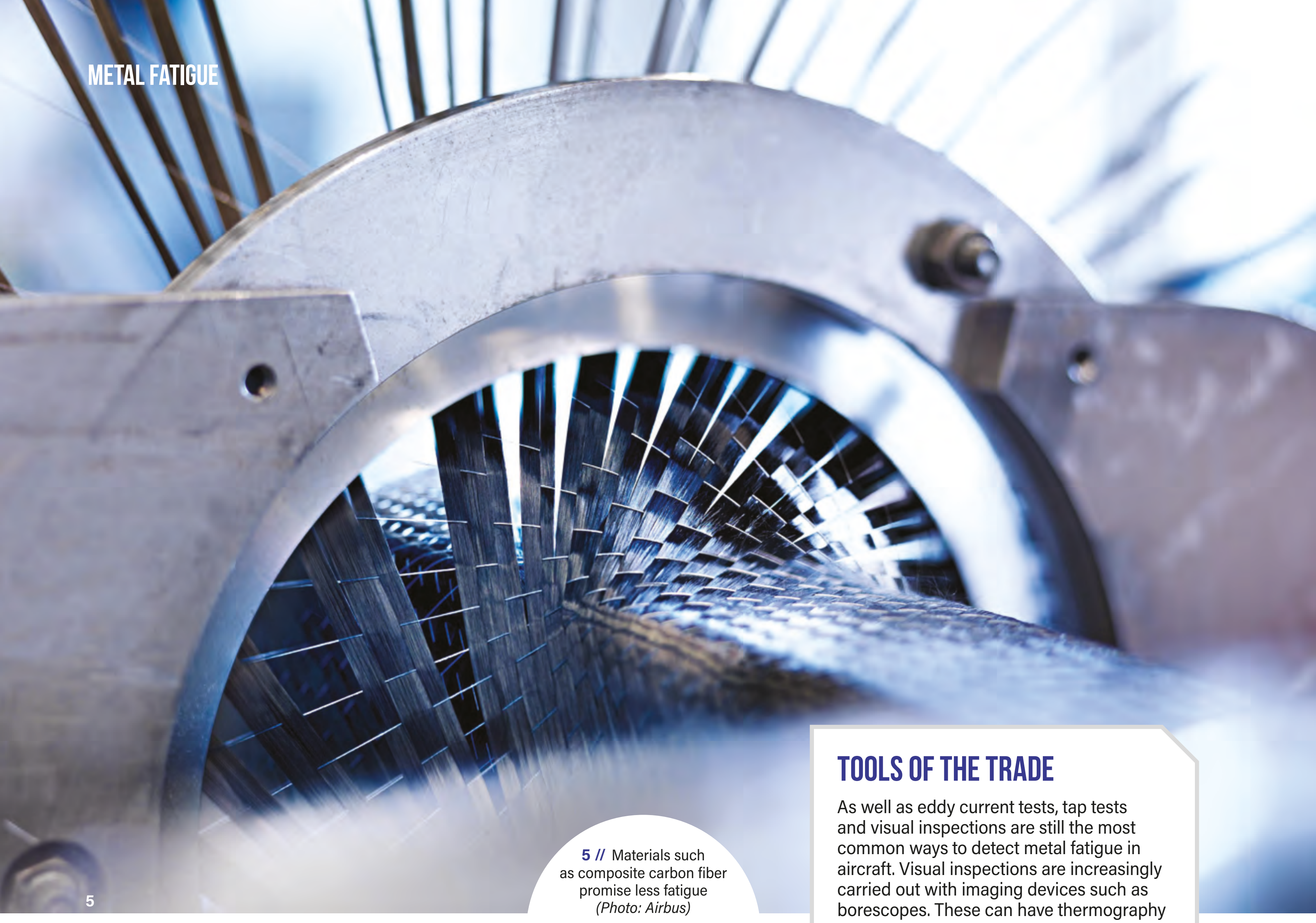
4 // Regulators have established detailed requirements for checking aging aircraft, including regular visual inspections *(Photo: Boeing)*

COMPOSITES AND ALLOYS

CFM International's preference for ultrasound inspections over visual inspections for the fan blades may reflect a concern about corrosion. Ultrasound tools are good at detecting a loss of thickness and are normally used more for the inspection of airplane parts made from composites.

Composite materials used in aircraft have a greater resistance to fatigue damage than metals. But composites are still an emerging material and how they will perform over the long term is still largely unknown.

"We know a lot about how metals age because of the long time we've been



5 // Materials such as composite carbon fiber promise less fatigue *(Photo: Airbus)*

working with them," Laubach-Hoch says. "But with composites you don't always see the damage. While composites can absorb an impact, the damage is sub-surface."

A new generation of lightweight metal alloys is also finding its way into aircraft components. Under FAA regulations these alloys are subject to the same testing and inspection regime as older alloys. However, the complexity of parts that use these alloys, such as engine components, makes it more challenging to predict the fatigue damage capability of certain components. "In those cases more testing may be required to develop material properties and understand the durability aspects of the new alloy," the FAA spokesperson adds.

30,000
CFM56 engines in use by more than 550 operators around the world

OPERATIONAL FACTORS

Another major issue that creates variability in fatigue damage on aircraft is differences in how they are operated. Aircraft that are used repeatedly for short hops undergo a different set of stresses than aircraft that repeatedly fly long haul. This is also true of any aircraft's individual components.

In the case of the CFM56-7B turbofan engine involved in the recent Southwest incident, use cycles for the engine could even have been a misleading indicator of the condition of individual blades, believes DeLisi. The 24 blades in the engine are replaceable. There is currently no requirement to track the use cycles of individual blades and therefore no way of knowing how many times a replacement has been used. "When these blades failed, they created structural damage to the cell, which was surprising," he says.

"If a mechanic was doing a routine inspection and was to see a small nick in one of these blades, Southwest could pull the blade and put in a new one.

"As we try to figure out what went on here, tracking individual blade replacements might be something we look at recommending." \\

TOOLS OF THE TRADE

As well as eddy current tests, tap tests and visual inspections are still the most common ways to detect metal fatigue in aircraft. Visual inspections are increasingly carried out with imaging devices such as borescopes. These can have thermography devices fitted to them, which send thermal waves through the material and analyze them, in a similar way to how ultrasound probes use sound waves to detect cracks.

Acoustic emission instruments rely on the sound the metal naturally produces to detect cracks. Antonios Kontos, an associate professor of mechanical engineering at Philadelphia's Drexel University, is currently developing acoustic emission testing for the aerospace industry. He says, "Small sensors are attached to the structure and we only record activity if a sound occurs. When a crack grows on the aircraft you might hear a change in the sound that is made."

Besides these testing techniques there is data from onboard sensors. "The modern aircraft has hundreds if not thousands of sensors on the plane, each with a specific sensing role, almost like the airplane's nervous system," says Kontos. "But, it's hard to connect metal fatigue with sensing at this point because it's a hard thing to monitor in real time. All we can do is monitor some of the factors that might contribute to it – temperature, for example."

NIST-TRACEABLE TESTING AT THE PUSH OF A BUTTON

Automated and traceable calibration saves time and money while ensuring reliable data

The signal conditioner is a key component in the critical path of important test data, so its performance specifications must be rigorously proved and documented. At a minimum, yearly calibration helps to ensure defendable test data. However, yearly calibration is costly, often requiring weeks of downtime, and making sure each channel works properly at test time means hours of tedious, difficult manual verification.

The Precision 28000 signal conditioner self-test subsystem automates rigorous yearly calibrations and quick Go/No-Go tests without removing the system from the equipment rack. The GUI control software provides the necessary software modules to perform tests on all supported 28000 conditioner cards. The user initiates tests via the software running on a Windows-based host computer. Full test reports document the results and provide further documented proof of performance.

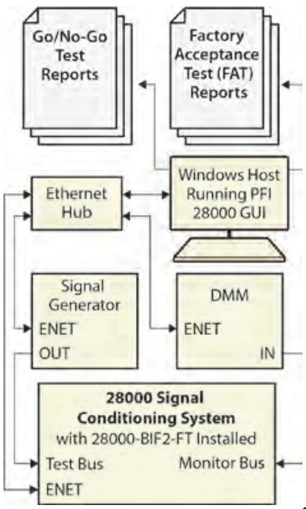
All test and measurement systems require periodic calibration. Typically, this means dismantling systems, uninstalling cards, and shipping components to an in-house calibration lab or back to the manufacturer. Precision Filters' built-in test hardware and software let you leave the system in the rack and perform NIST-traceable calibration tests on-site. For traceability, a high-performance digital multimeter (DMM) is kept in calibration by a third-party metrology test lab.

Test software residing in the 28000 GUI verifies calibration and traceability information of the DMM and then proceeds through an extensive test routine designed specifically for each card. Every card function is exercised and all data-critical performance characteristics are accurately measured and compared with published specifications.

These calibration tests are the same rigorous measurement routines performed in the factory before shipment. The calibration tests also serve as an excellent factory acceptance test (FAT) to be used by customers on receipt of their new equipment.

Yearly calibration shows basic compliance with quality standards, but it does little to discover problems that may have developed between tests. Finding a faulty channel during a yearly calibration may be too late – especially if that channel was used on many tests throughout the year. The most rigorous test protocols require additional tests be run before, and sometimes after, every test. To keep verification tests viable within the time constraints of actual testing, these checks must be quick and easy and minimize delays.

The 28000 suite of Go/No-Go tests was designed with speed and simplicity in mind. While the FAT verifies all channel parameters, Go/No-Go quickly verifies only the present runtime settings of each channel. Gain, filter setting, DC offset and excitation levels are measured and verified quickly and presented in report form, making the Go/No-Go report an excellent addition to a quality assurance report. Knowing your equipment is working as it should will give you the confidence to begin your testing.



1 // The 28000 signal conditioning system has hundreds of channels and a mix of programmable transducers

2 // Self-test subsystem diagram for the 28000

The Precision Filters 28000 system brings together high-quality signal conditioners with *in situ* annual calibration and fast, easy Go/No-Go testing to verify system health at test time. This approach has something to offer all members of the measurements team.

The metrology department, responsible for maintaining high-quality test equipment in spec and traceable year after year, appreciates the 28000 system's built-in, NIST-traceable calibration capabilities. Test engineers, who are routinely challenged to defend their test data, value Go/No-Go testing to verify cable and sensor health and system functionality – complete with automated reports. Data analysts value the high quality, highly accurate and validated output data. And project engineers, who are responsible for staying on budget and are always concerned with the yearly bottom line, appreciate the 28000's low lifetime costs and low overall cost of ownership.

Precision's 28000 self-test subsystem assures your team that the system is working correctly – providing reliable data and saving thousands of hours of expensive downtime. \\

ACOUSTICS AND VIBRATION TEST SYSTEM PROVES ITSELF

China's Aircraft Strength Research Institute has used m+p international to perform vibration, impact reliability and acoustic fatigue tests across a range of aircraft

The Aircraft Strength Research Institute (ASRI) is the only aircraft strength research, verification and identification center in the Chinese aerospace industry. ASRI provides ground testing facilities for full-size aircraft, which helps to predict vital performance data before the airplane embarks on its maiden flight.

ASRI serves as a center of excellence in testing and qualification for the latest aircraft developed in China and supports the many other institutes involved with the overall production of aircraft in China. The tests at ASRI play an important role in the overall aircraft development process, including design, manufacture, testing and test flights.

During normal operation many parts of the airframe endure extremes of both temperature and acoustic excitation. This is especially the case around areas such as the jet exhaust, the exhaust nozzles and the tail of the plane, where temperatures can exceed several hundred degrees while being submitted to sound pressure levels of up to 163dB (during full thrust measured at an angle of 30° along the outer edge of the tail plane and 2m (6.6ft) from the outer edge). Consequently, damage can occur during initial testing. Examples of this damage include loose rivets and fairings, if they are not designed with the suitable durability.

However, the aerospace industry is always striving for better performance and cost-effectiveness. Engineers are constantly looking to reduce weight and increase the overall operational life of aircraft structures. When an aircraft is an infinite life design based on the fatigue limit, the safety margin of the aircraft is very high. But the aircraft will be heavy and there may be compromises in performance.

As an alternative, Chinese engineers are looking to use finite life designs, which require extremely accurate testing and simulation for both acoustics and temperature. The aim is to use the combination of finite life designs and accurate testing and simulation to reduce the weight of aircraft as much as is possible, without compromising the integrity of any of the components.

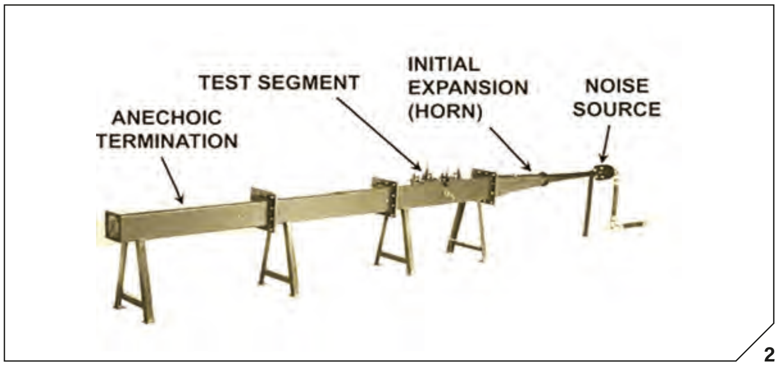
To rigorously simulate the acoustic levels required as part of this testing campaign, ASRI has used the m+p international traveling wave tube closed-loop acoustic control system since 2011. This control system can achieve up to 165dB. In addition, engineers have used six m+p VibControl vibration controller systems, which are present at the ASRI site in China. The hardware platform is a high-channel count m+p VibRunner ideally suited for the specific needs of noise and vibration engineering and general data acquisition. The structural tests performed on aircraft include sine sweep, random, impact and shock response spectrum analysis.

For high-end vibration and strength testing, the stability of the system and absolute confidence in the test data are crucial. Engineers at ASRI have been extremely confident in the overall system stability and reliability that m+p international offers and have confirmed the advanced nature of the system's technology. \\

1

1 // China's Aircraft Strength Research Institute provides ground testing for full-size aircraft

2 // The progressive wave tube used during acoustic testing



2

CT SCANS HELP VERIFY 3D-PRINTED PARTS

Image-based modeling can help save time and costs when testing additively manufactured parts

Additive manufacturing (AM) of metal parts is becoming increasingly common in aerospace and other industries, but still carries risks in terms of accuracy, quality, strength and reliability. Given the investment needed for AM, it is crucial to overcome workflow gaps and gain insight into the real-world performance of parts.

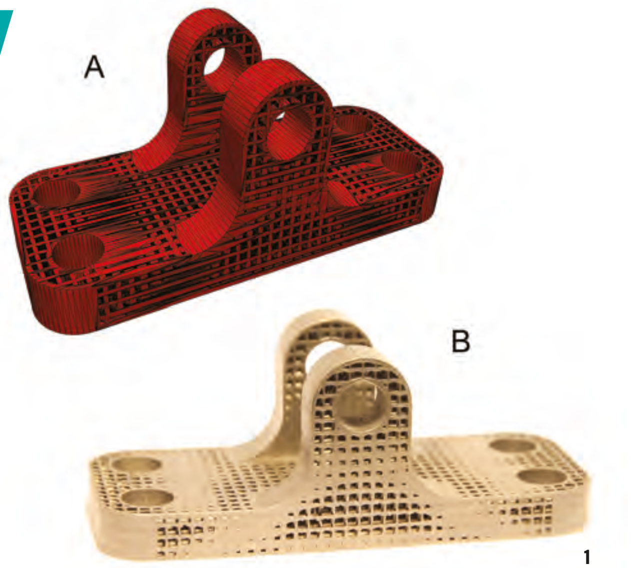
The University of Pittsburgh, North Star Imaging, Synopsys and Ansys have successfully built a workflow using North Star Imaging's CT systems along with Synopsys Simpleware and Ansys Mechanical to better understand if the original design of a lightweight bracket meets its intended purpose when printed.

Albert To and his group at the University of Pittsburgh used Ansys to redesign a typical bracket geometry, with the goal of better integrating lattice structures and reducing weight. The design was built using a titanium alloy (Ti_6Al_4V) and an EOS DMLS laser powder bed AM machine (Model M290).

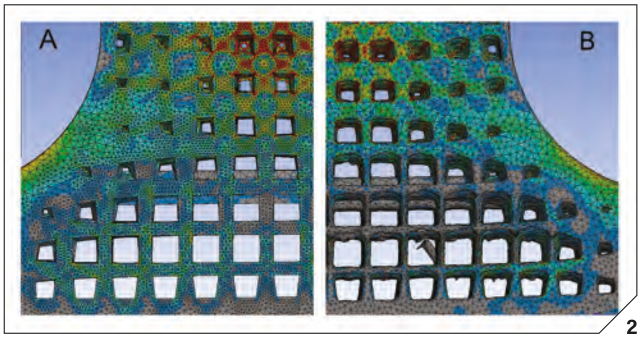
After the redesigned part was printed, it was scanned with North Star Imaging's X5000 CT system and the images were acquired and reconstructed using NSI's efX-CT software. From there, the data can be reviewed, visualized or analyzed using tools such as the Simpleware software.

The Simpleware platform was used to create an optimized 3D surface and volumetric mesh from the image data. Once processed, the image data was exported as a volumetric finite element (FE) mesh from the Simpleware interface direct to Ansys.

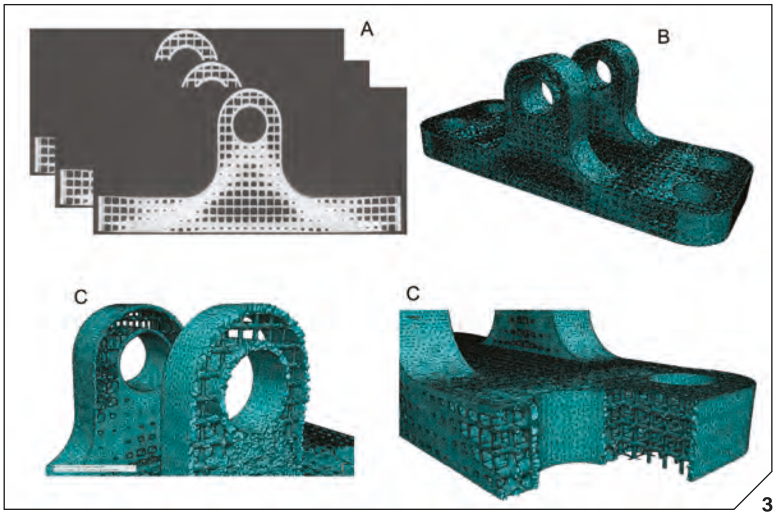
Synopsys' Kerim Genc comments, "The Simpleware environment allows a diverse and typically separated set of engineers in design, AM, CT scanning and simulation to collaborate in a unified workflow that adds value to the overall manufacturing process."



1 // (A) Final bracket design. (B) The AM titanium alloy bracket built using the laser powder bed AM machine



2 // Solved FE mesh on both the original design CAD (A) and the image-based FE mesh generated in Simpleware software (B)



3 // (A) Representative stack of image data generated from CT scan of the bracket. (B) STL surface reconstruction. (C) Cross-sections of FE mesh

Comparison of the AM part with the original CAD is crucial to characterizing defects. A deviation analysis tool in the Simpleware software suite was used to compare the image-based STL geometry with the original CAD design. This showed two types of manufacturing errors: a bend in the base of the bracket and breaks in the struts of the lattice structure. A structural FE simulation was carried out on the original CAD design and the image-based FE mesh exported using the Simpleware FE module to ANSYS to solve mechanical loading problems.

Ansys commented, "We were kind of surprised, honestly, by what we found via the North Star scan and the subsequent Simpleware model construction from that image data. The printed part looked perfect on the outside, but what we found deep inside the lattice structure wasn't what we had hoped to produce.

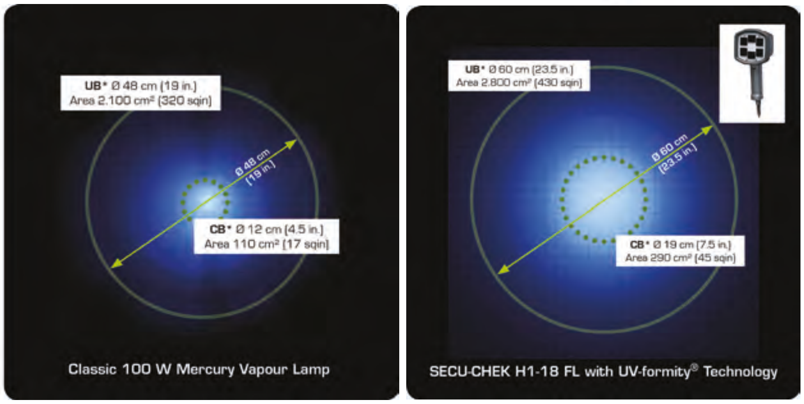
"That said, the printed part had very good structural performance despite the visual disparities we discovered via the scanning inspection process."

For aerospace and other industries, the stages presented here are suitable for closing design loops and better understanding the effect of unexpected defects and inconsistencies. Having this knowledge from the scanned parts means that manufacturing defects can be identified and resolved before a costly production process. \\

UV LAMPS PROVIDE SECURE AND FAST INSPECTION

1

UV LED Lamps with UV-formity technology make the inspection faster, easier and fatigue-proof, with more optimal and uniform irradiation



2

German company Secu-chek is a non-destructive testing (NDT) company that develops and manufactures market-leading UV LED lamps.

Secu-chek UV LED lamps enable the user to perform fluorescent magnetic particle and penetrant inspection better than ever before. The lamps ensure secure operation by design and support human vision as required without limitations, compromises or degradation of the NDT process. They are designed to operate without any problems, 24 hours a day, seven days a week.

The UVE series of flood lamps fulfill all major requirements, such as Airbus AITM 6-1001 (Issue 11), ASTM E-3022, Boeing, Rolls-Royce RRES 90061, NADCAP, Pratt & Whitney and many more, battery and mains powered. The test reports can be ordered individually as required.

Secu-chek's UV-formity technology is used in the company's UVE and UVN series of flood lamps to present an extremely uniform beam. The technology enables the lamps to generate very large beams with a soft transition from the large central beam to the edges, even in short distance when moving the lamp.

The usable beam of Secu-chek's handheld flood lamps is up to 10 times more than common focused UV LED handheld lamps with hard drop-off at the edges. The usable beam (UB) is the area irradiated with an intensity of more than 100µW/cm² (1W/m²) in 38 cm (15 in,) distance.

The central beam (CB) is the is the area irradiated with an intensity of more than 1.200µW/cm² (12 W/m²) in 38 cm (15 in,) distance. The usable beam (UB) of the UVE 365 H1-18 FL has a dimension of 2,800cm² (430in²), 60cm (23.5in) in diameter and the central beam (CB) has a size of 19cm (7.5in) in diameter and irradiates an area of 290cm² (45in²).

The large usable beams have a soft and smooth intensity drop from the center to the edges, to ensure fast, easy and reliable detection of indications and full orientation in the inspection area. The large beams enable ergonomic inspection where the lamp intuitively follows the eyes, giving a completely clear and sharp view.

The central beams are up to seven times larger than the central spot of a mercury vapor lamp. This allows fast and fatigue-proof observation and easy interpretation, with the central vision minimizing lamp movement and allowing natural, free eye movement.

3

Other features include integrated UV LED monitoring, which automatically shuts off the lamp in the event of failure of a single UV LED element, low battery or other critical failures. This feature ensures that the inspection can be performed at least as well as when using mercury vapor lamps, without additional checks or burden to the users.

The lamps also feature an automatically dimming white light. This allows enhanced stress-free interpretation and the use of white light without flash-blinding the eyes.

White light output is adjustable by the user during operation and can be mixed with the UV. It can also be cross-faded, where the UV goes off and the white light goes on. The smooth continuous transition of the illumination allows uninterrupted observation of indications and the area of interest, even when activating the white light.

Other integrated features bring further benefits to the inspection process. The lamp warns the user, with a blinking status indicator, as long as the required time to adapt the eyes to the darkness (1,3 or 5 minutes pre-adjustable) has not elapsed after switching on the lamp. This helps to prevent audit failures.

An eco-mode also automatically switches off the UV if the lamp is not moved and automatically resumes to full power immediately it is picked up again. This makes the life of the lamp up to 10 times longer than if in continuous operation, and effectively reduces the cost of the UV LED lamps by up to a tenth part in the long term, while saving energy. This feature, which is only available in the UVE series, can more than compensate for the initial higher purchase cost compared with any UV LED lamp without eco-mode. \\

1 // Secu-chek H1-18 FL UV LED hand-floodlamp

2 // Comparison of the beam from a 100W Mercury Vapor and Secu-chek UVE365 H1-18 FL

3 // Secu-chek hand lamps run for up to 12 hours with a fully charged Bion 1 Li-Ion battery pack

INNOVATION DRIVES POWER GENERATION FOR AVIATION TESTING

Electrical component test systems must keep pace with advances in aviation power system technology

The global fleet of commercial aircraft grew by 4% in 2017. Thanks to economic demand the backlog for new aircraft now exceeds 10 years. As new aircraft drive down the cost per available seat mile, commercial air carriers see an opportunity to increase profits through fleet renewal. The B787 and A350 are flagships for the newest generation of aircraft, and their use of cutting-edge technologies to lower costs and improve customer experience changes the landscape for aircraft to come.

With increased technology comes increased demand on aircraft power systems. The latest generation of aircraft electrical power generation components therefore come with a completely new set of challenges and complexities for both the OEM and MRO communities.

Following OEM warranty obligations, these aircraft became a valuable revenue source for the MRO market. Much of the test technology in use today will be obsolete once these electrical components make their way into the third-party MRO workshops. To be competitive, repair organizations must anticipate the need to invest. This investment must take into consideration not just coming technology, but the ever-increasing demand for faster turn-times, reduced rework, and skill-set demands. Overcoming these challenges requires more than a simple vendor, but rather a testing partner. This partner needs the experience behind it to tackle the coming challenges.

In partnership with market-leading experts, Test-Fuchs has worked diligently to develop the next generation of electrical component test systems. The LMP series' capabilities match the complexity found in today's most demanding units under test. The series combines Test-Fuchs' proven technology with testing innovation to improve a company's bottom line and give a competitive advantage.

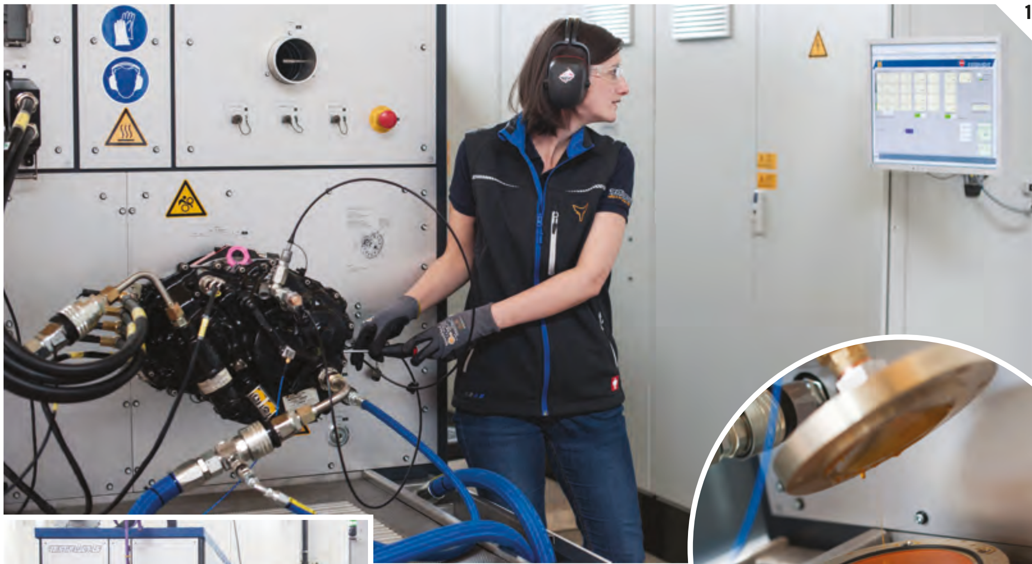
The newest LMP design is available with various capabilities. Test-Fuchs always works very closely with its clients to develop the exacting specifications needed to fit each test environment.

The company has introduced one of its more sought-after solutions – the direct-drive LMP. The direct-drive LMP replaces the traditional gearbox with a purpose-designed direct-drive prime mover. This solution reduces complexity, gearbox failure, noise and power loss throughout the system.

In addition to its newest LMP design innovations, Test-Fuchs continues to push the envelope in traditional gearbox drive-system quality and capability. With new – and formerly unheard of – speed, torque and versatility requirements coming out of the aircraft power R&D segment, the company is in constant contact with its supply chain, encouraging them to push their own performance.

The aircraft that we fly in 30 years' time will have characteristics that are nearly unimaginable to us today. Being able to test those characteristics will take focused growth from everyone up and down the supply chain. Test-Fuchs is committed to ensuring the LMP product line anticipates the aircraft of tomorrow.

Now, with manufacturing facilities in both the USA and Austria, and 11 support offices around the world, Test-Fuchs has never been more prepared to meet the testing demands of tomorrow. The company is ready to partner with its clients to meet that demand. \\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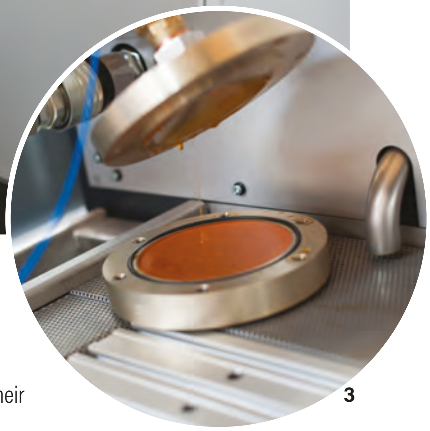

3

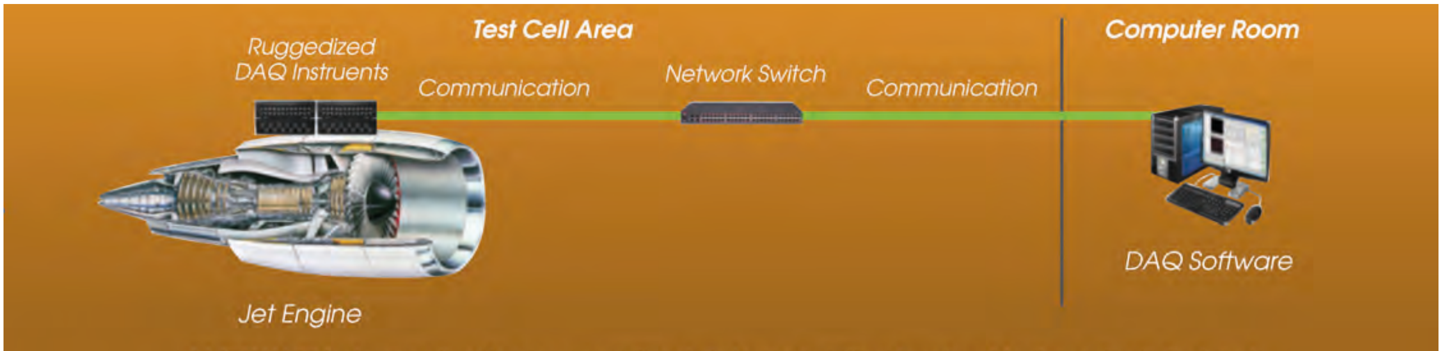
1 // Installation and adjustment of a unit under test with the LMP series

2 // The LMP series provides efficient and comfortable testing

3 // The uncomplicated control of patch filter

RUGGEDIZED TEST EQUIPMENT

Jet engine testing places huge demands on data acquisition systems, so it's critical that manufacturers select the right hardware and software



AMETEK VTI Instruments offers a ruggedized data acquisition family of test products for harsh environment testing, including the, RX0124, RX0224, and RX1032, respectively.

The jet engine is the very definition of 'mission critical'. A critical failure could cause a serious accident that endangers hundreds of lives. To prevent this, manufacturers perform extensive and costly testing on jet engine components, systems and manufacturing processes. These tests include measuring temperature, flow, pressure, rotation, strain and vibration under extreme conditions.

Selecting the right data acquisition hardware and software is critical to ensuring accurate data for jet engine testing. Since such testing has unique requirements, test engineers must choose data acquisition products that not only make high-quality measurements but offer high reliability as well. To withstand the rigors of jet engine testing, you need a ruggedized data acquisition system.

The traditional way to set up a jet engine test is to wheel it into a test chamber and install the sensors and cables. The extreme test conditions mean that the data acquisition instruments cannot be positioned close to the test cell. Long cable runs for each of the hundreds of sensors must make their way from the engine inside the test chamber to the instrumentation and be labeled correctly. This process takes many hours to complete, and it is also prone to errors.

One problem with long cables is that they are more susceptible to damage than shorter ones. In addition, long cable lengths make test signals vulnerable to interference and noise from the high temperatures, shock, vibration and other components, such as motors and ignitors, while a test is running. To improve the signal-to-noise ratio, engineers use high excitation voltages, but these produce more heat and can shorten equipment life.

A more innovative approach to testing in harsh environments is to use ruggedized data acquisition hardware instead of laboratory-grade equipment. Using ruggedized equipment enables engineers to place measurement instruments directly in the test chamber, close to the jet engine, and sometimes on the engine itself. An example of this type of test setup can be seen above.

Instead of taking the engine under test into the chamber and then configuring the sensors, engineers can now install sensors, transducers and data acquisition equipment directly on the engine before pushing it into the test chamber. Rather than having to set up the engine and separately configure the test equipment, engineers can do both steps at once. Placing instrumentation closer to transducers and sensors also substantially reduces cable length. This reduces setup time, cost and the potential for human error.

// Ruggedized test equipment that can be mounted on the jet engine inside the test chamber offers a number of advantages

Shorter cable lengths also help produce higher-quality measurements. They reduce the potential for interference and lower signal loss, and test engineers can use lower excitation voltages and therefore extend equipment lifespans. Environmental noise and interference are less of a concern. Data received and used in this innovative testing approach is of a higher quality and is more reliable.

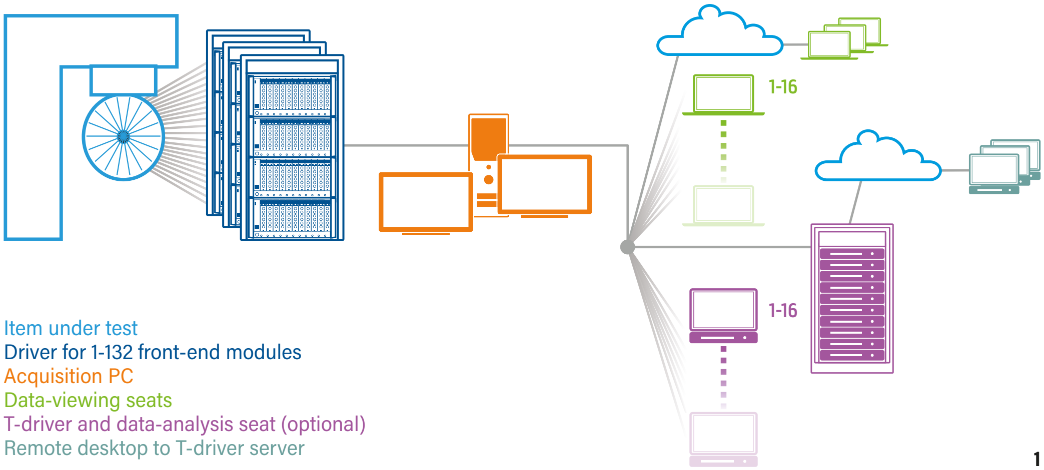
There is no need to manage and keep track of hundreds of long cables. Test engineers no longer need worry about whether cables are securely connected or broken. It is a lot easier to check short cables than to trace hundreds of long ones.

Using ruggedized instrumentation saves time, money and frustration. Test setup is much simpler and measurement accuracy is improved, simplifying maintenance and resulting in greater uptime and lower support costs. \\

Written by Jon Semancik, director of marketing, AMETEK/VTI Instruments

DYNAMIC REPETITIVE TESTING FOR HIGH-VALUE PRODUCTS

A new approach to data acquisition when dealing with repetitive testing for large, complex and high-value systems and components



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1 // Schematic of an example BK gas turbine testing setup with the T-driver and remote analysis seats

2 // A group of test seats where operators and engineers monitor the measurement in real time, performing analysis and processing data simultaneously

Testing takes time, and with greater size and complexity, the time and difficulty involved increase tremendously. Reducing the length of time spent in the test cell can provide substantial returns for both the time-to-market and overall testing costs. This is particularly apparent when dealing with repetitive, dynamic testing for large, complex systems such as gas turbines and for components that require the use of substantial data acquisition systems with hundreds or thousands of channels.

The BK Data Distribution Core for dynamic testing and the BK Gas Turbine Testing are fine-tuned to meet the standards of gas turbine testing. These two new solutions combine their features with a user-centric workflow to reduce cost and time to market. Aligned with Brüel & Kjær's approach of recognizing the different roles that exist in the testing process, these systems are structured to address the needs of users for each stage in the complete testing process.

Beginning with the test-design phase, the system parameters can be set up with the graphical user interface or, for highly complex setups that require input from multiple specialists, with a single spreadsheet-based setup that enables experts to set up their domain-specific areas of the test simultaneously, before the test object is anywhere near the test cell. This setup is then transferred to the system, where the test engineers and operators interact with the test via a simplified interface that requires minimal training. During acquisition, data is monitored in real time and is immediately available for analysis by test specialists at their own desks.

The ability to integrate steady-state or low-speed data in the system enables full integration into the test cell environment, providing synergy with individual systems, reducing operation complexity and simplifying data handling. The system can input low-speed process data and output metrics calculated from dynamic tests. A major benefit of the integrated data is the immediate correlation of data and effects – a simple example is being able to see increased vibration on startup as due to the reduced effectiveness of cold lubricants rather than an unknown cause.

System scale can vary greatly, from single-user, standalone systems with just a single acquisition module on a single laptop, to linked systems acquiring data from thousands of channels and distributing to many computers for real-time processing.

A key aspect of these systems that enables a simplified and quick setup in the test cell is the use of Brüel & Kjær LAN-XI data acquisition hardware. LAN-XI provides an extremely flexible hardware solution, allowing the connection of a multitude of signal types and trouble-free data acquisition. LAN-XI Dyn-X capability enables measurement over a huge dynamic range, registering the smallest clicks and loudest bangs without risk of under- or overloading.

Due to the massive amounts of data that can be acquired during these tests, data transfer can take as long as the actual test, potentially doubling the time needed with test cell equipment before data can be disseminated for analysis.

BK Data Distribution Core and BK Gas Turbine Testing eliminate that extra time by performing data transfer, backup and conversion as the test is in progress. The T-driver ensures that data can be recorded, worked and shared efficiently and easily while preserving data security on multiple levels. While test data is being recorded, it can be shared with multiple test seats where the raw data can be post-processed and analyzed by multiple specialists at the same time. Combined with the ability to preconfigure channels to segregate proprietary data, the T-driver makes this solution suitable for partnered projects. The test can be run once, acquiring all the needed data in one run, while maintaining the integrity of proprietary data. \\

PREPARE FOR THE ATTACK ROLE

Vidsel Test Range in northern Sweden, Europe's largest overland range, is a unique European test and training facility. The range is part of the Test and Evaluation organization of the Swedish Defence Materiel Administration (FMV) and a civil authority.

In order to take on different roles and responsibilities as part of a changing environment, new requirements are put on aircraft. An example is when the Luftwaffe performed operational test and evaluation of the GBU 48 system on a Eurofighter, preparing for German deployment in the support of NATO's Very High Readiness Joint Force (VJTF). For this, the Bundeswehr chose Vidsel Test Range.

During an intensive six weeks, four Eurofighters completed the mission. For the trial, different types of stationary and moving targets were prepared and in some cases GPS jamming was carried out.

The ground restriction area of Vidsel Test Range is 3,000km^2 (1,160 square miles) and the restricted air space is 8,000km^2 (3,100 square miles), ground to unlimited, allowing trials/exercises requiring large spaces. Customized targets, static or remotely controlled, can be engaged with live weapons. Target lasing and EW/jamming is regularly performed. High-performance in-house target drones provide challenging air scenarios.

Some examples of weapon systems employed at the range are Taurus, AMRAAM (advanced medium-range air-to-air missile), Meteor and GBU 24.

Besides being a fully equipped test facility, Vidsel is also used for training and in service firings. Its large size makes it possible to vary scenarios from sortie to sortie, supporting full combat loops with live firing, low flying and the surprise factor. \\

SYNCHRONOUS MEASUREMENTS MADE EASY

New aircraft development involves rigorous testing – both on the ground and in the air. At the sharp end of this development testing are test pilots, who routinely take high risks to verify that all technology included in the aircraft works the way it was designed and built. Aircraft under test often have to undergo testing to the extremes of their performance envelope. It is during these critical phases that test pilots are most at risk.

When it comes to the acquisition of measurement signals, it is absolutely crucial that they are synchronized, otherwise results may be interpreted completely incorrectly.

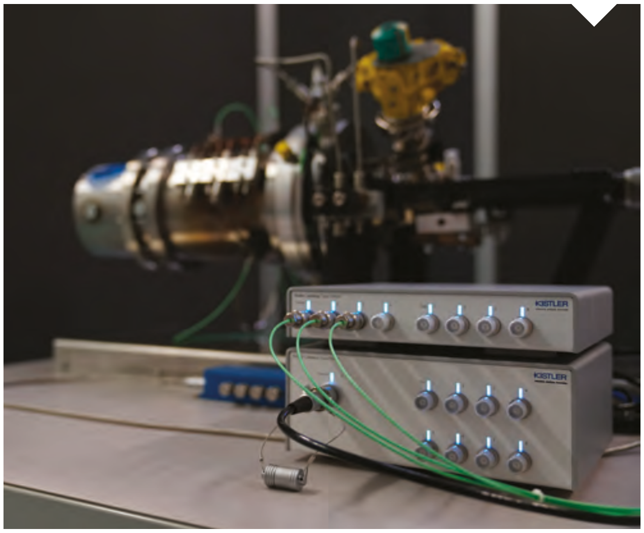
The Precision Time Protocol (PTP), as described in the IEEE 1588-2008 standard, describes an ingenious procedure whereby the clocks of local network components can be adjusted to achieve an accuracy in the sub-microsecond range – without additional cables.

The elegant thing about PTP is that the user does not have to worry about synchronization. The devices synchronize themselves automatically via the normal network cables. Only the topology must meet the requirements of PTP. For example, there cannot be any non-PTP-capable switches between the individual PTP devices. To overcome this, Kistler LabAmp devices all have two network connections and integrated PTP switch functionality. Depending on the required data rate and number of channels, several devices can be connected in series without the need for an external PTP switch.

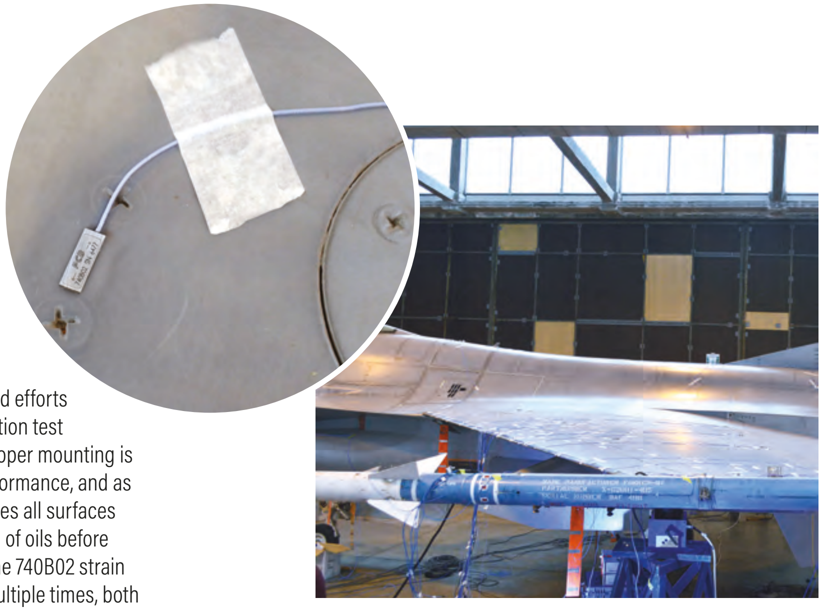
In Kistler devices, digitized measuring values receive their time stamps directly behind the analog/digital converter, enabling precision in the sub-microsecond range.

Multiple 5165A and 5167A LabAmp devices can be integrated into a network for synchronized measurements. This allows, for example, quasi-static measurements with a piezoelectric dynamometer on a 5167A to be easily extended by adding a few voltage signals and an IEPE accelerometer, all just by adding additional, synchronized 5165A devices. On the software side, various options are available. \\

Example rocket propulsion test bench: PTP synchronized LabAmp Types 5167A and 5165A for six-component force measurement and three pressure pulsation measurements to look for combustion instabilities in the combustion chamber



MODAL ANALYSIS WITH A STRAIN SENSOR



PCB Piezotronics' Model 740B02 reusable Piezoelectric ICP (injection control pressure) strain sensor has unparalleled 0.0006µE resolution with an amplified +/-5V output and a 100kHz upper-frequency response. Test engineers can now verify high-stress locations and modes with micro-excitation, without risk of structural damage from artificially high shaker forces, ensuring a linear response.

At 0.5g, this sensor is far lighter than typical high-sensitivity accelerometers, thus reducing localized mass loading for thin, lightweight test articles. It installs in one minute, can be removed in 10 seconds, and can be reused multiple times just like an ICP accelerometer.

PCB's 740B02 dynamic strain sensors differ from resistive strain gauges in two ways. First, they can be mounted and reused using a quick-bonding cyanoacrylate gel, which makes the bonding procedure much faster and more compatible with the instrumentation timings and efforts required for a ground vibration test campaign. Nonetheless, proper mounting is critical to good sensor performance, and as with traditional strain gauges all surfaces must be clean, dry and free of oils before applying adhesive. Since the 740B02 strain sensor can be reapplied multiple times, both the lifetime cost and initial labor cost for installation is dramatically reduced.

The second difference compared with resistive strain gauges is that the 740B02 combines a quartz sensing element and a built-in microelectronic ICP signal amplifier within a titanium housing. The calibration of the strain sensor is not performed on-site as with foil gauges. Instead calibration is performed in a controlled metrology lab, where the sensors are dynamically excited using a cantilever beam in its first resonant mode. In addition, each 740B02 sensor is mounted on the beam and is calibrated using resistive foil reference gauges. \\

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PCB PIEZOTRONICS

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A REFERENCE POINT FOR SOFTWARE SYSTEMS

Spirale Vision is a new Climats software system for environmental test chambers and benefits from remarkable ergonomics.

The software is intuitive and offers quick and easy handling. It enables efficient management of test chambers and better control of equipment when used with an extra-large 15in touchscreen.

Spirale Vision is also customizable. The interface can be set up to adopt various graphic designs. Users can integrate their own wallpapers and include their own logos, and the interface gets completely integrated into their work environment.

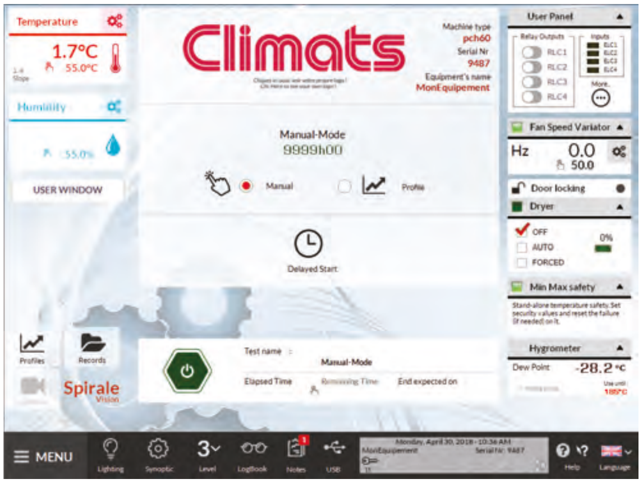
With three different levels, Spirale Vision is suitable for all users. The Production Mode limits the use to previously defined profiles. Users can also archive their tests with only one click.

The Laboratory Mode displays the profile of running tests directly on the screen thanks to the CycleWin recorder. Finally, the Advanced Mode adds extensions such as additional measurements and complex automations.

Spirale Vision also ensures complete traceability of tests in a number of ways. All tests are saved and stored automatically; the camera function displays and saves real-time pictures of test products; and test profiles can be transferred on a plug-and-play USB stick.

Additionally Spirale Vision enables equipment to be remotely controlled over the internet. The software's supervision system can also be set up to manage all of a laboratory's test equipment from a single station. Furthermore, an operation workflow diagram accessible using the remote assistance via an Ethernet connection makes the maintenance of environmental chambers much easier.

Spirale technology operates all Climats equipment and controls more than 5,000 environmental test chambers and test benches around the world. \\



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CLIMATS

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LIGHTWEIGHT, HIGH-PERFORMANCE DATA ACQUISITION UNIT

Flight test instrumentation (FTI) engineers today have a difficult task – capture more data in less time. Data must still be collected reliably on each and every flight, and the acquisition systems need to be developed and installed quickly and be capable of adapting to changing needs, both during and after the development cycle. Keeping size, weight and power (SWaP) requirements down is something every industry seeks to achieve and for FTI this means smaller, lighter and more power-efficient chassis.

Curtiss-Wright has developed an innovative airborne data acquisition system (DAS) – the Axon – to meet the increased data, lower SWaP and installation needs of current and future programs. The Axon is an ultra-compact DAS that is dramatically lighter than similar offerings from other organizations. Increasing data needs are met with industry-leading throughput, ensuring that even higher demands in the future can be accommodated.

Axon works with the widely used Acra KAM-500 and TTC DAU chassis, supporting the same data formats and configured using the same setup software. Data can be synchronized using a protocol such as the IEEE 1588 Precision Time Protocol.

The rapidly deployed system, which has flexible installation options including remotely locatable modules, saves time and helps reduce schedule risks.

In short, the Axon range provides a powerful, compact, light system with several innovative features to ensure it will meet FTI engineers' needs for years to come. \\

CONFIGURABLE CONTROL BAY

Certia provides customers with test and measurement solutions across a wide range of applications including test rigs, simulation and integration, training, maintenance, and research and development.

The company responds to customer requirements. From a simple tool up to a complex integration test rig; from a laboratory test rig to an automatic acceptance test rig on a production line; from a mechanical unit to a high dynamic controlled loop, hydraulic power pack and services.

In 2018 Certia developed a brand-new generic control bay. The system can be easily interfaced with all existing test rigs without any wire modification. It can be configured from 128 to more than 384 channels, including digital input, digital output, analog input, analog output, pulse width modulation and main buses such as CAN (control area network), ARINC and AFDX (avionics full-duplex switched Ethernet).

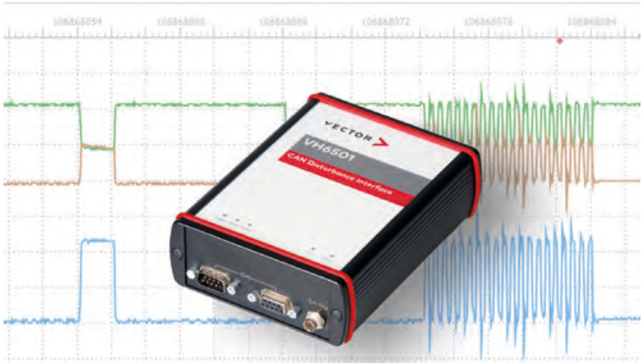
Equipped with a high-end, real-time computer and field programmable gate array, the system is able do real-time acquisitions and control a large range of actuators.

For very large test rigs, several systems can be connected together with a fiber-optic network. The control bay is provided with the Cockpit software suite, including modules for data acquisition, coordinate measuring machine test writing, test reporting, health monitoring, and maintenance with an augmented reality solution.

Certia has been involved in major aerospace and defense programs since 1987. The company's main customers include Airbus, Nexter Systems, Renault, PSA, Safran group, UTC group, Circor, Bosch Braking Systems, Westinghouse, Air France Industries and Air Algeria.

All of these clients have selected Certia as a supplier for their most critical test rig development projects. \\

DISTURBING CONTROL AREA NETWORKS IN AVIONICS



The VH6501 enables precise and reproducible disturbances of CAN/CAN FD networks

For precise and reproducible disturbances of CAN/CAN FD (Control Area Network with Flexible Data-Rate) networks in avionics, Vector offers the new combined hardware, VH6501. The device is a flexible yet very compact disturbance device and a network interface combined in one unit.

The combination of the compact disturbance device and the network interface enables the use of very simple test setups for CAN/CAN FD robustness without the need to use an additional network interface or a special cable.

The VH6501 hardware enables test engineers to generate disturbances of almost any kind precisely and reproducibly in CAN/CAN FD networks. This makes it the ideal tool for testing the fault handling of CAN/CAN FD nodes. Such tests are an essential part of robustness tests of aircraft networks.

The digital disturbances can be configured in the CANoe testing tool using the integrated Communication Access Programming Language (CAPL) as a sequence output and as a trigger condition. In addition, many typical analog disturbances are possible, such as short-circuits of the CAN signals.

Further fields of application are determining the exact sample point of a line replaceable unit (LRU), checking the LRU's behavior in the bus-off state, reaction of swapping the CAN lines, and modification of the R/C network parameters.

With the help of the CANoe Option Scope and the PicoScope hardware, all disturbances generated by VH6501 and the behavior of the LRU can be visually recorded and accurately analyzed. The seamless CANoe integration makes it quick and easy for users to create their own automated tests using the CAPL API for this hardware. \\

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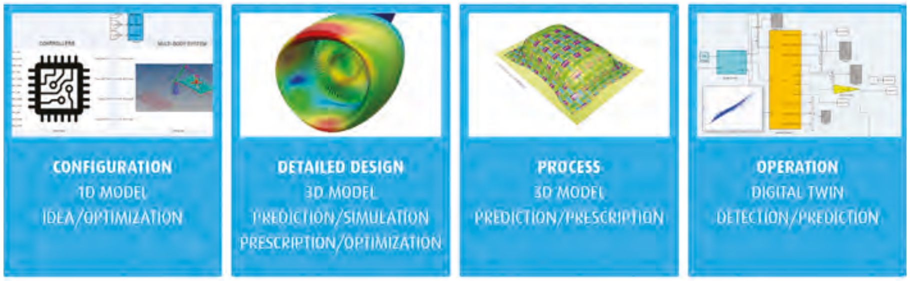
THE DIGITAL TWIN IN AEROSPACE



Buzzwords such as IoT, digital twin, digital transformation, and industry 4.0 have an increasing impact on development and manufacturing in the aerospace sector, traditionally known as a technology pioneer.

The digital twin has quickly established itself in product development and the entire product lifespan of aerospace components and systems. The virtual prototype models, which have been used in development with great success for many years, are the basis of the digital twin.

In a recently hosted webinar series, Altair described its vision of the digital twin and the IoT. A digital twin is created from a digital development model by collecting the data from the operating system and feeding it into the virtual model. This enables precise predictions to improve future products.

By means of an aerospace aircraft engine, the webinar demonstrated how a digital twin is created and how it can be used to predict the remaining useful life and maintenance intervals of an engine in use. The goal was to predict when the engine would have to be serviced or exchanged. In the development of such complex systems, various tools are being deployed in different development stages.

First, in the concept phase, single dimension system simulation tools such as solidThinking Compose, Activate and Embed are being used. Then, a first design and a 3D model are created. To generate the model, Altair offers various tools for a simulation-driven design approach, for example, OptiStruct and solidThinking Inspire. Having added details to the simulation model, virtual tests have to be performed. Here, Altair Solver products such as RADIOSS, OptiStruct, MotionSolve, AcuSolve, FEKO and many more can be applied. When the product shows the desired features, they can be validated in tests and the product is ready for production.

From the real-life product in use, equipped with the necessary sensors and communication means, data can now be collected and added to the simulation model. This way, the digital twin enables assumptions to be made about the current product status and predicts the remaining useful life or service work.

Some companies seek the built-in expertise of turnkey Product as a Service (PaaS) solutions, while others want to highly customize their solution for a business advantage. Either way, with the adoption of Altair's digital platform, customers can design and optimize products and easily connect, control and manage them directly on the cloud infrastructure.

This end-to-end offering also enables clients to speed up their data visualization, exploration and discovery. Companies also have the freedom to choose their IoT stack and complete their IoT offering. \\

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LIGHTWEIGHT ACCELEROMETER

The Endevco 35C is lightweight, with an ultra-miniature footprint, making it suitable for sensing in the most space-restricted testing and measurement applications.

The accelerometer's hermetically sealed titanium case provides protection from humidity and other contaminants that can degrade performance. The 35C has been designed with a low noise floor for a superior signal-to-noise ratio, fostering accurate measurements. The Endevco family of sensor solutions includes piezoelectric, piezoresistive, IEPE (Integrated Electronics Piezo-Electric) and variable capacitance accelerometers, piezoresistive pressure transducers, rate sensors, electronic instruments and calibration systems.

Endevco sensors are designed and manufactured to ensure critical accuracy and reliability in test and measurement applications in the aerospace, automotive, defense, industrial, medical, power generation and space industries. \\

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A PROPULSION MIX-UP?

As development and testing of hybrid-electric aircraft ramps up, a look back at the last time hybrid aircraft were in the skies serves to remind us of the challenges of innovation

When it comes to innovation, it's often said that on the road to success there will be countless failures. As we enter the age of hybrid electric aviation propulsion, it is worth remembering the trials and tribulations involved the last time hybrid propulsion technology was developed for aeronautical use – in the form of the hybrid piston/jet-engined aircraft.

History is not littered with examples. The real burst in development of hybrid jet/piston-powered aircraft happened in the early days of the jet engine, as engineers attempted to compensate for the shortcomings of the early designs.

A good example is the XF15C. The experimental US Navy aircraft was built at the end of World War II and is one of only 15 aircraft designs ever built that is powered by both a propeller and turbojet engine.

At the time of its development, interest was high in novel jet engine technology and the US Navy was keen to incorporate it into its fleet of aircraft. The contract for the development of three "composite-engined" XF15C prototype aircraft was awarded to Curtiss in April 1944, with the brief that the thrust of the jet engine would be used for high-speed maneuvers and a conventional piston engine for cruise and to extend range.

The first prototype flew in February 1945, powered only by its 2,100hp (1,566kW) Pratt & Whitney propeller engine. The Allis-Chalmers J36 turbojet, a US-produced version of the British de Havilland Goblin jet engine, was subsequently fitted under the tail of the airplane. A month later the first prototype crashed, reportedly because of a failure in the piston engine.

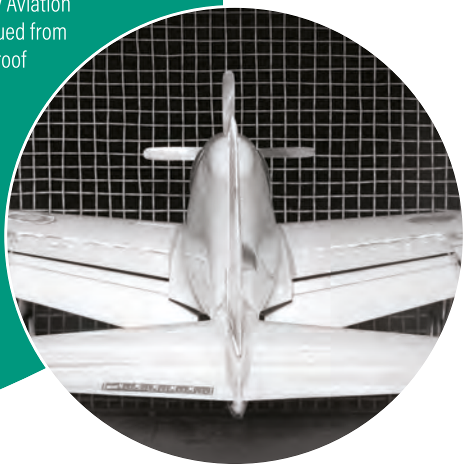
The second prototype flew in July 1945 and flight testing continued until the end of 1946. In theory the XF15C was the fastest fighter in the US Navy during that time. The aircraft achieved 469mph (755km/h) using both engines at an altitude of 25,300ft.

However, the XF-15C's success was short-lived and by the end of World War II, the US Navy had begun looking at different, purely jet engined designs. Only the three prototype XF15Cs were built.

The XF15C draws easy comparisons to the US Navy's other composite-engined fighter, Ryan Aircraft's FR-1 Fireball, which suffered a similar fate, although it was moderately more successful. Development of the Fireball started around two years before the XF15C. Ryan managed to produce 66 of the aircraft before the contracts for 1,300 Fireballs were cancelled because of the end of the war and other jet engine aircraft designs superseding it.

Of the two remaining XF15C prototypes, one was scrapped after the war. The last Curtiss XF15C was recently put on static display at the Hickory Aviation Museum in North Carolina after being rescued from Quonset Air Museum, Rhode Island after a roof collapsed because of ice and snow in 2014.

Although the more recent success of hybrid electric cars suggests otherwise, it may be that pure-electric aircraft could rapidly supersede battery hybrid airplanes. Only time will tell if hybrid electric planes will end up in the air, or in a museum. \\



FEB 27, 1945
First flight

XF15C
Model number

48FT
Span

44FT
Length

18,000 LB
Gross weight

469MPH
Top speed (both engines)

163MPH
Cruising speed (piston only)

635 MILES
Range at full load

41,800FT
Ceiling

21,000HP AND 2,700 LB
Thrust of the P&W and jet engines

1
Pilot