MARCH 2019

Aerospace TESTING INTERNATIONAL

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Bend & Flex

Discover the latest technologies and processes being used to analyze wing materials and combat flutter

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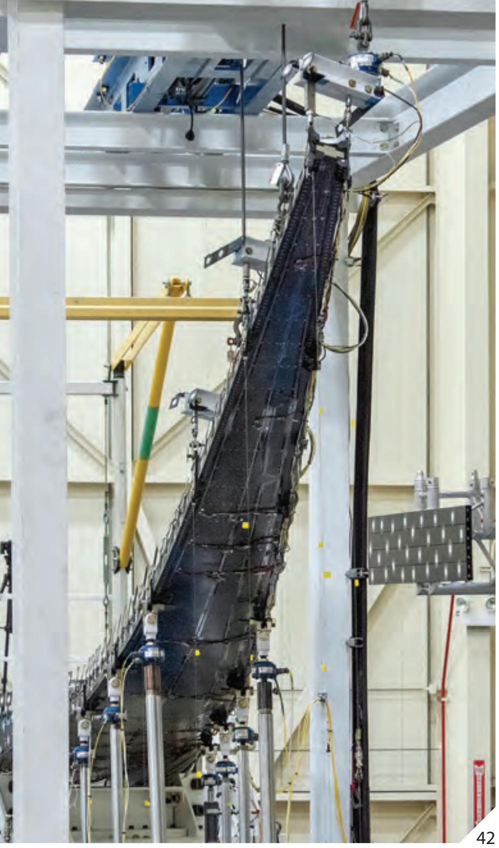

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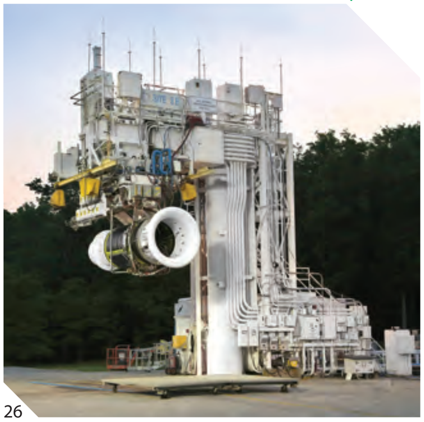

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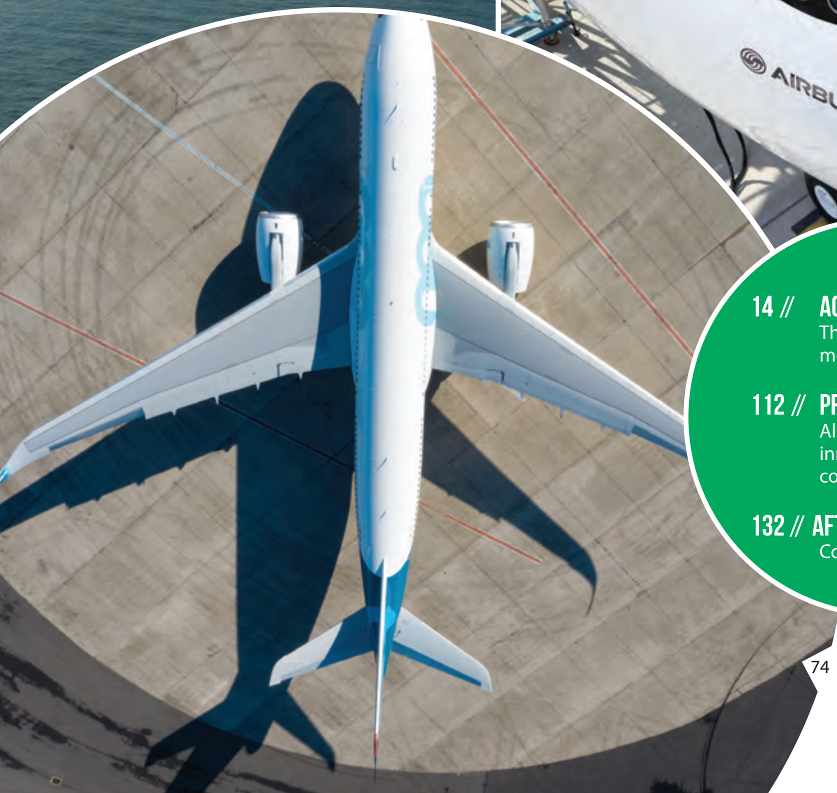

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Inside this issue

// The grounding of the 737 Max

As this issue goes to press, Boeing's 737 Max remains grounded around the world, following the tragic crash of Ethiopian Airlines Flight 302 on March 10. The aircraft crashed shortly after taking off from Addis Ababa, killing all 157 people on board. The Ethiopian Airlines crash happened five months after a Boeing 737 Max operated by Lion Air went down after taking off from Jakarta, Indonesia, resulting in the death of 189 people.

The incidents have plunged Boeing into crisis. In the aftermath of the Ethiopian Airlines crash, Boeing's share price tumbled more than 10%, wiping US$25bn from its market value. The media then became focused on the Federal Aviation Administration, which was the last aviation safety regulator to ground the aircraft. Commentators accused the regulator of being slow to react to the 737 Max's problems and criticized the close relationship between Boeing and the US government.

Once the FAA had grounded the 737 Max, Boeing described the move as being made out of "an abundance of caution", a phrase that it may regret using, considering the similarities between the two crashes that investigators are now uncovering. Initial evidence is pointing toward the 737 Max's Maneuvering Characteristics Augmentation System (MCAS), which is intended to stop the aircraft stalling or losing lift. A preliminary report into the Lion Air flight blamed faulty sensors triggering that airplane's MCAS when it should not have done. Pilots in the USA have also reported difficulties with the MCAS. Boeing is developing a software update to solve the issues.

Losing one of a new aircraft type less than two years after its introduction is terrible. Losing two is extraordinary. Investigators, regulators and Boeing will work to assess exactly what caused both crashes and how future issues can be avoided. While this happens, to continue operating the 737 Max would be irresponsible.

Another, less widely reported effect of the Ethiopian Airlines crash has been the postponement of the first test flight of Boeing's 777X aircraft, which was scheduled to take place on March 13. The 777X is highly anticipated by the aviation industry and heavily promoted by Boeing. The aircraft contains even more innovations than the 737 Max, including folding wing tips, so that it can have a greater wingspan while still fitting in at airport terminals.

The delay to the 777X's first flight because of the Ethiopian Airlines crash shows that the company has sensitivity about its public image and understands the seriousness of the incident. It also shows that the industry is locked into a cycle of product renewal that irrepressibly promotes technological improvements and innovation – but that this cycle is not more important than safety.

Testing of commercial aircraft is as thorough and well regulated as it can be. Engineers expend a massive amount of effort improving the accuracy and reliability of tests. When test programs have to occur within tight commercial timescales and budgets, when they deal with new and complex technologies, the job becomes tougher. But the goal is always to guarantee the safety of passengers. Every engineer involved in this can take pride in working toward that goal.

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COVER IMAGE: DNW-HST

WORLD
test update

// VAHANA AIR TAXI PASSES 50 TEST FLIGHT MILESTONE

A³, the Airbus subsidiary based in Silicon Valley, marked the 50 test flight milestone for the full-scale prototype of its Vahana electric vertical take-off and landing (eVTOL) in February.

The aircraft, which was first flown in January 2018, has so far flown for a total of five hours at the Pendleton UAS Range in Oregon, USA.

The eight-prop eVTOL has a 20ft (6.25m) wingspan, can carry two passengers, and is designed for a range of 60 miles (100km), and a cruising speed of 142mph (230km/h) with a ceiling of 10,000ft.

During the latest tests, engineers have been investigating how the vehicle reacts to impulse inputs to assess its response to certain roll, pitch, yaw and thrust inputs to guide the development of its flight controls.

A demonstrator is planned to be ready next year.

Oregon, USA

WATCH THE VIDEO ON OUR WEBSITE

// ELECTRIC AIRPLANE COMPLETES FIRST FLIGHT

Bye Aerospace's electric Sun Flyer 2 successfully completed its first official flight test with a Siemens electric propulsion motor on February 8 at Centennial Airport, south of Denver, Colorado.

Bye is developing the two-seat Sun Flyer 2 and the four-seat Sun Flyer 4 with the aim of becoming the first FAA-certified, US-sponsored, all-electric airplane for flight training and general aviation markets.

The company successfully conducted the maiden flight of a Sun Flyer 2 prototype during April 2018.

The electric propulsion system for the Sun Flyer 2 airplane, which is being provided by Siemens, is a 57 lb (26kg), SP70D motor with a 90kW peak rating (120hp), and a continuous power setting of up to 70kW (94hp).

George E Bye, CEO of Bye Aerospace, said, "The airplane performed exactly as planned. My thanks to the entire Siemens team for their participation as we enter this next, important flight test phase of Sun Flyer 2 with the Siemens electric propulsion system."

Denver, Colorado

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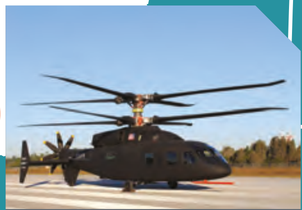


// DEFIANT HELICOPTER STARTS GROUND TESTS

The Sikorsky-Boeing SB1 Defiant helicopter has started the ground testing program for its unique rotor at the Sikorsky Development Flight Center.

The Defiant has a rigid, coaxial design, which enables greater speed and range compared with conventional helicopters with a single rotor.

The Defiant demonstrator is powered by a Honeywell T55 engine, which also powers the CH-47 Chinook. The engine is slightly modified to operate better at slower speeds.

The Defiant is one of two helicopters being developed as part of the US Army's Future Vertical Lift program, which aims to develop a successor for the Blackhawk and Apache helicopters.

West Palm Beach, Florida

WATCH THE VIDEO ON OUR WEBSITE

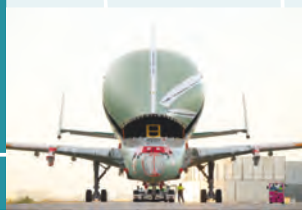
// AIRBUS BELUGA XL ARRIVES IN BRITAIN

Airbus's massive Beluga XL cargo airplane landed at the company's Broughton factory in North Wales for further ground testing on February 15, 2019.

The Beluga XL is 63m long (206ft), around 7m (23ft) longer than the Beluga ST it is replacing. Based on the A330, it incorporates a highly enlarged cargo bay structure and modified rear and tail section. The Beluga XL fleet will increase Airbus's air transportation capacity for its industrial network by about 30%, says the company.

Flight testing of the Beluga XL began on July 19, 2018, from the Airbus Toulouse headquarters in France. The aircraft is expected to start regular operations, moving oversized aircraft components between Airbus factories, before the end of 2019.

Broughton, Wales



// A330NEO CERTIFIED FOR LONGER FLIGHTS

The European Aviation Safety Agency has certified the A330-900 for ETOPS (Extended-range Twin-engine Aircraft Operations) of beyond 180 minutes of diversion time, opening up new routes for aircraft operators.

The ETOPS granted by EASA includes an option for a rating of up to 285 minutes. This extends the A330-900's potential air diversion distance to around 2,000 nautical miles (3,700km) in total.

READ MORE ON PAGE 74

The approval means that airlines operating the A330neo, which is powered by Rolls-Royce Trent 7000 engines, will be able to fly more direct and fuel-efficient routes, as well as direct non-limiting routes.

The Federal Aviation Authority's respective ETOPS certification is expected soon from the USA.

Toulouse, France

// ARIANE 6 TEST RIG OPENS IN GERMANY

The next phase of testing for Europe's Ariane 6 launcher commenced last month when a new test stand was officially opened at a rocket engine test site in Germany.

Test stand P5.2 was officially opened last month and will be used to test the entire cryogenic upper-stage of Ariane 6, called the Upper Liquid Propulsion Module.

READ MORE ONLINE

Construction of the €50m (US$56m) test stand started in autumn 2014. The stand is expected to be fully commissioned and operational by the end of this year.

Hansjörg Dittus, DLR executive board member for space research and technology, said, "This equipment allows DLR engineers to conduct both refueling and defueling, as well as complete stage tests, shortening development times and increasing the maturity of liquid-fueled, chemical space propulsion systems."

Lampoldshausen, Germany

// COMAC PREPARES THREE C919 AIRCRAFT FOR TESTING

Another three C919 prototypes will be built and flown this year as preparations for manufacturing China's home-built, narrow-body passenger aircraft gather pace, Chinese state media has reported.

According to the China Daily website and China Central Television, the developer of the C919, the Commercial Aircraft Corporation of China (COMAC), is testing the assembly area for the aircraft, while modifications are being carried out to test aircraft 102 and 103 for flight tests.

COMAC has said it is producing six aircraft for test flights, and will complete more than 1,000 compliance tests. Two other aircraft will undergo ground tests only, including static and fatigue tests. The aircraft, which first flew in May 2017, is expected to enter commercial service in 2021.

The C919 can carry 168 passengers and has a range of 3,000 nautical miles (5,555km).

Beijing, China

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ULTRAFAN WITHDRAWN FROM BOEING NMA ENGINE COMPETITION

Rolls-Royce has withdrawn from the competition to power Boeing's proposed New Midsize Airplane (NMA) because of concerns over the timeline. The NMA has been discussed in the industry for several years, but has not been officially launched by the company.

The NMA, which is also referred to as the 797, will seat 220 to 270 passengers and have a range of 5,000 nautical miles, industry experts predict. Boeing has had discussions with CFM, Pratt & Whitney and Rolls-Royce about supplying the engine for the NMA.

But Rolls-Royce said in a statement issued last week that it is unable to supply the UltraFan jet engine to meet Boeing's proposed NMA timetable and that withdrawing from Boeing's NMA process will "enable us to have a high confidence in engine maturity toward the end of the next decade".

The company had previously said that the UltraFan engine would be available from 2025. This would have fitted broadly with when the industry expects Boeing's proposed NMA to enter service.

Chris Cholerton, president – civil aerospace at Rolls-Royce, said, "This is the right decision for Rolls-Royce and the best approach for Boeing. We remain committed to the development of new technologies and will continue to mature and de-risk our next-generation UltraFan engine architecture in preparation for future applications.

"We had begun its development before the Boeing opportunity emerged and it must undergo a rigorous testing regime before we offer it to customers, which we do not believe can be achieved within the NMA timeframe.

"Withdrawing at this stage will enable Boeing to structure the final part of the competition in a way that best suits."

The testing of the core technologies for UltraFan started in 2016. Rolls-Royce engineers aim for UltraFan to offer a 25% fuel-efficiency improvement over its first generation of Trent engines through the use of composites, lean-burn technologies and a high-powered gearbox. The engine is being to designed to be compatible for use on both wide-body and narrow-body aircraft.

Last week, Rolls-Royce provided an update on the progress of UltraFan's development that revealed that its engineers had successfully tested the engine's Advanced Low Pressure System (ALPS). This includes the fan blades, a fan case and the annulus fillers. Rolls-Royce said the testing of the ALPS is ongoing at its site in Derby, UK. \\

// The UltraFan engine's blades comprise 500 layers of carbon fiber with a leading edge made from titanium

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// Mitsubishi's Regional Jet is planned to enter service in 2020

MITSUBISHI REGIONAL JET STARTS TYPE CERTIFICATION

Certification flight testing of Mitsubishi's Regional Jet (MRJ) has begun at the company's flight test center in Moses Lake, Washington state. The testing, which is anticipated to take most of this year, marks a significant milestone for the troubled project.

Development of the 70- to 90-seat MRJ started in 2004, but has been hampered by problems. The aircraft was originally planned to enter service in 2010, but since then its design and expected entry into service has been changed several times.

The latest problems – regarding the avionics – were revealed in 2017. Mitsubishi is also engaged in a legal battle with competitor Bombardier over the theft of intellectual property and is countersuing the Canadian manufacturer for alleged anti-competitive actions.

Mitsubishi now plans for the 90-seat capacity MRJ90 aircraft to enter service in "mid-2020", with the smaller MRJ70 to follow, up to 18 months later.

The company said, "We have begun certification flight testing with Flight Test Aircraft 4. We are getting good results.

"Certification flight testing will be ongoing and we will continue to coordinate with the aviation authorities. We intend to begin quarterly updates so that we are able to provide more detail on our progress."

Mitsubishi has so far produced four MRJ test aircraft and has two more nearing completion in Japan. These will join the testing fleet this year. \\

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NASA

DELTA OPENS "WORLD'S LARGEST" ENGINE TEST CELL

Delta Air Lines has finished building what it claims is the world's largest jet engine test cell in Atlanta, Georgia, USA. The 48ft-tall (15m) cell has inlet and exhaust sections that measure 66ft (20m) and 78ft (24m) respectively. The test cell is capable of safely running a mounted, stationary engine at full power with 150,000 lb of thrust.

The US airline's current test cell has a 68,000 lb thrust capacity. The test cell will provide capabilities to test a new assortment of engines that the airline's fleet will use in the future, including the Rolls-Royce Trent 1000, 7000 and XWB, as well as the Pratt & Whitney PW1100 and PW1500 variants of the geared turbofan engine.

Construction of the test cell started in June 2017. It is the first cell built by a US-based airline for more than 20 years.

The official opening of the test cell was held in February. Engineers will run a number of tests to prove and validate the cell. It will then be commissioned with tests on the Trent XWB engine and Trent 1000 electric start system installation, followed by Trent 1000 commissioning, correlation and production testing, with the first production test scheduled to take place before the end of this year.

The test cell will also be used by Delta's maintenance subsidiary, Delta TechOps, to provide support for the latest generation Trent XWB, Trent 1000 and Trent 7000, in addition to the Rolls-Royce BR715, which it has been providing maintenance, repair and overhaul since 2015.

The cell sits alongside a 130,000ft^2 (12,000m^2) engine workshop opened by Delta Air Lines in August 2018. The workshop features six 25-ton high-bay cranes located across four bays to provide 10 hook-up points and a total of 66, 6ft-diameter (2m) concrete piers with an average depth of 42ft (13m).

Don Mitacek, senior vice president of TechOps for Delta Air Lines, said, "This new test cell is great not only for the future of Delta, but also for our future aircraft technicians and engineers.

"The quality of the work and expertise of our people are the reason we are able to confidently invest so heavily in our future. Both facilities are a reflection of the accomplishments and the dedication of our people." \\

// Delta Air Lines' engine test cell in Atlanta, Georgia, USA, can run engines at up to 150,000 lb of thrust

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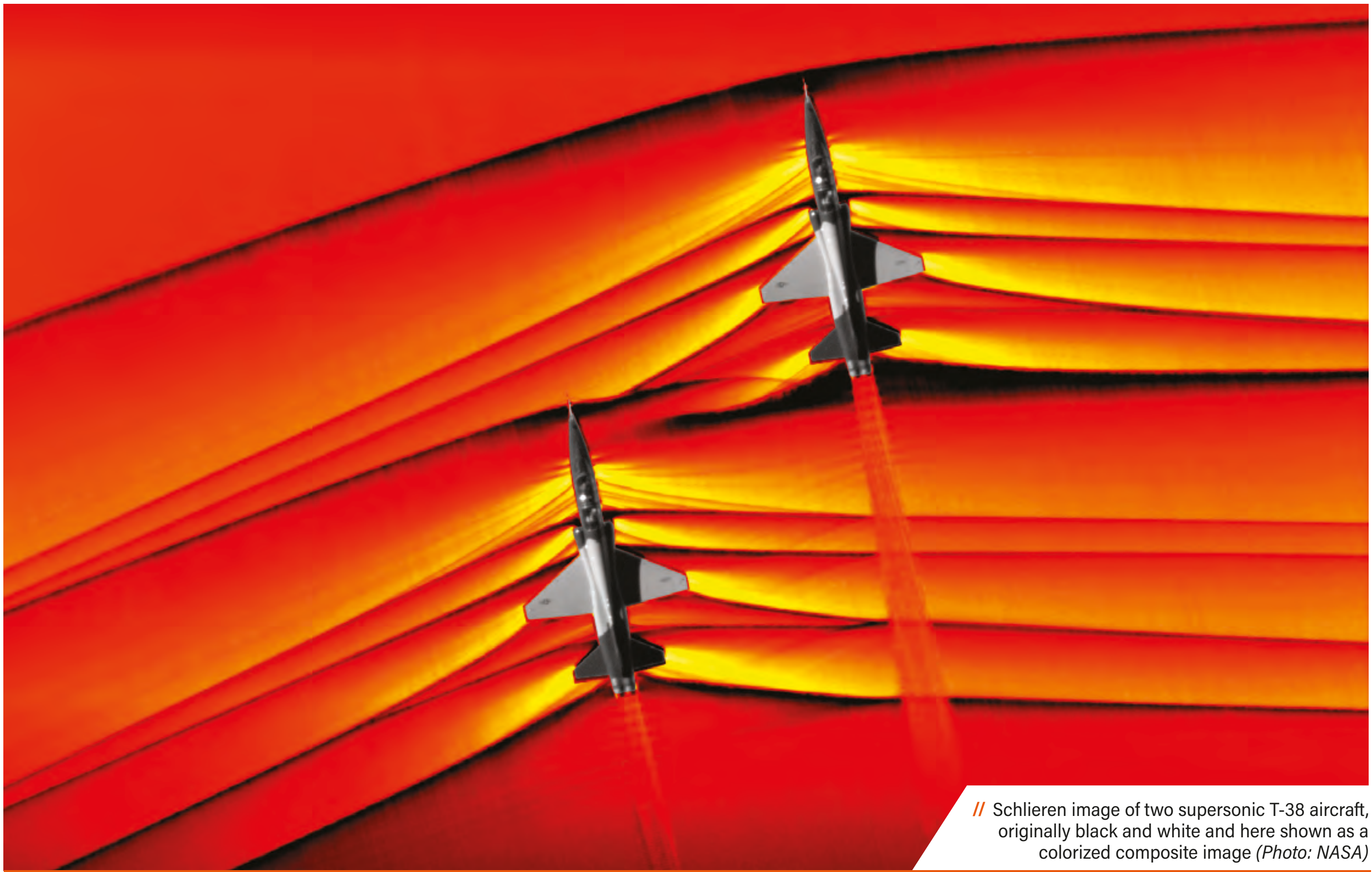

// Schlieren image of two supersonic T-38 aircraft, originally black and white and here shown as a colorized composite image *(Photo: NASA)*

NASA CAMERAS CAPTURE SUPERSONIC SHOCKWAVES

Researchers from NASA have captured the first images of the shockwaves from two supersonic aircraft flying in formation. The images, which were captured using the Schlieren technique from a camera system on board a NASA B-200 King Air, are of two US Air Force test pilot school T-38 aircraft approximately 30ft (9m) apart.

The images were taken during the fourth phase of the Air-to-Air Background Oriented Schlieren (AirBOS) flights, which recently took place at NASA's Armstrong Flight Research Center in Edwards, California.

The test flight series aims to better understand how supersonic shockwaves interact with aircraft plumes, as well as with each other. The data from the flights will help advance research and knowledge about supersonic shockwaves as NASA progresses toward quiet supersonic test flights with the X-59 prototype aircraft.

To capture the images, the King Air, flying a pattern around 30,000ft (9,000m), had to arrive in a precise position as the pair of T-38s passed at supersonic speeds approximately 2,000ft (600m) below. Meanwhile the cameras, able to record for a total of three seconds, had to begin recording at the exact moment the supersonic T-38s came into frame.

"The biggest challenge was getting the timing correct to make sure we could get these images," said Heather Maliska, AirBOS sub-project manager at NASA. \\

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THERMOGRAPHY FOR FACIAL TRACKING

Adrian Marinescu, a researcher from the University of Nottingham, UK, has been measuring the temperature of pilots' faces to monitor concentration levels and improve cockpit designs

Workload as a concept in the field of human factors is important because it helps us gain a better understanding of workplaces and how they can be designed to take into account human abilities.

The idea of workload seems intuitive. Most of us have experienced working at different levels. Despite this, quantifying it poses challenges and it remains an active area of research. Subjective measures, such as asking a person to estimate their level of workload after performing a task, rely on memory – and workload can be remembered incorrectly. Another popular technique is to assess task performance. The main disadvantage of this approach is that performance may not be sensitive to changes in workload.

Our research developed a third technique of workload assessment – physiological measures – and was aimed at tasks that have a dominant cognitive nature, such as piloting an aircraft.

This approach assumes that as more demands are placed on an operator, more physiological resources will be used. One advantage is that most physiological parameters are not under conscious control and can be recorded continuously in a non-intrusive manner. We chose to monitor face temperature using thermography, heart rate, breathing rate and pupil diameter, because these measures interfered the least with the task.

Facial thermography measures variations in surface temperature on the face using a thermal camera and uses facial landmark tracking algorithms to capture the temperature variation on a person's face without restricting head movement.

Our research initially explored the human physiological response to workload in a laboratory setting. The study involved participants playing a computer game with varying levels of difficulty while their physiological signals were monitored. This approach allowed us to more accurately control the level of demand imposed on the participant while minimizing external influences.

The results demonstrated that facial thermography and pupil diameter can be used for non-invasive real-time estimation of workload. The most noticeable changes were observed in the nose area, which showed significant decreases in its temperature.

The research was later extended to a six degrees of freedom, high-fidelity helicopter simulator study, with commercial pilots as subjects, to test if highly trained individuals would have a similar physiological response to the general public. This study showed that it is feasible to deploy physiological monitoring such as facial thermography in an aircraft cockpit, and that pilots do show similar physiological changes to the general public. However, a similar study with a larger number of participants is needed to confirm these findings.

Future studies will look at applying these measures to different domains, collecting data from a larger population, exploring other measures such as functional near-infrared spectroscopy, which measures blood oxygenation levels in the brain, and making use of the latest developments in deep learning to analyze facial expressions. The research will increase our understanding of how humans interact with work environments, such as cockpits, in addition to informing the design of such workplaces. There is also high potential to apply these technologies in other sectors. \\

exp

Exceeding ectations

The F-35 Integrated Test Force's seven weeks aboard HMS Queen Elizabeth has proved compatibility between the ship and jet and paves the way for the first operational cruise in 2021

> ***"It was almost too windy for us toward the end of the second period"***

2

3

2 // Peter 'Wizzer' Wilson, F-35 STOVL lead test pilot, BAE Systems *(Photo: BAE Systems)*

3 // Sqn Ldr Andy Edgell, RAF, developmental test project officer *(Photo: Crown Copyright)*

Royal Navy test pilot Cdr Nathan Gray landed an Integrated Test Force F-35B Lightning II aboard HMS Queen Elizabeth on September 25, 2018. The HMS Queen Elizabeth is the only operational fifth-generation aircraft carrier and lead ship of the sole class designed for the F-35B. The landing marked the beginning of an intensive round of first of class flight trials, under the Developmental Test 1 (DT-1) and DT-2 programs.

Involving two highly instrumented, telemetered Integrated Test Force (ITF) jets, Gray and three other test pilots (RAF Sqn Ldr Andy Edgell; US Marine Corps [USMC] Maj Michael Lippert; and Peter 'Wizzer' Wilson, F-35 STOVL lead test pilot, BAE Systems), the trials were completed over two periods at sea, from September 25 to October 17, and October 28 to November 19. The ship, its crew and the Integrated Test Force of military and contractor personnel, including nine deployed from BAE Systems, were dedicated solely to the running of the first of class flight trials.

ITF lead test pilot and project officer for DT-1 and DT-2, Sqn Ldr Edgell explains, "Those seven weeks at sea were the culmination of two years of planning. But the F-35 work goes much further back, especially at BAE Systems and in particular on the shipborne rolling vertical landing [SRVL], which has been worked on for 17 years."

1 // The view from flying control after the first F-35 landing on HMS Queen Elizabeth *(Photo: Kyle Heller/ Crown Copyright)*

"The only surprise was that everything looked so much like the simulation"

To a large extent, the DT effort might be considered a real-life validation of experience gathered during many thousands of hours of trials in BAE Systems' Warton, Lancashire, UK, full-motion F-35B/Queen Elizabeth Class (QEC) simulator. Warton's 'sim' is perhaps the highest-fidelity system of its type, helping to de-risk subsequent flight trials, not only by exploring the aircraft's behavior around the ship, but also enabling the pilots to experience emergencies and define procedures for escaping them.

Wilson says, "The simulator has an unparalleled level of detail in the minutiae of the ship's air wake, incorporating extremely complex air wake models created using computational fluid dynamics [CFD]. The result is a simulator the likes of which has never been experienced before."

He and his colleagues were impressed with the system's flight model. However he admits to having unfounded doubts over the level of detail in its visuals. "We knew the simulation was very good immediately we saw it, but the ship model appeared to lack ultimate detail – the islands seemed too clean and the flight deck almost sterile.

"So, there was certainly some surprise when we arrived at the ship and saw that the lack of detail was real; the designers have created a very clean ship to minimize its signature. Having now flown at the ship and returned to the sim, I remain impressed by the level of realism in the visual model."

"We'd put in so much work on the Warton simulator, so we were confident about the results that were likely to come out of the trials," Edgell says. "But in the test world it's all about the 'unknown unknowns'. You can work your hardest to mitigate every risk you consider might arise, but still lose sleep wondering what you haven't thought of. In the event, we surpassed our own expectations."

WAKE MODELING

Aircraft carriers are large vessels with considerable wakes, while a detailed understanding of the behavior of hot gases exhausting through their funnels and of how gas ingestion might affect an aircraft engine is also important for safe operations. Add to that the complex

SHIPBORNE ROLLING VERTICAL LANDING

An aircraft's maximum recovery weight dictates the fuel and stores load it can safely 'bring back' to the ship. The F-35B's bring-back capability increases dramatically if it's recovered using a brief landing roll, the so-called shipborne rolling vertical landing (SRVL), which could make all the difference between a pilot jettisoning valuable ordnance into the sea or bringing it back to use another day.

Conventional carrier aircraft 'catch' an arrester wire on landing, while shipborne Harrier operators generally prefer to hover before landing, there being no arrester gear aboard their ships. For a successful SRVL, the pilot must fly a precise approach through the ship's air wake, landing for a short run and quick stop using aircraft braking and deck friction, a set of variables carefully modeled in Warton's simulator.

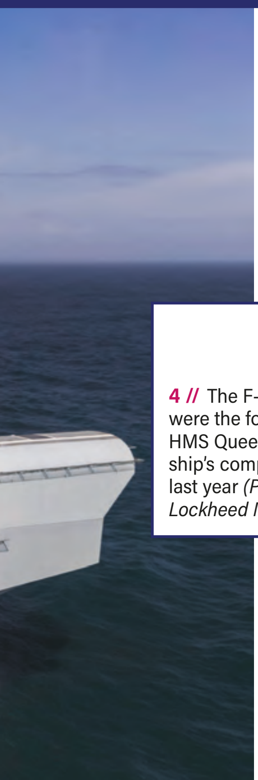
Before DT-1, BAE Systems' Wilson had completed in excess of 2,000 SRVLs in the simulator and it was he who flew the first SRVL onto Queen Elizabeth. "The procedure worked well," he says, "and we saw a range of overtake speeds at touchdown, giving us the confidence that our wheel brake and deck friction models are sufficiently accurate."

How did the reality compare with the sim? "The major differences were with the helmet-mounted display and the quality of the visual landing aid, both of which are notoriously difficult to model.

"We need to understand more with respect to the alignment of the helmet-mounted display to the outside world throughout the SRVL and we need reliable lights in the flight deck to make SRVL viable in sea states above 3 [waves above 0.5-1.25m (1ft 8in to 4ft 1in)]."

"We have some work to do for the landing safety officer too, making sure the workload is manageable so that every approach is conducted within the strict parameters necessary for success.

"But if you asked me to embark an F-35 onto HMS Queen Elizabeth today, I'd ask you whether or not I could do an SRVL, since it's already my preferred means of getting aboard."



4 // The F-35 trials were the focus of the HMS Queen Elizabeth's ship's company during last year *(Photo: Lockheed Martin)*

"This was about wedding the aircraft with the carrier, ensuring they were interoperable and worked the way we'd modeled"

5 // The Royal Navy's Cdr Gray completed the first F-35 launch from HMS Queen Elizabeth *(Photo: Kyle Heller/ Crown Copyright)*

airflow around the QEC's twin-island design, and the constant variable of wind over the deck, and the Warton sim had asked much of its CFD experts.

David Atkinson, BAE Systems' F-35/QEC integration lead, says, "We had large eddy and dynamic air wake modeling in the simulator, using CFD modeling produced by the University of Liverpool. The modeling demonstrated its benefit, especially when the pilots were approaching the ship with a starboard crosswind and the islands create a wake across the ship's side.

"Flying in those air wakes in the simulator prepared them well for the lumps and bumps they might experience hovering alongside the ship."

Atkinson believes the first vertical landings of the F-35B on HMS Queen Elizabeth matched the simulator experience exactly, while its fidelity also impressed the vessel's Flying Control and officers of the watch, all of whom had rehearsed that first day in particular at Warton, so there were no surprises along the way. "The only surprise was that everything looked so much like the simulation," he says.

Subsequent high hovers, and hovers over the deck, looked for interactions between funnel gases and the F-35B's Pratt & Whitney F135 turbofan engine, while the effects of the aircraft's own efflux on the deck were also examined. The compatibility between F-35 and the deck elevators, hangars and other fundamental systems, including ground-support equipment and even lashing patterns, was also verified.

Unrelated to the QEC trials, a fuel tube problem was identified as the cause of the F-35 program's first full aircraft loss after a USMC jet crashed on September 28, 2018. Subsequently, one of the embarked ITF machines required a full engine pull-back and component change. This major work hadn't been planned for the First of Class Flight Trials, but was completed without affecting the program in a negative way.

4
Test pilots who flew the first of class flight trials

1,200MPH
Top speed of F-35B

MILESTONES

Trialling a new aircraft on a brand-new ship inevitably generated a few issues, the most important among them a realization that the Queen Elizabeth's flight deck lighting and SRVL fixed visual landing array were less than optimal. In fact, the second QEC vessel, Prince of Wales, is

DATA COLLECTION

DT-1 and DT-2 gathered a vast quantity of data relating to specific test points, but also generated a resource that will serve the UK F-35/QEC program throughout its service life – currently reckoned to be around 50 years.

Given the volume of data collected, AVM Smyth sees little requirement to embark heavily instrumented jets beyond DT, while the opportunity to do so will become more difficult once Queen Elizabeth deploys for its first operational cruise, scheduled in 2021. Data gathered in October 2018 might therefore inform capabilities yet to be envisaged, three or four decades into the future.

For now, David Atkinson from BAE Systems says, "The aircraft were telemetering data back to the ship and we analyzed that for test point progression. Now it's all about combining the data with further simulator work over the next two years or so, expanding the envelope for release to service."

Meanwhile, DT-1 and DT-2 data has also prompted modifications to the simulator and informed DT-3.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6

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6 // Night flying trials conducted during the testing program *(Photo: Dane Wiedmann/ Lockheed Martin)*

7 // Refueling was also part of the trials *(Photo: Kyle Heller/Crown Copyright)*

already being completed with improved lights, while the Queen Elizabeth will be modified.

That the lighting issues and minor issues with helmet alignment were the only major problems uncovered in seven weeks of testing shows the value of the prior simulator work and the maturity of the aircraft and carrier. But did such thorough preparation make for an anti-climactic campaign once those initial landings and launches had been completed?

Atkinson says not. "There were milestones almost every day, relating to the F-35 or other aircraft that came to the ship, including the USMC MV-22 Osprey and CH-53. We even had the Zumwalt-class destroyer USS Michael Monsoor come alongside. We did replenishment at sea operations with a US fleet auxiliary ship and with RFA Tidespring, so the ship was completing its own firsts as we were achieving ours with the jet.

"Among the more significant F-35 firsts, we had the debut ski-ramp launch at night and the first launch with external stores, but we completed a number of tasks too, including minimum performance testing."

DT3 & OPERATIONAL TEST

Queen Elizabeth will embark F-35s again later in 2019, when the UK trials program moves on to operational test (OT).

Looking back at the 2018 trials, Wilson says, "We moved at a faster pace than anyone had expected and achieved more than we thought we would. That's largely thanks to the simulation we'd done, but the crew

"We were confident about the results that were likely to come out of the trials"

"There were milestones almost every day, relating to the F-35 or other aircraft that came to the ship"

8

9

8 // Ski ramp procedures verified after the simulator runs were successful *(Photo: Kyle Heller/ Crown Copyright)*

9 // The two ITF F-35s approach Queen Elizabeth for their first landings in September 2018 *(Photo: Lockheed Martin)*

of HMS Queen Elizabeth and the ship herself were outstanding."

Such was the rate of progress that some DT-3 test points were completed, notably the high wind over deck trials, Hurricane Michael providing the required natural assistance. Edgell says the team achieved what he called the "pipe-dream envelope". "We had four tiers of envelope – a very basic envelope that would enable OT to go to sea later this year and a slightly bigger envelope that we could declare Initial Operational Capability Maritime with – that was really the baseline we were aiming for, so anything beyond that was a bonus.

"We went two tiers beyond that, even achieving all the headwind, crosswind and tailwind testing that we'd aspired to in the pipe-dream envelope. And it wasn't a matter of good luck; it was about having the right people on the ship, having put in the right amount of work, and placing the ship where we needed it to be. In fact, it was almost too windy for us toward the end of the second period."

50KTS
Windspeed across the deck

7
Weeks of flight trials

The success bodes well for the remainder of DT-3, but AVM Harv Smyth is careful to stress the challenges of OT yet to come. Air Officer Commanding 1 Group, Smyth not only has responsibility for the RAF's combat airpower, including F-35, but also has UK military flight test under his remit.

A former Harrier pilot with extensive shipborne experience, he visited Queen Elizabeth during the 2018 trials, and found the experience "reassuringly familiar". Smyth is quick to praise those involved in DT-1 and DT-2. "This was about wedding the aircraft with the carrier, ensuring they were interoperable, and worked the way we'd modeled," he says.

"Later this year we'll begin operational test – where we need to prove we can warfight from the ship. It tests everything, from sustainment rates, through to our ability to get weapons to the aircraft, to feed it with data, get data from the jet off the carrier, and more.

"I consider DT-1 and DT-2 as getting us to base camp; now we face the climb to Everest. We're all prepared. We know what we have to do. But that doesn't mean to say it won't be hard work and I'm mindful to ensure people are aware of that." \\

// BEN SAMPSON

Grou

1 // Gulfstream engineers use an iron bird to evaluate the fly-by-wire flight controls, hydraulics, electrical systems and landing gear of aircraft before their maiden flight

nd force

The laboratories of leading commercial aircraft makers are growing in size and complexity as more testing is carried out on the ground

2 // Members of the integrated 777X test and validation team operate a simulated flight using the airplane's actual flight deck *(Photo: Boeing)*

Engineers in the aerospace industry are always under pressure to shorten development times for new aircraft. One way to achieve this is to reuse proven designs, architectures and components. But with new technology, societal trends, customer demands and commercial pressures, there will always be a need for development. Aircraft are becoming more complex, varied and interconnected, with more electronics and electrical systems on board.

The onus therefore falls on engineers to innovate better and quicker ways of evaluating and certifying aircraft. Flight testing is an expensive and time-consuming process, so engineers are aiming to test more of an aircraft's systems at higher levels of integration on the ground, before flight testing.

BOEING 777X DEVELOPMENT

The forthcoming 777X, which completed its maiden flight last month, provides a good example of the way in which laboratory testing is playing a greater role in modern commercial aircraft development.

Boeing Test & Evaluation (T&E) built one of its most complex laboratories ever to test the 777X and verify its systems' maturity before the first flight. The 11,600ft² (1,000m²) Airplane Zero Lab features an accurate recreation of the 777X flight deck, integrated with all of the airplane's components and testing equipment in one place. Engineers are using the laboratory to run the 777X's systems in a virtual environment before its first flight.

Boeing has also built the Integration Test Vehicle Lab to test the 777X's flight controls and hydraulic systems, including the folding wing tips, which are unique to the 777X. The lab consists of an upstairs control room with an operational flight deck and electronic equipment to capture test data, and a large open bay below, where the airplane's flight controls and hydraulic system components are laid out.

The Airplane Zero Lab represents the full functionality of the aircraft, which means teams can perform systems tests that would normally be carried out on the first flight test aircraft, called Airplane One. This has benefits in terms of project management.

Micah Leibrant, 777X systems verification manager from Boeing, says, "The front loading and identification of issues early on using the lab reduces impacts to the program's cost and schedule. Staying on plan at the individual system level is especially important when integrating multiple systems into an airplane.

"A key capability that can be tested in the lab is the end-to-end onboard-offboard communication pathways. Testing these in the lab is beneficial because we can verify the airplane's architecture and applications, the ground infrastructure and the applications off-airplane. It enables a smooth entry into service with the airplane and applications to support our customers."

The laboratories enable Boeing T&E engineers to simulate a large amount of the system functionality as it would function on the actual airplane. Automation is used throughout the laboratories wherever possible.

Boeing T&E engineering manager Joe Williams expects the amount of simulation on actual hardware to increase over time. "Industrywide, we've moved to use lab or test environments to the fullest

GULFSTREAM'S GROWING R&D CENTER

Over the past decade, Gulfstream has invested significantly in its R&D campus in Savannah, Georgia, USA. It was established in March 2006 with a single office building. Today it has three office buildings, two laboratories, two office buildings and employs around 2,000 engineers.

The site hosts an acoustics test facility for in-development and in-production aircraft; a cabin laboratory dedicated to advances in cabin technology, such as entertainment systems and cabin management; a composites laboratory for evaluating new materials; and a tooling laboratory.

Four dedicated laboratories were built for the company's latest G500 and G600 aircraft: an integration test facility for the flight deck, to evaluate major avionic and aircraft systems and software and to test the galley and cabin management system; an iron bird to evaluate the fly-by-wire flight controls, hydraulics, electrical systems and landing gear; a system integration bench to integrate the avionics and aircraft systems with the aircraft's data network; and a conceptual advanced simulation environment laboratory used to develop fly-by-wire control laws and perform human factors evaluations. Separate labs were built for the G600.

Dan Nale, senior vice president of Gulfstream's programs, engineering and test, says, "We'll continue to use the G500 and G600 labs while the aircraft are in service. The labs are a good way for us to test software updates and new services before installing them on the actual aircraft. We also use the integration test facility to accelerate resolutions to potential in-service challenges to further support our customers. We still use the Gulfstream G550 integration test facility, and that aircraft has been in service for more than 10 years."

2

"The greater the integration of systems on the airplane, the greater the challenge to ensure the test assets are synchronized"

extent possible. We can exercise integrated systems extensively to enable earlier verification of functionality," he says. "It's hard to say where we'll end up, but we can expect some airplane-level verification in the future."

However, testing such integrated systems in simulated environments on the ground is an approach that has challenges. As an aircraft's design evolves, so too must its laboratories.

"Keeping a capability like the simulation environments synchronized with maturing airplane development has to be managed throughout the development cycle," says Leibrant. "The challenge is not so much with an individual system, but rather with the entire integrated airplane. The greater the integration of systems on the airplane, the greater the challenge to ensure the test assets are synchronized."

HUMAN FACTORS

Dan Nale, senior vice president, programs, engineering and test at Gulfstream, is proud of the amount of testing his team can perform before the first test aircraft takes to the skies. He cites human factors as an area where the company has reaped the benefits of simulation using hardware. The company used these techniques to reduce the time it took to develop and test its latest aircraft – the G500 and G600. These aircraft received updated flight decks – the control yoke was moved to an active control sidestick, the cursor control devices were shifted from outboard to the center column, touchscreens were installed in place of buttons, dials and switches, and new pilot seats were used.

Engineers evaluated and tested the new flight deck designs across a range of

3 // An iron bird will recreate an aircraft's systems on the ground as far as possible, including its landing gear and hydraulics *(Photo: Gulfstream)*

"Industrywide, we've moved to use lab or test environments to the fullest extent possible"

pilot sizes and types at the company's Savannah R&D center in the Conceptual Advanced Simulation Environment (CASE) and an integration test facility. Pilots with different backgrounds were brought to the laboratory to 'fly' the aircraft while the human factors team evaluated how they interfaced with the various elements of the flight deck.

"For the G500, we brought in five crews of pilots, including the regulatory authorities, to different test sessions to expose them to all aspects of the Symmetry Flight Deck," says Nale. "We basically did 100% of the human factors testing in the labs. The labs enabled us to do more human factors testing on the G500 and G600 than for all our other aircraft combined."

Nale agrees that the amount of testing prior to a maiden flight is increasing. Before the G500 made its maiden flight, the aircraft had already flown about 30,000 hours in laboratory simulations, enabling much higher maturity before the first flight. "The pilots even 'flew' the exact flight test card as for the first flight," he says. "In fact the G500 and G600 represent the most rigorous certification programs we've done – in large part because of the work we've accomplished in the labs.

"The work done in the labs allows us to perform, practice and evaluate high-risk maneuvers on the ground before doing them in the air. It also enables us to identify improvements and address them prior to flight test and, ultimately, delivery to the customer. It's not uncommon for our flight test aircraft to come back without a single squawk. In fact the G600 flight test aircraft once flew 22 consecutive sorties without a single issue.

"Having the engineers and test pilots in the same building with the labs was a huge benefit. The labs have had great correlation to the aircraft. Many issues were found in the labs before they're discovered on the aircraft, enabling us to drive the maturity and reliability of the development and test programs."

SIMULATING TRENDS

As well as the actual aircraft components, engineers use computers that have been modified to handle inputs and outputs, paired with data acquisition systems to construct aircraft integration systems laboratories. They then use them to run simulated real-time scenarios.

Supplier National Instruments offers hardware-in-the-loop (HIL) systems that comprise a data acquisition device, such as its compactRIO or PXI systems, combined with some or all of its signal conditioning or fault insertion equipment. Margaret Bennett, senior solutions manager at National Instruments, says, "HIL is the first step out of the door into the real world for testing. The systems create signals, inputs and outputs, which are in line with what we would expect to see in the real world."

AEROSPACETESTINGINTERNATIONAL.COM // MARCH 2019

4

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4&5 // Boeing's integrated systems test team performs simulated operations in the Airplane Zero Lab, June 2018 *(Photos: Boeing)*

"HIL is a process for verifying embedded software. In many ways it's a form of validation. It's not for recreating and testing hardware's physical characteristics."

Although laboratories are developed bespoke for aircraft by large OEMs, some parts of simulation test instrumentation and equipment can be reused. It's here that the National Instruments approach to hardware can be helpful to engineers, claims Bennett. "Unlike some of our competitors, we have a consistent, open platform. We don't black box anything – our products are based on COTS components," she says. "You learn HIL as a discipline on the job and you would have to gain knowledge about National Instruments' solutions if you use our products. But you don't have to relearn everything each time you switch programs. That saves time and money."

HIL is one of several types of real-time simulation technologies that real time test equipment supplier Opal-RT offers. Within HIL, it offers a number of applications such as rapid-control prototyping and high-power HIL. Charles Fallaha, Opal-RT's team leader for more electric aircraft development, says, "There's been more interest in simulating high-switching power electronics components and systems.

"As more power electronics are used on aircraft, people need to know about the pollution they might cause – things like electromagnetic interference, which might cause power failures and malfunctions with potentially catastrophic consequences. With our equipment we can create the harmonics needed to accurately simulate those power electronics."

When inputs and outputs are not at levels that would be found in components on an aircraft, amplifiers and power supplies are used in a laboratory to boost the I/O signal and create realistic scenarios, such as take-off and landing.

Tom Kirk, senior technical sales at Opal-RT, believes there is plenty of opportunity to increase the amount of real-time simulation done in the aerospace sector. "We're moving away from mechanical and hydraulic systems in aircraft design and there's an impact on design and testing, in power issues and high heat flows," he says. "We've been working with the aerospace sector for 20 years and it's still behind the automotive sector in this type of testing.

"Aerospace companies tend to keep work in-house to protect IP. But its possible now to use models that have proprietary information removed. There's more of an opportunity to leverage the value that external suppliers can provide."

As people become more familiar with simulation, its use will almost certainly grow, but validation with flight testing will always be part of the testing process. Leibrant from Boeing says, "Flight testing is required to verify airplane-level effects and to ensure that the integrated product meets the performance requirements. An example is non-interference of electronic/electrical systems. These considerations are not readily simulated and typically drive airplane-level verification activities." \\

11,600FT²
Footprint of Boeing's Airplane Zero Lab

30,000HRS
Time G500 spent in flight simulation before its maiden flight

"It's not uncommon for our flight test aircraft to come back without a single squawk"

// BEN SAMPSON

Gearing up

Air-breathing rockets could radically alter the space industry by reducing the cost of launches and increasing the number of testing facilities available to engineers

1 // The SABRE engine is being developed to be integrated with a variety of air vehicles *(All photos: Reaction Engines)*

"Reaction Engines is making huge strides in its development program"

Reaction Engines is a company with an ambitious end-goal in mind – to develop its revolutionary rocket engine SABRE. It's an engine that could be the next leap forward in aerospace propulsion. The design combines technological elements of jet and rocket engines to create a fuel-efficient, reusable and scalable propulsion system.

SABRE (Synergetic Air-Breathing Rocket Engine) is designed to operate in two modes. From take-off to Mach 5, while still within the atmosphere, the engine sucks in air like a conventional jet engine, to support combustion of the hydrogen fuel. Once above the atmosphere, SABRE switches to conventional rocket mode and uses liquid oxygen (LO_X) stored on board. The engine's air-breathing characteristics reduces the amount of heavy LO_X a launch vehicle has to carry.

Reaction believes SABRE will enable the introduction of a range of hypersonic air vehicles and the development of satellite launch systems, delivering access to orbit at much lower cost than existing rocket technology.

"It's no longer a research project," says Dr Robert Bond, head of future programs at UK-based Reaction Engines. "It's a development program with an engine in the first stages of demonstration. But like all high technology endeavors there remains a strong research element – in the materials, fluid flow and combustion."

Reaction Engines can trace its beginnings back to the early 1980s and an ill-fated research program led by British Aerospace and Rolls-Royce to develop a spaceplane called HOTOL (Horizontal Take-Off and Landing). Reaction Engines was launched in 1989, when the HOTOL project ended, with the aim of commercially developing the air-breathing SABRE engine and illustrating its potential with the Skylon single-stage-to-orbit concept.

Three decades later, Reaction Engines is making huge strides in its development program. A £26.5m (US$36m) funding injection last year by Boeing, Rolls-Royce and existing investors followed a £20.6m (US$27.4m) investment by BAE Systems. The company has now expanded to 200 employees, built engine and heat exchanger test infrastructure in the UK and the USA, and finalized plans to ground test the core of its SABRE engine.

1,000°C
Airflow temperature that the engine's precooler will be exposed to during ground tests (1,832°F)

-150°C
Temperature to which the precooler chills incoming air for use in the engine (-238°F)

SYSTEMS TESTING

The SABRE engine has three main parts – the precooler, the engine core and the thrust chamber. These systems are being developed and validated on the ground to reduce flight test time. Reaction Engines' engineers plan to demonstrate each of the engine's systems independently, before an integrated ground test of the engine.

"We're allowing three to four years to prove the core technologies before integration," says Bond. "All the work we do from now on has to be done in parallel with a partnership program to integrate the engine further and then onto a vehicle."

The ground test campaign is beginning with the testing of the engine's precooler at a high-temperature airflow test facility built by Reaction Engines at Front Range Airport near Watkins, Colorado, this year. The purpose of the precooler is to reduce the temperature of the air going into the engine at high flight speeds, preventing overheating and enabling the air to be used as oxidizer. Small-scale laboratory testing of the precooler was conducted several years ago under cryogenic conditions at the company's headquarters in Culham, UK, to prove the effectiveness of its frost control system. Crucially the latest test procedures don't need to reduce the temperature of the air leaving the precooler to sub-zero centigrade temperatures, as the current SABRE engine concept uses a modified thermodynamic cycle.

During the high-temperature tests, the precooler test article (HTX) will be exposed to airflow conditions in excess

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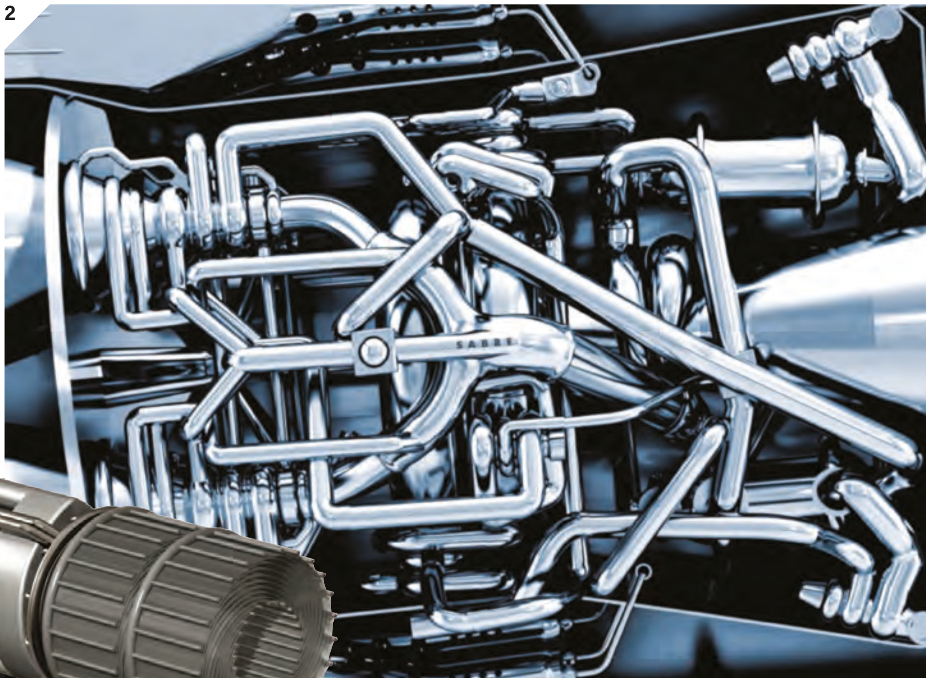

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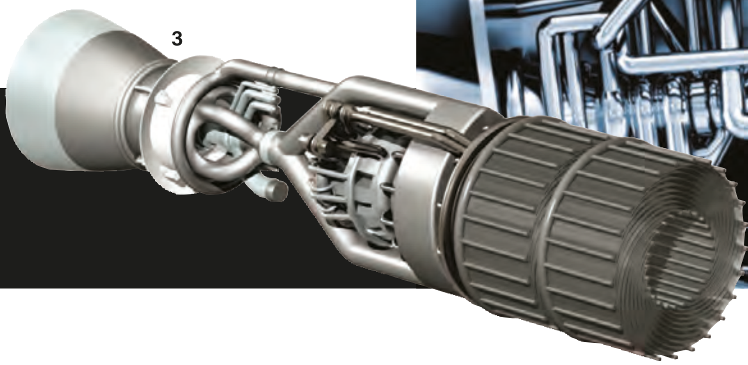

2 // SABRE's combustion chamber uses oxygen chilled from the precooler mixed with hydrogen

3 // The SABRE engine is capable of Mach 5.4 in air-breathing mode


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of 1,000°C (1,832°F), the same as the temperatures expected during high-speed flights of up to Mach 5. The HTX test article was commissioned and shipped to Colorado from Reaction Engines' site in Culham at the end of last year.

After the HTX testing, Reaction Engines plans to make the Watkins facility available to industry, technology developers and universities that could benefit from the facility's niche capabilities.

ENGINE CORE

The second section of the engine, the core, is the gas turbine and main air-breathing part. Engineers are conducting a preliminary design review of the section and are planning to start the testing of a demonstrator before the end of 2020.

The engine core demonstrator tests will take place at a UK test facility being built at Westcott, Buckinghamshire. The site is a former UK government rocket engine test site and the new facility will consist of a multipurpose propulsion test stand, an assembly building, workshops, offices, a control room and cryogenic hydrogen storage. When complete, Westcott will be the biggest test facility equipped to run tests with liquid hydrogen fuel in the UK. The requirement for hydrogen is a tricky aspect of the test program. Mark Wood, chief operations officer at Reaction Engines, says, "Trying to buy enough hydrogen to test the engine at Westcott is challenging. It's expensive and we need to use 5-7kg [11-15 lb] a second. We are preparing to use tons of it."

The Westcott site, which will also host the test programs for other subsystems of the engine, will be made available for use by other companies and organizations for testing, as with the site in Colorado.

> ***"We don't want to have to book time on a stand and then risk missing that window"***

"We anticipate there will be plenty of opportunity for people to use the facilities where relevant," adds Wood.

VALIDATION TESTING

Among the other systems to be tested at Westcott are combustion systems, including SABRE's thrust chambers and nozzle systems. The design of this part of the engine is also challenging. "We've already done some tests on the combustion system and nozzle. It's a complex nozzle system because it has to operate in air-breathing and rocket modes, so we've considered several

25KM
Altitude to which SABRE will operate in air-breathing mode (82,000ft)

5-7KG
Liquid hydrogen needed per second at Reaction Engines' Westcott test facility while firing the engine (11-15 lb)

ROCKETS THAT BREATHE

Air-breathing rockets, which use the abundant resource of the oxygen in the atmosphere as an oxidizer to improve the efficiency of the engine's performance, have been designed and tested since the early 1930s. Early approaches were based on the **ramjet** engine, the successor to which is the **scramjet**. Both types have influenced the development of rocket combined-cycle engines. Apart from SABRE, the two major types that have been developed are aerospike engines and liquid air cycle engines (LACE).

The **aerospike engine** has a nozzle that resembles a spike, or a spike that has been shortened. The most recent and furthest developed example was Lockheed Martin in the 1990s, which developed a linear aerospike engine for its X-33 spaceplane. However development was ended when funding was pulled from the project in 2001. Various companies have developed aerospike concepts; most recently US company Rocketstar.

The **LACE** works by compressing and liquefying the air that enters a ram-air effect intake. The liquid oxygen is removed through mechanical systems and used as an oxidizer. The concept was developed by NASA in the 1960s. A related more recent example of development in this area was the Japanese ATREX (Air Turbo Ramjet Engine with eXpander cycle) project, which resembled a precooled turbojet engine.

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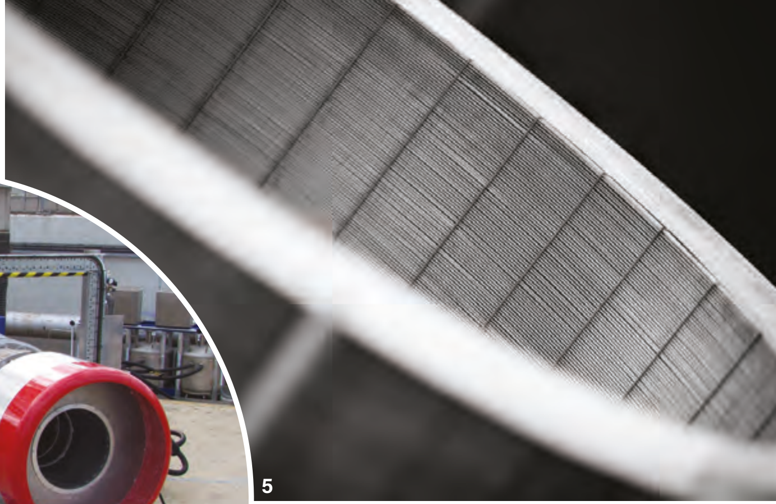
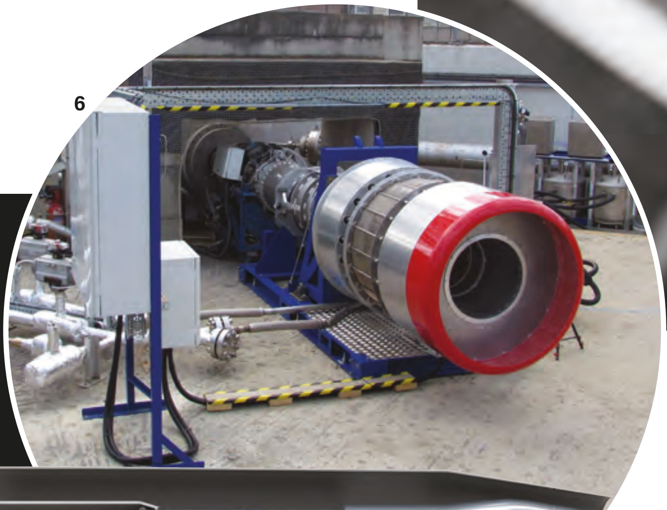
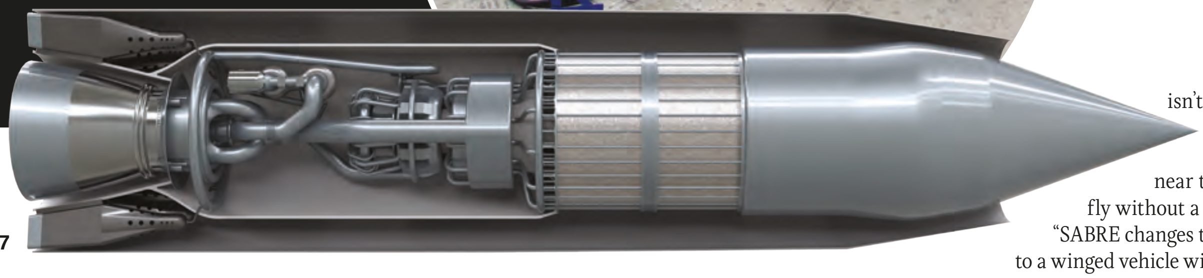
4 // Artists' impression of SABRE's Test Facility 1, which is being built at Westcott in the UK







5 // SABRE's heat exchanger is made of thousands of thin-walled tubes to provide high surface area to low weight

6 // The precooler has been tested extensively in the laboratory

7 // The SABRE engine has three core parts: the precooler, the engine core and the thrust chamber

> **"The heat exchanger technology could be used to improve the performance of conventional jet engines"**

designs," says Bond. "Most testing has been around the fluid dynamics and flow. We've done modeling that shows the performance. The tests will validate the models for confidence."

Conventional rockets are designed to exit the atmosphere as soon as they can, because air creates drag. However, a SABRE-based vehicle will stay in the atmosphere for longer, with the wings providing lift, so the engines don't have to be as powerful. Noise will also be reduced. "It can be a much more effective way of reaching orbit and it's easier to abort a mission and recover from it if there is a malfunction," says Bond. "You won't always lose your payload. It means it no longer has to be ocean or orbit."

SABRE does still have small LO_X tanks because they are required beyond the atmosphere to oxidize the liquid hydrogen fuel the engine uses. Typically 70-75% of the mass of a conventional rocket is liquid oxygen and its tanks. With SABRE, the aim is to harvest the oxygen from the air up to an altitude of 26km (16 miles) and speeds of up to Mach 5 while in air-breathing mode. The LO_X will be used for space flight – rocket mode – and speeds of up to Mach 25.

Building its own test facilities is an expensive step for an aerospace company. There are facilities and expertise in Europe that Reaction Engines could use, such as Lampoldshausen in Germany, where the Ariane rocket engines are tested. Wood explains the reasoning behind the move: "We could not find places with the facilities we required and the flexibility around timings we need. We don't want to have to book time on a stand and then risk missing that window."

Bond adds, "There are many facilities for conventional aero-engines, but we are more in the experimental end, with prototype development. Having said that, we are looking at certification and we're talking to the UK CAA."

Another key goal of the testing is to prove the reliability of the engine. "The reusability of the engine helps drive down costs," says Woo, "but reliability isn't typically high for launch vehicles. Large rockets are assembled at or near the launch pad and they fly without a test flight.

"SABRE changes the architecture of a launch to a winged vehicle with an air-breathing engine. You don't need as much propellant. You can use a smaller, more manageable vehicle that can do horizontal flights and test flights."

DIVERSIFICATION

There are currently more than 70 launch system projects in development around the world. But not many have the financial backing of top tier aerospace and defense companies such as Boeing and BAE Systems, or the 30-year pedigree of Reaction Engines. Bond sees last year's successful round of fundraising from investors as a reflection of the progress the company has made recently and of the credibility of the company's test program.

Bond says, "The major aerospace companies can see we are getting to test some of the key technologies. It makes you seem real and draws people in. When you move from PowerPoint to reality is when the money and interest start to flow."

The company also believes that elements of the engine's technology, such as the heat exchanger technology developed for the precooler, could be used to improve the performance of conventional jet engines and could transfer to other sectors such as automotive and energy. Reaction's management recently set up an applied technologies division and sees achieving such applications as a medium-term goal for the company.

Bond says, "When we were small, we were financially vulnerable. We're a bigger company now and more resilient, but nevertheless we need to develop an income stream from a variety of sources."

Developing a technology first, then looking for a solution, is rarely an easy approach to engineering. It is also easy to be transfixed by the promise of cheaper, easier spaceflight and potential applications across different sectors. But as Reaction Engines starts the first ground tests of hardware this year and starts proving reliability, not just learning as it goes along, after 30 years the company is finally moving along the TRL scale – from research to product development. \\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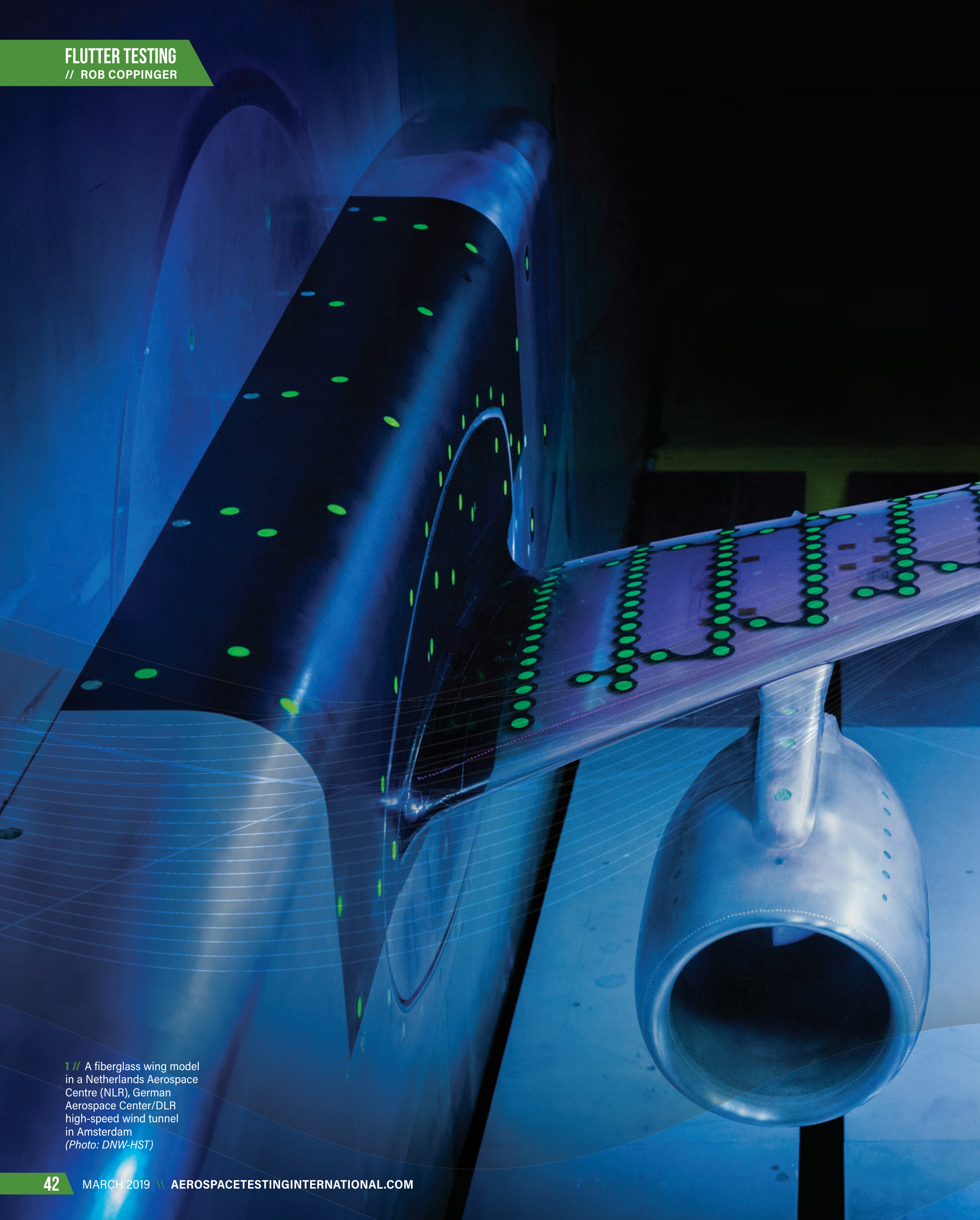
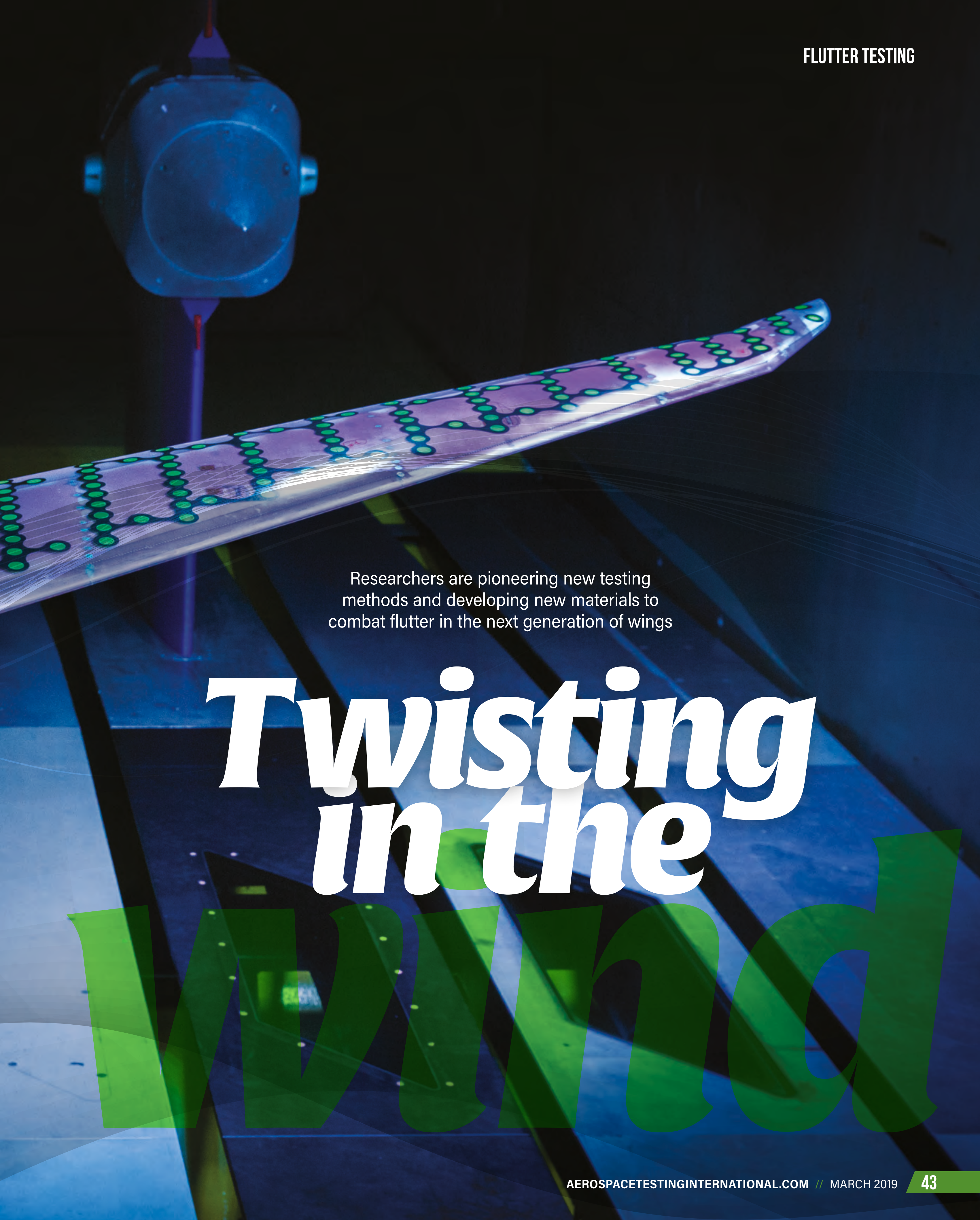


1 // A fiberglass wing model in a Netherlands Aerospace Centre (NLR), German Aerospace Center/DLR high-speed wind tunnel in Amsterdam *(Photo: DNW-HST)*



Researchers are pioneering new testing methods and developing new materials to combat flutter in the next generation of wings

Twisting in the wind

2 // NASA researchers monitor a test of the passive aeroelastic tailored wing at the Armstrong Flight Research Center in California *(Photo: NASA/Ken Ulbrich)*

Longer, lighter, thinner wings with improved fuel burn are the research goals of all major aircraft manufacturers. But such designs have an enemy: flutter – vibrations induced by turbulent airflow passing over an aircraft's fuselage and wings (see *What is Flutter?* overleaf). These vibrations can become stronger until they match the aircraft's natural resonance and damage or even destroy the aircraft.

Longer, lighter, thinner wings that have a higher aspect ratio are better at providing lift and produce less drag. This minimized drag, along with the reduction in weight, makes an aircraft more fuel efficient. But thinner wings are more susceptible to flutter and ways have to be devised to make them resistant.

"We are stabilizing our wing with a twist," says NASA structural efficiency technology lead Karen Taminger, describing the solution her research is investigating. Her team has been working with a scale-model wing that at full size could be used on a commercial airliner such as the Boeing 777.

Taminger works on NASA's high aspect ratio wing subproject, which is part of the agency's advanced air transport technology project. "We're trying to make the wing in a higher aspect ratio – longer, thinner and lighter," Taminger says. "When you combine those three factors, the wing becomes much more flexible. What we wanted to do was try to control and tailor that flexibility to work for us, rather than fight it."

NASA calls the solution a passively aeroelastic tailored wing. A composite wing, the 12m (40ft) scale-model was tested during September and October last year at the Armstrong Flight Research Center in California. The wing is designed to passively control flutter. It does this not with the load bearing structure of the ribs and spars, but with the skin. This flutter-resistant skin is a tow-steered composite.

"In a fiber tow-steered composite, the load can be distributed directly onto a specific spot"

A typical composite structure has fibers laid in one direction in one layer and in another direction in the next, to give it strength in those different directions. In a fiber tow-steered composite, the load can be distributed directly onto a specific spot, such as a wing stiffener. In the Armstrong test wing, instead of the fibers being aligned with either the leading edge, trailing edge or neutral axis of the wing, they meander. "They going from the root to the tip, closer to the leading edge for one part and then turn, going closer to the trailing edge before coming out straight at the tip," says Taminger.

COPING WITH FLUTTER

If you push down on the tip of a metal or composite wing, the wing will bend downward. This is not the case with the tow-steered wing. "What we saw was, when you pushed down on that neutral axis, it imposed a forward twist at the tip," Taminger says.

That forward twist leads to the wing tip turning in on the leading edge, which means that the wing loading from airflow is directed into the thicker section of the wing. That thicker structure is flutter resistant and can absorb and passively alleviate the power of gusts.

In the Armstrong center test rig, the wing was subjected to a 2*g* of force in one direction and -1*g* of

force in other directions. "As we loaded it up, we could see the effect of the tow steering changing the stiffness along the wing. After we got up to about 60% of the 2.5*g* maximum load, it started to level out," says Taminger.

"Then we could see that it turned into the wind. It does the opposite of what you would expect."

> **"The wing had to be large enough so that the loads, strains and responses were valid to extrapolate"**

STRAIN ROSETTE

Engineers placed 400 strain gauges and eight fiber optic strands across the wing for the tests. Each fiber optic strand had a strain sensor built in every 1.2cm (0.5in), along the full length of 12m (40ft) wing. Effectively the fiber-optic strands gave around 20,000 strain measurements.

While most of the fiber-optic strands and their sensors were laid straight, some were placed in a triangle pattern. This was to try to, "simulate a strain rosette so that we could measure more localized strains, which we needed to do because of the way the fibers were laid out in the wing," says Taminger.

A strain rosette uses three strain gauges oriented at 0°, 45° and 90°.

"We knew that every half-inch along the length of that fiber optic, we had a fiber grading that could give us a localized strain measurement," says Taminger. So her researchers laid out the fiber-optic strand in a triangle shape so that it achieved the measurements required. This enabled the researchers to get localized strain measurements in multiple orientations at specific points in the wing.

TARGETS AND PATTERNS

The NASA researchers also used "coarse-scale photogrammetry" to measure loads on the wing by placing photogrammetry targets – sticks with dots on them – on the leading and trailing edge of the wing. The targets were then illuminated by a laser to give the gross deflection of the wing under loading.

Another photographic measurement process used was fine-grain digital-image correlation. This involves placing a high-contrast random paint pattern on the wing and pointing cameras down onto it. One of the parts of the wing daubed with this random paint pattern was the wing tip.

"You can measure in-plane and out-of-plane strains by comparing images unloaded and under load. We compare the shape of the droplets, and as they morph we get a visual image of the strains," says Taminger.

The next step for the research project is to study and perhaps test a full-scale wing, which requires funding that NASA does not yet have. "We wanted the wing large

WHAT IS FLUTTER?

Aeroelastic flutter is vibration in an aircraft's structure induced by turbulent airflow passing over the aircraft. It is an unstable, self-excited structural oscillation at a frequency where energy is extracted from the airstream by the motion of the structure. In extreme situations, where the flutter could lead to structural failure, passengers experience discomfort from the large-scale vibration.

Aeronautical research into flutter is primarily concerned with structural integrity and how wind induced vibration, if coupled with an aircraft's natural mode of vibration, can lead to catastrophic failure. The natural mode is the frequency at which the material vibrates. Such a frequency can generate vibrations that grow in strength until the material can no longer sustain them and it breaks apart.

3

3 // The passive aeroelastic tailored wing bends under pressure from the highest loads applied during testing at NASA's Armstrong Flight Research Center in California *(Photo: NASA/Ken Ulbrich)*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4 // Adjustments being made to the passive aeroelastic tailored wing testing apparatus at NASA's Armstrong Flight Research Center, California (Photo: NASA/Ken Ulbrich)

AIRBUS WING OF THE FUTURE

Airbus's Wing of the Future program is exploring materials, manufacturing and assembly techniques, aerodynamics and wing architecture technologies at the company's facility in Filton, UK.

The program, which was launched in 2015, includes full-scale demonstrations of new wing technology. Long, narrow wings with a high lift-to-drag ratio for better fuel efficiency are being researched, alongside wings with folding tips.

The program is investigating the use of composites and new manufacturing processes to enable new wing designs with fewer components, which will make building them quicker and easier. Lower-cost composite technologies and metal alloys are also being examined. Engineers are using traditional strain gauges, digital image correlation, thermal stress analysis, photoelastic analysis and mechanoluminescence tests to investigate materials and structures. Various displacement systems such as photogrammetry and scanning laser tracking systems are also being used.

enough this time, 40ft, so that the loads, strains and responses were valid to extrapolate," Taminger says. "Our next step in the program is to scale up, at least on paper, to a full-scale wing."

REAL-TIME MEASUREMENT

In Europe work has been undertaken to improve the measurement of flutter during tests. "We are developing our flutter analysis toolkit to be faster and more precise and to have a database in the back end," says Yves Govers, German Aerospace Center Institute of Aeroelasticity structural dynamics and system identification deputy head.

The toolkit was created from testing undertaken in 2017 at the German–Dutch Wind Tunnels (DNW) High-Speed Tunnel (HST) in Amsterdam, a joint facility between the German Aerospace Center (DLR) and the Netherlands Aerospace Centre (NLR).

"It was an industrial project with Embraer, where we used our expertise to give more control over the wind tunnel testing process," Govers explains. "If you hit an aircraft wing, you see it vibrating up and down. This is the fundamental eigenfrequency of the wing, which we call the wing bending mode."

2.5G
Maximum load placed on NASA's aeroelastic tailored wing

The eigenfrequency, which is also known as the natural frequency, is the frequency at which a system tends to oscillate in the absence of any driving or damping force. A bending mode can be described as when the wing tip flexes up and down relative to the fixed wing root.

"The special feature of aircraft wings is that with varying altitude and flight speeds, these frequencies change, and it might happen that they get together," Govers says.

The Embraer, DLR and NLR researchers used the wind tunnel work to develop a method of monitoring flutter in real time. A highly elastic fiberglass wing model was placed in the DNW HST in Amsterdam and it was tested in airspeeds corresponding to an aircraft flying at between 850km/h and 1,100km/h (530-680mph). The model was fitted with pressure sensors and strain gauges that fed data back to the researchers.

The wing model was tested at various angles of attack. When using traditional testing methods there was a delay before this data could be analyzed, but with this test setup the researchers could now identify exactly what safety margins remained before the onset of flutter and the possible destruction of the model.

Flutter will continue to be a challenge as long as aircraft are flying, but the improved analysis techniques and passive technological solutions that are being developed by engineers all around the world should mean an end to the ominous prospect of aircraft shaking themselves to destruction. \\

"We are developing our flutter analysis toolkit to be faster and more precise"

Unmanned & untested?

The environmental testing of drones is a growing business thanks to the increasing number of applications being found for them

Imagine a farmer standing on the edge of a 500-acre (200ha) corn field. A heavy rain recently came through and he needs to find out if part of the field is swamped. The corn is 2m (6.5ft) tall and there is no way to access the middle of the field. Or, perhaps a marine biologist wants to determine the health of a whale in the wild. To do this, the biologist requires a sample of the spray from the whale as it surfaces. Not too many years ago, the mechanisms to make these determinations would be difficult, expensive and possibly dangerous – if they could be done at all.

The small drone market has quickly grown in size and capability. Aircraft that carry sophisticated electronics and data gathering equipment are becoming indispensable tools for many industries, such as film making, mining, agriculture, natural sciences, traffic control, and many more.

With this variety of applications, comes a widening variety of flying conditions. Manufacturers have responded with more robust vehicles that subsequently require testing in extreme environments.

"Free flight tests are needed to understand stability and controllability, especially in windy conditions"

TerraXcube is a test facility in northern Italy that studies the influence of extreme climates on human, ecological processes and technologies using a range of climatic chambers. One of its major projects is DronEx, led by senior researcher Andrea Vilardi.

DronEx was started to answer the growing need to provide harsh but controlled environments for drone testing. TerraXcube's facilities are being used to assess the performance of drones as design improvements are introduced and help devise new standards as the demand for increased capability continues.

"Thanks to connectivity and reliability improvements, soon drones will perform autonomous applications, even in bad weather conditions such as rain and snow storms," Vilardi says. "Aviation authorities will play a role in the definition of the regulatory framework for operating in these conditions."

Test engineers at TerraXcube estimate the expected operational environment for drones, and then determine if the design can operate reliably in harsh conditions. A drone can carry an impressive array of sensors and cameras, but if it fails in the field or proves to be unsafe or unflyable, it is all for naught.

CLIMATIC TESTING

The University of Ontario Institute of Technology (UOIT) in Oshawa, Canada, has a full battery of testing capabilities ranging from a wind tunnel that can simulate adverse weather conditions, to climate chambers and vibration tables. Don Toporowski is the general manager of the Automotive Centre of Excellence (ACE) at UOIT and also regularly tests drones for the aerospace industry. "Our work with drones is mostly with manufacturers who have voluntarily decided that they want to improve the reliability and performance of their drones," he says.

The amount of drone testing conducted at the center has doubled every year for the past few years, driven by applications in different industries. There is also growing awareness among manufacturers of the issues that drones will face as they share airspace more with other aircraft, believes Toporowski. "The public and manned aircraft operators will begin to feel their presence and worry more about safety," he says.

The NLR research agency's Netherlands Aerospace Centre in Marknesse, Holland, has a group dedicated to drone R&D, offering testing and consultancy. René Eveleens, department manager of flight test and certification, describes it as a growing business. He says, "NLR is doing a lot of inspections for smaller drones at the moment, and we are flight testing larger drones more. Up until recently, most people have followed the RPAS open regulations."

EASA's RPAS (Remotely Piloted Air Systems) regulations cover the assessment and operation of smaller drones that weigh up to 150kg (330 lb) (see sidebar, *Drone regulation basics*). Eveleens says there is still much to learn about assessing drones. "Especially in the larger category of between 25kg and 150kg, there are challenges in finding the balance between the risk assessment associated with the operation and the amount of qualification that is expected from the platform. Here the regulations for the specific RPAS category are followed."

FAA REGULATES SMALL DRONES

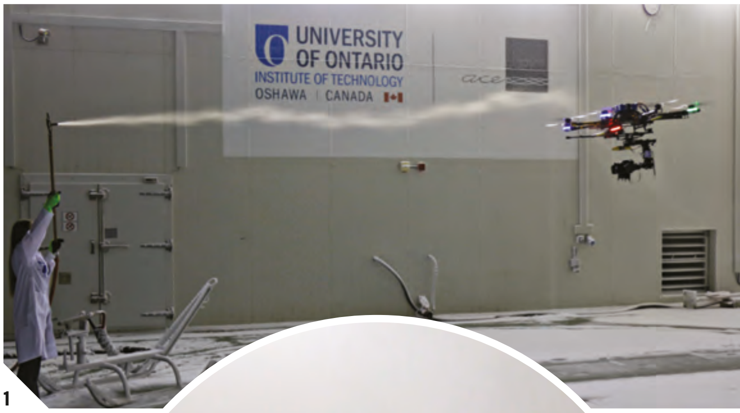
The FAA classifies a small drone as weighing under 25kg (55 lb). Within this category, the operator has to follow its Part 107 guidelines.

These stipulate that you learn the Part 107 rules, become FAA-certified by passing a Knowledge Test, and then register the drone with the FAA.

For a drone that weighs more than 55 lb, operators need to apply for an exemption under the Special Authority for Certain Unmanned Systems (49 USC §44807) with the FAA.

SIZE MATTERS

All aircraft, large or small, manned or unmanned, must fly in a controllable, predictable manner. Airworthiness, reliability, and thrust and rotor performance are always key factors in aircraft development and testing. Drones are no exception to this rule.



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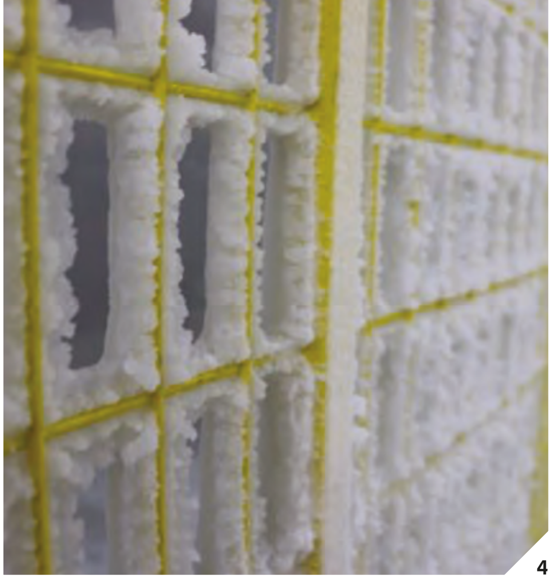
1 // The University of Ontario's climatic wind chamber is used primarily for automotive testing but is often adapted for testing drones

2 // A range of conditions can be recreated in the wind tunnel, including fog

3

3 // A small drone is closely monitored under test at the University of Ontario's climatic wind tunnel



"Some of our clients are doing voluntary testing to demonstrate that they meet regulatory requirements around airworthiness," Toporowski says. "But rather than aiming to meet specific regulations, they are trying to prove that they have done sufficient due diligence around reliability and airworthiness."

Facilities such as TerraXcube have been designed and built to provide a controlled and repeatable testing environment for drones. The testing of small drones has an advantage over testing the airworthiness of large manned aircraft, because the environment inside the test facility can be controlled relatively easily. "When the drone is ready, outdoor tests are made to check controllability, stability and performance. The problem is that these tests are affected by the environment – we aim to solve the non-reproducibility of the same climatic conditions with our facility," Toporowski says.

"Thanks to connectivity and reliability improvements, soon drones will perform autonomous applications in rain and snow storms"

TESTING CHALLENGES FOR DRONES

Caring for a human being while in flight is a huge challenge and design complication for aircraft. There are therefore significant differences between drone and manned aircraft environmental testing. There is more design work and verification involved with a manned aircraft compared with a drone. Vilardi says, "For manned aircraft, standards are defined in terms of temperature, humidity and pressure inside the aircraft cabin according to the vehicle altitude. Tests involve all of the aircraft's systems."

The onboard system complexity of drones is simpler than manned aircraft. However, sound design practices still have to be followed to produce a reliable product. Vilardi believes that the best approach for test procedures for drone avionics is to follow existing standards for manned aircraft testing, such as DO-160.

MULTIROTOR AND FIXED-WING TESTING

According to Toporowski, there are only minor differences between testing multirotor and fixed-wing drones. "Most multirotors will fly free or tethered in the tunnel. While the fixed-wing aircraft do that as well,

DRONE REGULATION BASICS

The European Aviation Safety Agency (EASA) has developed an EU-wide regulatory framework for the assessment and operation of smaller drones up to 150kg (330 lb). The so-called Basic Regulation for EASA came into force in September 2018.

The new regulations differentiate between Open category drones, which are considered sufficiently low risk to not require authorization to operate; and Specific drones, which require authorization for operation by a competent authority before they are used.

4 // Icing can be repeatedly reproduced by the university's wind tunnel

5 // The tunnel has room for quadcopters as well as fixed-wing drones

“The most common mode of failure has been mechanical failures of the onboard electronics”

6

7

6 // Experiments for industry in the wind tunnel have included how icing affects drone performance for OEMs

7 // Aerodynamic testing of fixed-wing drones also involves free flight in the wind tunnel

they also spend some time fixed on a force balance to work on aerodynamics,” he says.

Vilardi says, “Thrust, motor speed and power consumption are the main parameters investigated when considering the propulsion system. Effort has to be taken to avoid ground effect, which influences measurements. But, testing just the propulsion system is not enough to characterize drone performance entirely. Complete tests are mandatory. For the overall drone tests, the multirotor thrust is affected by rotor relative position and rotor arm shapes.

“For fixed-wing drones, the lift generated by the wing will be influenced by the airframe body, tail, primary and secondary flight control surfaces. In both cases, free-flight tests are needed to understand stability and controllability, especially in windy conditions.”

Drone size makes a difference in how to approach a test program. According to Eveleens from NLR, if a drone is smaller, advantages and disadvantages exist when testing. It makes handling and moving the aircraft easier, but limits the number of onboard sensors that can be used during testing. In addition, since these are unmanned aircraft, all the monitoring has to be done on the ground.

COMMON TEST ORDERS

Facilities such as TerraXcube and UOIT will conduct a variety of tests on a drone following a controlled and repeatable test regimen. The test order often follows the same path, regardless of the project. “When clients come in, they tend to divide their project into thirds,” Toporowski from UOIT says. “One-third aerodynamics work in wind only; one-third climatic testing in rain, snow and ice clouds; and one-third on reliability on the shaker table.”

150KG
Weight up to which unmanned aircraft are covered by EASA’s Basic Regulation (330 lb)

25KG
Weight up to which a drone can be flown under FAA Part 107 rules (55 lb)

Engineers at UOIT streamline vibration testing by removing all of the flight time that does not impact on equipment life. The data is crunched down into a condensed acceleration profile and fed into the shaker table. This enables the shaker table to produce the forces that the aircraft encounters over a full year of missions in just a few hours.

“What has surprised us is that the mode of the failure of almost all of the aircraft so far has not been structural. They are typically quite robust,” says Toporowski. “The most common mode of failure has been mechanical failures of the onboard electronics. Joints, soldering and connections often cannot survive the repeated stresses and vibrations encountered during flights and landings. This is an area of reliability that the data suggests should be an area of focus for engineers working to improve drones.”

Choosing the right test setup for a drone is critical. When conducting electromagnetic compatibility (EMC) testing in an anechoic chamber, choosing and installing transponders has to done so as to not interfere with the normal operation of the drone and its datalink. Eveleens says, “We have experience at finding the right sensor for the right phenomena required for the flight test. We also have the experience with scaled flight testing.”

Vilardi describes TerraXcube’s test setup as being defined by the user. “Tests are performed inside a dedicated climate-controlled facility in which environmental quantities are set by the user. Temperature, pressure and humidity are the key parameters that are considered. Rain, snow and wind can also be investigated. We put an accelerometer on the drone to measure the forces and accelerations it faces in take-off, flight and landing.”

MARKET DRIVERS

The testing of unmanned systems is also a rapidly growing activity for terrestrial vehicles as well as aircraft. Toporowski believes that the market for autonomous cars is driving research in the technology quickly ahead.

“The aim of producing autonomous cars that can operate in inclement weather is really driving research,” Toporowski says. “Terrestrial vehicles face the same issues as drones, but it’s a much bigger and better-financed market. The work we do to allow autonomous terrestrial vehicles to operate more reliably is certain to transfer into better testing capabilities and science for the smaller drone market.” \\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Team wo

The testing of interoperability between drones and manned aircraft poses a number of challenges for engineers

The debut of manned-unmanned teaming (MUM-T) occurred in World War II when, in 1944, a US Air Force B-17 Flying Fortress took off from RAF Fersfield, UK, headed to a fortified German submarine bunker. Three chase aircraft followed the bomber.

The B-17, designated a BQ-8 robot airplane, was a flying bomb with 9,000kg (20,000 lb) of Torpex on board, twice its normal bomb payload and designed to be remotely piloted to the target. The BQ-8 concept was to launch like a normal aircraft with two pilots, reach a cruise altitude of 2,000ft, arm the explosives, and then have the crew parachute into the English Channel safely. The rest of the mission would be flown using remote control operated by a pilot on one of the chase aircraft.

Although the mission failed when the airplane spun out of control, the concept and benefits of MUM-T, along with the technology to execute these types of missions, continued

rking

1 // The S-100 unmanned air system was operated by a pilot sitting in the rear of the H-145M

2 // Textron conducted two demonstration flights to prove the integration of the software and hardware. The key accomplishment was it demonstrated that the flight test aircrew could use the MUM-T capability within an operational environment

"Intelligence can be relayed directly back to a manned aircraft"

to mature within defense applications. But only now is it becoming an operational reality once again.

AIRBORNE CONTROL

Developments taking place will soon remove the ground operator from the unmanned aerial vehicle (UAV) chain and replace them with an airborne controller, who will fly alongside the drone, or drones, in a formation. The controller will be able to instruct the UAV as singles or pairs for specific missions, freeing up manned assets to focus on more challenging missions. MUM-T programs under development now are not focusing on the most dynamic or kinetic scenarios. As technology advances, MUM-T will evolve to include more complex missions.

The Defense Advanced Research Projects Agency (DARPA) and the Air Force Research Laboratory (AFRL) aim to develop an operational environment where manned and unmanned air vehicles fly in collaboration. Their initial role predictions for MUM-T are Intelligence, Surveillance and Reconnaissance (ISR), air defense and air-to-ground strike missions using information supplied along a kill chain, and stand-off air-to-air engagements.

All these scenarios will require significant quantities of information to be developed in terms of autonomous algorithms. For an ISR mission, autonomous US Air Force platforms will have access to large amounts of topographic information from the US National Geospatial-Intelligence Agency and target data from military sources. Intelligence can be relayed directly back to a manned aircraft, where the operator can instantly adjust the mission profile. The ultimate goal is the teaming of a mixed manned-unmanned formation in the air-to-air role.

3 // Textron has not yet determined how many drones can be controlled using the Synturian system. Future trials may include an unmanned surface vessel with an airborne drone operating with it

Such teaming will put far more sensors into the air, giving pilots increased situational awareness. The exchange of information between the platforms enables the aircrew not only to receive a considerably greater package of information, but the pilot will also tell the unmanned platform when best to engage the enemy and how. These potential capabilities will likely see future unmanned platforms leading a mixed strike package with manned aircraft at the rear.

The benefit of having an aircrew at the rear is that they can effectively direct the fight taking place within hostile airspace while they remain in orbit in a safer more permissive airborne environment. Unlike ground controlling platforms, the MUM-T allows the aircrew capability to enter hostile airspace, once the threat has been removed or significantly degraded.

TACTICS ON THE FLY

The MUM-T possibilities provide the capability to completely revise the tactics being employed – instantly, if the situation dictates it. One aircraft has the potential strike, ISR or combat air patrol capability of a fleet, while the risk of losing a pilot in hostile territory is drastically reduced. It's a force-multiplier capability that comes without risking the lives of aircrews. Costs in developing this technology can be reduced by installing the


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necessary autonomous mission control hardware and software in surplus legacy aircraft. Such an idea is already in development with the Lockheed Martin Skunk Works and the US AFRL, as part of the Have Raider II demonstration in 2017. It involved an autonomous F-16 conducting simulated strike missions at Edwards Air Force Base in California, before rejoining on the wing of a manned F-16.

Shawn Whitcomb, Lockheed Martin Skunk Works Loyal Wingman program manager, says: "The demonstration was a critical step in future Loyal Wingman technology development and operations."

But throughout these trials, the F-16 was controlled from a static ground station. Lockheed Martin is currently seeking to develop this baseline technology to allow MUM-T using F-16s.

SEARCH AND RESCUE

While much MUM-T development focuses on military applications, there are some projects exploring the commercial benefits of the technology. Airbus Helicopters and Schiebel, an Austrian drone manufacturer, became the first European aviation companies to demonstrate MUM-T at its highest level of interoperability last year. LOI 5 is where the manned aircraft exercises full control of the unmanned, including its take-off and landing. The series of test flights where LOI 5 was achieved was sponsored by the Austrian Armaments and Defense Technology Agency and involved a manned H-145M and an unmanned S-100 Camcopter. The aircraft flew together in different scenarios, which included the detection of objects hidden in spaces not accessible by manned helicopters. The Camcopter S-100 was controlled and piloted by an operator sitting in the H-145M.

Throughout the test phase, the challenges of data transfer interference, electromagnetic compatibility of the drone with the helicopter, and the integration of a complete drone mission planning and control system into the H-145M's architecture were successfully tested. Airbus is now looking at optimizing the human-machine interface, based on the conclusions of the crew workload using these results. Mark Henning, program manager at Airbus Helicopters, says, "Smaller drones with vertical

5 // Synturian operates with one field-of-view, a military map-centric configuration, and uses halo icons to illustrate each UAV under its control

5

INTEROPERABILITY: LEVEL BY LEVEL

Interoperability is the capability of different networks or systems to communicate, exchange data, and use the information that is exchanged. Interoperability in MUM-T consists of five Levels of Interoperability (LOI):

LOI 1: The pilot receives the data from the UAV's payload indirectly via a third party, which is either a ground station or ship.

LOI 2: The pilot is in direct communication with the UAV and is able to receive data from its payload in flight.

LOI 3: The pilot has control over the payload on the UAV, but not over its flight.

LOI 4: The pilot has control of the UAV's flight, but the landing and take-off aspects are still handled by a third party.

LOI 5: The pilot is able to control all aspects of the UAV's flight and payload, including the take-off and landing.

In the future, LOIs may be added to show a greater reliance on automation of the intelligence acquisition process by the UAV itself.

4

4 // The Synturian system as used on the demonstration flight on May 4, 2018. From this work station, the Scorpion aircraft behind served as a surrogate UAV

6 // The demonstration using the R-350 UMAT proved the benefits of UAV deployment in operations, by increasing the reach and forward reconnaissance of manned platforms and reducing the risks to the helicopter within the battlespace

GERMAN ARMY TESTS TEAMING

German-based drone maker UMS Skeldar is a leading player in the development of MUM-T in Europe and the associated avionics and software. In November 2018, the company partnered with the company Elektroniksystem und Logistik (ESG) Defence and Public Security in a number of test exercises with the Bundeswehr (German Army) using a Skeldar R-350, an Unmanned Mission Avionics Test Helicopter (UMAT), and a Bell UH-1D manned helicopter.

The tests, which were conducted at Manching Airfield near Munich, demonstrated the capability to integrate the mission systems of the manned and unmanned aerial platforms. A Bundeswehr pilot acted as the mission commander using live data and video stream from the unmanned R-350 and conducted a simulated reconnaissance while avoiding high-threat areas.

Axel Cavalli-Bjorkman, CEO of UMS Skeldar, says, "This demonstration is a significant development in delivering flexible mission-proven UAV assets to the German armed forces.

"Development of the appropriate technologies and procedures will allow a wide range of deployment scenarios of joint manned-unmanned teams for the Germany's armed forces."

Both companies are developing the technology following the test flights as part of Project MiDEA (mission monitoring by drones for reconnaissance).

take-off and landing capabilities can, for example, fly around obstacles such as trees or buildings, closer than a helicopter could. They are able to explore unknown territory and deliver information to the helicopter crew that's operating from a safe position. They can then step in with that helicopter's superior effects, having received a clear picture from the drone."

Chris Day, Schiebel's chief technical officer, believes that the MUM-T partnership provides "mission enhancing" advantages for army aviation. "The datalink between the manned and unmanned platform can be moved from a static to a dynamic environment, away from the ground, making it more robust and much harder to detect."

Airbus Helicopters' MUM-T technology can be applied to its entire product range, from the NH90 to the Tiger. The company is already developing its own rotary-wing drone for surveillance, designated VSR700, based on the manned civil Cabri G2 light helicopter.

The commercial applications are potentially significant. According to Mark Henning, a possible application is search and rescue (SAR). Accompanying an SAR helicopter could be a fleet of five drones, controlled from within the helicopter. As the rescuers observe the water below, they can enlarge the search area considerably by using the drones as extra eyes to locate a survivor. Once they're spotted, the helicopter will know immediately where to be.

"It multiplies the capabilities of both systems," says Henning.

7 // Airbus testing and certification of MUM-T is currently focused on the needs for the military, but there is potential for civilian applications in the future

"Airbus Helicopters' MUM-T technology can be applied to its entire product range"

A CRITICAL CAPABILITY

In the USA, much like when it pioneered MUM-T development 75 years earlier, the army views the capability as critical to future warfighting. Two systems have been tested: a Boeing AH-64D, and E variant helicopters operating with a MQ-1C Gray Eagle drone. The former allows only LOI 2, while the AH-64E allows LOI 3 and 4 beyond 100km (62 miles).

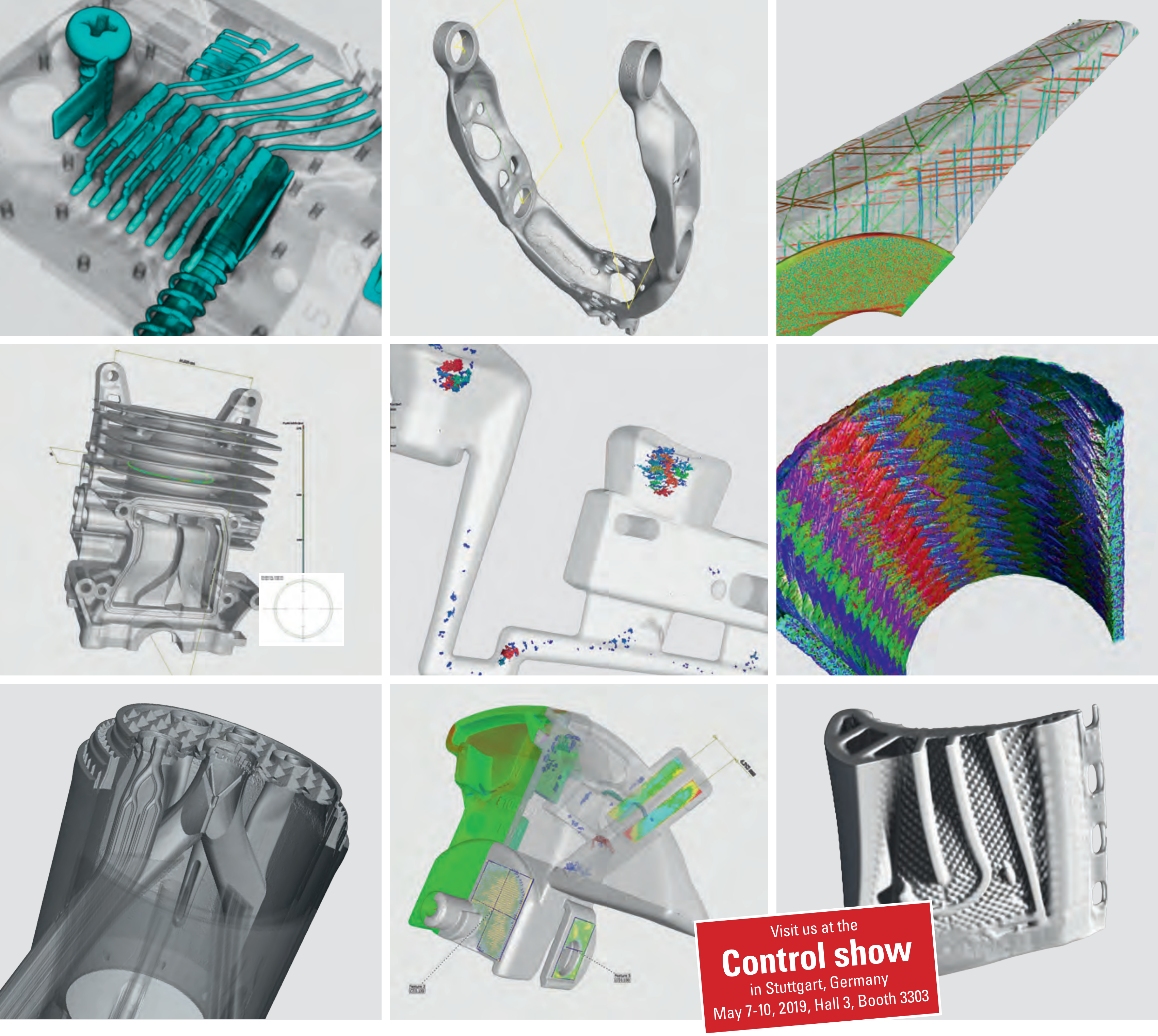
Presently, the AH-64E is the only military helicopter with fully integrated MUM-T capability. Army aviation units are continuing to develop the technology, which is providing unit commanders with the ability to use their ground forces economically, while expanding their battlefield situational awareness.

Another USA-based company leading MUM-T development is Textron, which has developed the Synturian system, a tablet device that can control multiple unmanned systems. Based on a military map-centric configuration with a modulated open architecture system, it can use different operating systems, including Windows. Synturian has already been flight tested on Textron's Scorpion jet.

Dan Hinson, chief pilot with Textron Aircraft, describes the two test flights: "The pilots had everything they needed to operate a UAV on a laptop computer loaded with the control software. The scenario involved one jet flying as the control node, with the second Scorpion on the ground simulating the UAV, and a ground control station that simulated other UAVs."

Airspace limitations prevented the use of a live UAV during the tests, so the Scorpion jet beamed down commands to a virtual UAV on the ground. The UAV's sensors were able to be slewed to specific points using pre-loaded maps via the operator in the rear of the airborne Scorpion. The whole process of directing the UAV was controlled with a few clicks of a mouse.

To date, Textron has not yet determined the number of drones that could be controlled using this system. But the long-term goal is to reduce the human footprint so one person can operate multiple UAVs from an airborne platform and remain out of reach of any threat. \\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// PAUL WILLIS

Sound barriers

A need to reduce aircraft noise is driving innovation in tests inside and outside the aircraft cabin

1 // The Centre for Air Travel Research in Ottawa, Canada, has a laboratory set up to recreate the vibrations passengers experience during flight

Aircraft noise is consistently one of the major issues in aviation. People who live close to airports are especially concerned about noise pollution on the ground. OEMs are seeking to reduce the amount of noise and vibration inside aircraft during flight, to improve passenger comfort.

Despite efforts over the years to mitigate the effect of noise and vibration from the airframe, recent trends in the industry are exacerbating the problem, according to Rick Klop, engineering manager of research and development at supplier Parker Aerospace.

"To begin with, more electrical power is being moved into the fuselage," he says. "Also, some of the hydraulic systems today are higher pressure. Both of these things have the potential to generate more noise and vibration."

NOISE-REDUCTION TESTING

At the Centre for Air Travel Research in Ottawa, Canada, the testing of noise-reduction technologies began not long after the center opened in November 2018. Anant Grewal, principal research officer at the National

2

2 // Vibration testing at the Centre for Air Travel Research is used to study the effect of vibration on the performance and health of helicopter pilots

"The measuring systems include electromyography sensors to measure muscle response"

Research Council Canada and manager of the Ottawa center says, "We helped an OEM evaluate a third-party active noise control system. We looked at the peak noise reduction achievable, as well as the regional extent of that reduction – in other words, the spread of its effect throughout the cabin."

The Centre for Air Travel Research has two testing laboratories for noise and vibration. The first, known as the human vibration lab, has a platform that recreates the vibratory environment of an aircraft using remotely controlled shakers.

Focused primarily on helicopter pilots, the laboratories main function is to study "the effects of vibration on human performance and even some longer-term health issues", says Grewal.

The second, the flexible cabin laboratory, is a test space that can recreate the cabin environment for a range of aircraft including business jets, regional aircraft and twin-aisled long-haul carriers. The laboratory can replicate in detail the physical environment of the cabin, the ventilation, the thermal conditions and the lighting. It even has functional call buttons on the seats.

PHYSIOLOGICAL AND SUBJECTIVE METRICS

Testing the effectiveness of noise-reduction technologies requires recreating the noise and vibratory environment of the aircraft. To do this engineers first measure the noise levels in the prototype aircraft containing the noise reduction technology, using an array of microphones. "Then we can recreate the same microphone array in our lab and use actuators to mimic the same sound levels," says Grewal.

The actuators are around 2in (5cm) in diameter and can be attached to the trim panels to recreate the noise environment. "They turn whatever they are bonded to into what are essentially speakers. Because of the number of actuators we are using you can achieve an environment that is very realistic."

The next step is to test the effect the cabin environment has on human subjects. This can be done both subjectively and physiologically. Subjective testing often means asking participants to fill out surveys of their experience. Testing the physiological effects is more detailed. "In the flexible cabin lab we have about eight integrated physiological measuring systems that measure various parameters," says Grewal.

The measuring systems used in the lab include electromyography (EMG) sensors to measure muscle response, heart rate monitors, even blood tests to measure stress hormone levels in the blood.

"Right now many of these sensors are fairly uncomfortable and need to be attached to the skin. But the sensors are becoming more advanced.

"There are EMG sensors available now that can be worn as headbands and others that can be embedded in seats. As these sensors become easier to use I think you will see more interest in using them."

250FT
Diameter of the microphone array used in tests for NASA's noise reduction research

30%
Perceived noise reduction at take-off using the Active Compliant Trailing Edge flaps

2IN
Diameter of actuators used in cabin tests

ACTIVE AND PASSIVE REDUCTION

According to Grewal, the noise reduction technologies his center is likely to be testing are of two types: active or passive. Passive technologies try to reduce the noise at source. One interesting development in this regard is the possibility of making aircraft components out of acoustic metamaterials, engineered with lattice structures that cut noise. Active noise reduction technologies include active noise control systems like the one developed for the Bombardier Dash 8 regional turboprop aircraft.


Photo credit: NASA
Team
Data Physics
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Grewal says, "Most successful active noise control systems have relied on reducing vibration at the interface by having actuators fitted to the fuselage. They introduce vibration sources that cancel out the source vibration."

A major source of noise and vibration in flight is the aircraft's hydraulic system, according to Klop from Parker Aerospace, whose company produces aircraft hydraulic systems and flight controls.

"It's quite a high-pitched noise," says Klop. "You have probably heard it every time you fly. It's a high-pitched kind of whining."

Klop and his team are constantly testing noise abatement methodologies for hydraulic systems. One approach they take is to reduce the forces generated by the hydraulic equipment at source.

"For a hydraulic pump we use a damping device to reduce the source vibration energy even prior to the pump being mounted in place."

Another approach creates devices that reduce fluid-borne noise. "Oscillating pressure in a hydraulic system causes vibration," Klop says. "You can reduce it by using actuators to act as mufflers. But we're focusing on reducing the vibration at source – designing the hardware so that it vibrates less."

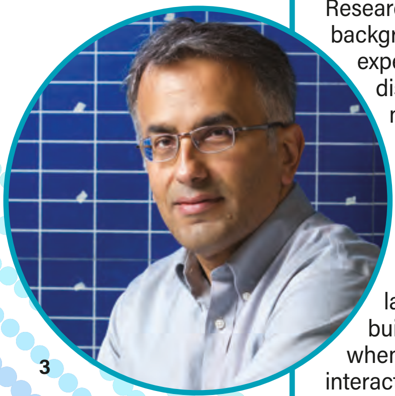
Cutting airframe noise is not only about benefiting passengers. It is also about cutting noise levels for people on the ground. NASA's Aeronautics Research Mission Directorate (ARMD) has been involved in a sustained effort to reduce the impact of civil aviation operations on community noise. The ARMD has been developing technologies for the exterior of airframes, designed to reduce the noise they generate.

FLIGHT TESTING NOISE REDUCTION MEASURES

Between August 2016 and May 2018 the ARMD carried out a three tests at NASA's Armstrong Flight Research Center in Langley, California, for two key noise reduction technologies. The first was a replacement wing-flap technology known as Active Compliant Trailing Edge (ACTE). The second was a modification to the landing gear.

"During take-off and landing, the two main sources of airframe noise are the flaps and the landing gear," says Sridhar Kota, the founder of FlexSys, the company that developed the ACTE technology. "In the gaps between the leading edge of the flap and the fixed section of the wing you

"Oscillating pressure in a hydraulic system causes vibration"



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3 // Anant Grewal, principal research officer at the National Research Council Canada

4 // The Centre for Air Travel Research's cabin laboratory is used to study passenger's perceptions of vibration levels

THE NOISE PERCEPTION GAME

There has been a concerted push in aviation to cut aircraft noise. However, reducing the noise sources on aircraft can actually result in an increase in passenger disturbance from noise.

"If you have tonal noise and a random background noise, the background noise can mask the tonal noise," says Anant Grewal, manager of the Centre for Air Travel Research in Canada. "If you take away the background noise the passenger might experience the tonal noise as more disturbing, even though the overall noise level has dropped."

Because of this phenomenon, noise sources that previously weren't a concern are now being reported as an issue.

Grewal gives the example of noise from the turbulence boundary layer. "This is random noise that builds toward the rear of jet aircraft when the turbulence boundary layer interacts with the fuselage. Then there's the various components you find in an aircraft system – the pumps, the fans, the environmental control system and ventilation. These may become more noticeable to passengers."

Another interesting phenomenon of sound is the disparity between overall volume and how it is actually experienced.

"Suppliers often have guarantees that their components and systems will stay within certain sound/pressure thresholds," says Rick Klop of Parker Aerospace. "But the sound/pressure level as perceived is affected by the environment – it might not have anything to do with the absolute value of sound power."

In other words, a person might perceive noise quite differently from how loud it actually is.

5// The Gulfstream G-3 used to test the Active Compliant Trailing Edge (ACTE) technology by NASA

6 // Sridhar Kota, founder of FlexSys, the company behind the ACTE

6

5

> **“NASA was able to boast a reduction in flap noise of 10dB with the ACTE flaps”**

get airflow and therefore vibration. It generates a lot of noise. You also get noise from the flap bracket assemblies – the parts that stick out of the wing to deploy the flaps.”

The ACTE shape-changing flaps form a continuous bendable surface. FlexSys initially developed the flaps in collaboration with the US Air Force, which was more interested in the technology’s potential to save fuel.

“For us noise reduction wasn’t our focus and in the first iteration of the technology there was a gap between the fixed section of the wing and the section that had our morphing technology in it,” Kota says. “NASA asked us if we could close that gap because it saw that it would help reduce noise, and it ended up working beautifully.”

So beautifully, in fact, that in its published results NASA was able to boast of a reduction in flap noise of 10dB with the use of the ACTE flaps. That translates to a 30% drop in perceived noise when the plane is taking off and landing.

The landing gear technologies tested were more numerous, but less effective overall. They included fitting sound-absorbing foam and metal chevrons along the edge of the landing gear cavity, as well as fitting a stretchable mesh over the top of it. According to NASA these procedures reduced low-frequency noise by 4-5dB and high-frequency noise by 2-3dB overall.

The acoustic tests were carried out using two identical Gulfstream G-3 aircraft, with one acting as a control and the other fitted with the noise reduction technologies. The test aircraft were equipped on board with a heavily instrumented testbed capable of measuring aircraft parameters such as its position, angle of attack and true airspeed.

During the three test campaigns, the two aircraft clocked up a total of 47 flights, encompassing nearly 1,100 passes over a microphone array on the ground at the end of the runway. The 250ft (75m) diameter array was composed of a spiral formation of 185 microphones.

“To get consistent results every time, the aircraft needed to be at the same speed and height, and on the same flight path,” says Kota, “so they had to use very experienced pilots.” \\

WAYS TO TRACE FUSELAGE NOISE

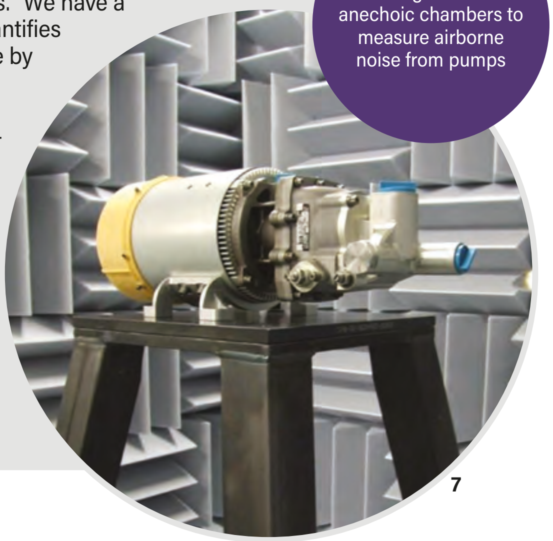
Most noise experienced in flight has entered the aircraft via one of two pathways – through the air or through the airframe structure. Most engine noise enters through the structure-borne pathway. Anant Grewal, manager of the Centre for Air Travel Research in Canada says, “It vibrates along the structure of the wing and from there along the structure of the fuselage and subsequently into the trim panels.”

Some engine noise will also enter the fuselage via an airborne pathway. “Sound waves from the engine get transmitted through the air, impacting the fuselage and causing it to vibrate,” Grewal says.

The aircraft hydraulics system creates a third pathway – fluid-borne noise. Identifying exactly how and where these three noise sources enter the plane’s interior is essential to understanding the impact of noise in flight.

At Parker Aerospace’s test facility, engineering manager of research and development Rick Klop and his team have rigs that tackle all three noise sources. “We have a semi-anechoic chamber that quantifies sound power from airborne noise by measuring the radiation energy,” he says. “Another rig allows us to characterize a pump from a fluid-borne noise perspective.

“It’s very complicated to simulate the pressure oscillations in the system. There are lots of effects that depend on the structure, the temperature and the material of the hose. With the source rig we can map out the pump’s fluid-borne noise characteristics with hoses and tubes.”



7 // Engineers use anechoic chambers to measure airborne noise from pumps

7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// IAN GOOLD

Aeropace

After a pause in the flight test program, A330-800 flying has resumed apace, building on the success of the larger -900 variant

In early January, Brussels Airways Airbus A330-303 OO-SFM (manufacturer's serial number 030) landed at Bob Sikes Airport in Crestview, Florida, for dismantling. To casual observers the arrival of the longest-serving active A330 might have suggested the hangar doors were about to close on the very successful European design after delivery of more than 1,400 machines.

But MSN 030's retirement does not signal even the beginning of the A330's end – the marque is alive and well. Indeed, A330-800 F-WTTO (MSN 1888), the latest development of the twin-aisle twinjet, is currently undergoing trials at Airbus's Flight Test and Integration Centre at Toulouse-Blagnac airport in southwest France.

ESTABLISHING THE PERFORMANCE ENVELOPE

The Airbus A330 family's latest two members, the A330-800 and the A330-900, have been re-engined under the A330neo (new engine option) moniker. The former has a range of 8,150 nautical miles (15,090km) with a capacity of up to 257 passengers, while the latter can cover 7,200 nautical miles (13,330km) and has a capacity of up to 287 passengers.

Both aircraft use Rolls-Royce's Trent 7000 engine, which has been developed exclusively for the new aircraft. The Trent 7000 has a 112in (2.8m) diameter fan This doubles the bypass ratio from five to 10.

"It flies just like an A330, only better"

1 // The A330-800 shares the same type rating with the other members of the Airbus A330 family *(All photos: Airbus)*


AIRBUS
neo

“Airbus cites 99% commonality between the A330-800 and -900”

2

3

4

2 // The A330-800 has a slightly shorter fuselage than the -900 variant

3 // The A330-800 has a wingspan of 64m (210ft), the same as the -900

4 // Airbus experimental test pilots François Barre (captain of the flight) and Malcolm Ridley (copilot), as well as test flight engineer Ludovic Girard before the A330-800’s maiden flight

With the A330-900 having received European Aviation Safety Agency (EASA) type certification on September 26, 2018 and the first customer deliveries of the aircraft underway, the focus of testing engineers has been transferred to the other variant, the -800.

By mid-February 2019, the -800 variant had logged 70.5 flight-hours – equivalent to around 20% of its predicted test requirements – during 22 flights since its first on November 6, 2018. Airbus hopes to receive formal European airworthiness approval before October 2019, ahead of first delivery and entry into service next year.

After a pause following the initial flights, testing has “resumed apace”, according to Airbus. Early test flights enabled the manufacturer to establish the A330-800’s full performance envelope, with high-speed flight “in normal law and direct law, including low speed, and high-speed maximum operating limit Mach number (M_{MO}) and velocity (V_{MO}) and maximum allowable speed (V_{max}) and Mach number (M_{max})”.

MSN 1888 is the fourth A330neo and the first -800 to be dedicated to certification. Previously, three larger A330-900s (MSNs 1795, 1813 and 1819) had flown, including the first production aircraft on which Airbus conducted passenger-cabin function and reliability, route-proving trials.

While not all-new designs, the A330-800 and -900 models feature novel sharklet wingtips and are powered by new 68,000-72,000 lb-thrust Rolls-Royce Trent 7000 engines. Airbus cites 99% commonality between the two variants.

The -800 and -900 are based on the earlier A330-200 and -300. However, the -800 variant is 5m (16ft) shorter than the -900, and hence a taller tailfin is required to provide longitudinal stability compensation. “The shorter fuselage means that the engines are closer to both the front and the back of the aircraft,” points out Jean-Philippe Cottet, the Airbus head of development flight test.

15,090KM
A330-800 range (8,150 nautical miles)

94,000
Parameters on flight test installation database

He says that from the front this makes a difference on the air-pressure monitoring anemometry equipment. And from the back it will have an effect on the aircraft’s behavior. Airbus will also have to check the difference in the structural response of the shorter aircraft during flutter testing.

Airbus has optimized the A330neo wing to deliver 4% lower fuel burn compared to the current A330, according to head of A330 marketing Crawford Hamilton. The increased performance is attributed to a 4m (13ft) wingspan increase to 64m (210ft), along with a consequent increase in aspect ratio.

“Span-wise lift distribution is closer to the aerodynamically optimum elliptical distribution – a combination that delivers a more efficient wing,” says Hamilton. “It also has a three-dimensionally optimized twist.”

The A330neo wing introduces reshaped slats on the wing inboard leading edge and modified trailing-edge flap-track fairings. Airbus has fitted a new upper-belly fairing made of composites.

The company claims to have achieved lower operating cost for the A330neo by leveraging the A350’s new-generation technology and the current A330’s exceptional 99.5% dispatch reliability. As well as longer wings and new engines, pylons and nacelles, the A330neo

"All weight from reinforcements will be fully compensated for by weight savings made elsewhere"

5 // The five members of the flight test team leave the aircraft after the A330-800's maiden flight

6 // The A330-800 is powered by the Rolls-Royce Trent 7000

offers new cockpit systems and cabin interiors, providing an extra 10 seats.

TIME IN THE SKY

For MSN 1888's initial four-hour flight on November 6, take-off and landing were performed with the A330-800's digital flight controls in direct law. During the flight, which went up to 30,000ft, aircraft general handling was explored in all three axes, with other tests covering cabin pressurization.

The opening test sequence of between five and 10 validation flights led what Airbus terms the initial flight test development phase. This was aimed at exploring the flight envelope, including performance flights that involved stalls and flutter tests.

Flight testing of the A330-800 in December 2018 and January 2019 included aerodynamic identification for development simulator modeling, additional flutter tests, and unspecified uncategorized effects – the latter including Mach, landing gear and center of gravity effects.

At the beginning of February, Airbus was preparing for the next phase of the campaign for characterization tests, including lateral and longitudinal identification; handling qualities testing for flight-control laws tuning; and more detailed handling quality checks. Certification tests, including autopilot trials, crosswind and minimum-speed checks, and systems tests are still to be conducted.

In addition to the high-speed flights to confirm M_{MO}, V_{MO}, V_{max} and M_{max} values, and the low-speed regime, initial test operations covered first-flight flutter, aerodynamic modeling identification flights, and airspeed calibration flights.

The passenger cabin of MSN 1888 has been fitted with instrumentation and a single station for the two flight test engineers. Cottet says, "Testing of the prototype is mainly dedicated to flight physics, handling qualities and performance."

A 9 metric ton weight increase to provide a 251 metric ton maximum take-off weight for both A330neo

FTI FOR PURPOSE

The A330-800 test aircraft's core onboard flight test installation (FTI) station is a modular system incorporating remote acquisition units and a power system. It gathers 418 onboard measurements, against 1,375 on the earlier A330-900, across more than 94,000 parameters on the FTI database, said Airbus's head of development flight test, Jean-Philippe Cottet.

Some 35GB of data are recorded during each flight-hour, compared with 60GB on the larger aircraft. For instrument calibration, the aircraft is fitted with two anemometric trailing cones, controlled from the FTI station and attached to the tailfin, flying in undisturbed air to provide accurate high- and low-speed and altitude readings.

During flight test, the aircraft is operated from the flight deck by two experimental test pilots and a test flight engineer (TFE). Cottet points out that the TFE will have followed the installation of all the aircraft systems "and knows perfectly how the aircraft should behave".

The FTI is overseen by two flight test engineers (FTEs), who direct each test flight from a single console in the cabin. Since much of the information gained from the A330-800 reads across from the previous A330-900 flight test campaign, the onboard test instrumentation needs only about half of the latter's capacity. The FTEs are able to modify the software of any onboard computer to adjust flight settings, according to Cottet.

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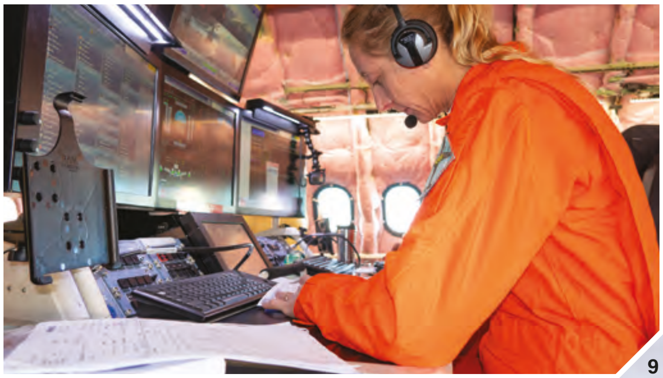

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7 // The A330-800's development program will include some 300 flight test hours

8 // The A330-800, MSN 1888, takes off from France's Toulouse-Blagnac Airport on its maiden flight, November 6, 2018

9 // Catherine Schneider was the Airbus flight test engineer for the A330-800's first flight

variants – announced in 2017 and available from mid-2020 – is to be obtained through a stronger (but not heavier) structure, supported by an upgraded, more robust landing gear, according to A330neo chief engineer Francois Kubica.

The manufacturer is also planning to enhance the A330neo's structure through local minor reinforcements to the wing and fuselage, but without increasing aircraft empty weight. "All weight from reinforcements will be fully compensated for by weight savings made elsewhere in the aircraft," says Kubica.

Local reinforcement is required for both main and nose undercarriage units and is complemented by new brakes and tires on the adapted wheels. Improved corrosion- and fatigue-resistance have been planned for the heavier aircraft.

35GB
Data recorded per flight-hour

418
Measurement points on board

"Flight test engineers are able to modify the software of any onboard computer to adjust flight settings"

A330-800 FOLLOWS -900

As A330-800 flight testing began, airframe and engine manufacturers were completing formal airworthiness approval of the A330-900 and both variants' new Trent 7000 high-bypass turbofan engines. The A330-900 accumulated 1,500 flight test hours during 450 flight tests in just 53 weeks with the three A330-900 test aircraft. This work validated the re-engined A330neo family's common cabin, flight and ground operations, powerplants and systems.

At the end of January 2019 Airbus also received its extended-range, twin-engine operational performance standards (ETOPS) clearance for the A330-900, which is awarded in two stages.

The initial EASA approval – for flight up to a maximum diversion time of 180 minutes from a suitable landing ground at single-engine cruise speed – was released in mid-November, subject to a restriction. Approval was restricted to engines incorporating work outlined in specific service bulletins. Unrestricted approval, which permitted a 330-minute diversion, followed six weeks later.

Airbus delivered its first A330-900 to TAP Portugal in late November 2018. The European carrier received two more in January and expects to receive 17 more before next year. During 2019 Airbus expects to increase A330neo manufacture. Meanwhile, Rolls-Royce has been accelerating Trent 7000 production.

The next three aircraft to be produced are earmarked for Icelandic low-cost, long-haul operator Wow Air, São Paulo-based Azul Linhas Aéreas Brasileirasa, and Air Mauritius.

For their inaugural A330-900s, each of these operators has adopted the Airspace-by-Airbus furnishings that the airframe manufacturer says provides "more personal space, larger overhead storage bins, advanced lighting, and the latest generation of in-flight entertainment and connectivity".

According to Airbus, the first examples of cabin layouts for the four customers have successfully undergone final cabin inspections, meaning that the customers are happy with the standard of passenger accommodation.

And as for how the A330neos fly, Airbus no doubt hopes each customer will echo the words of experimental test pilot Malcolm Ridley on landing the A330-800 after its first flight: "It flies just like an A330, only better." \\


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Drone detec

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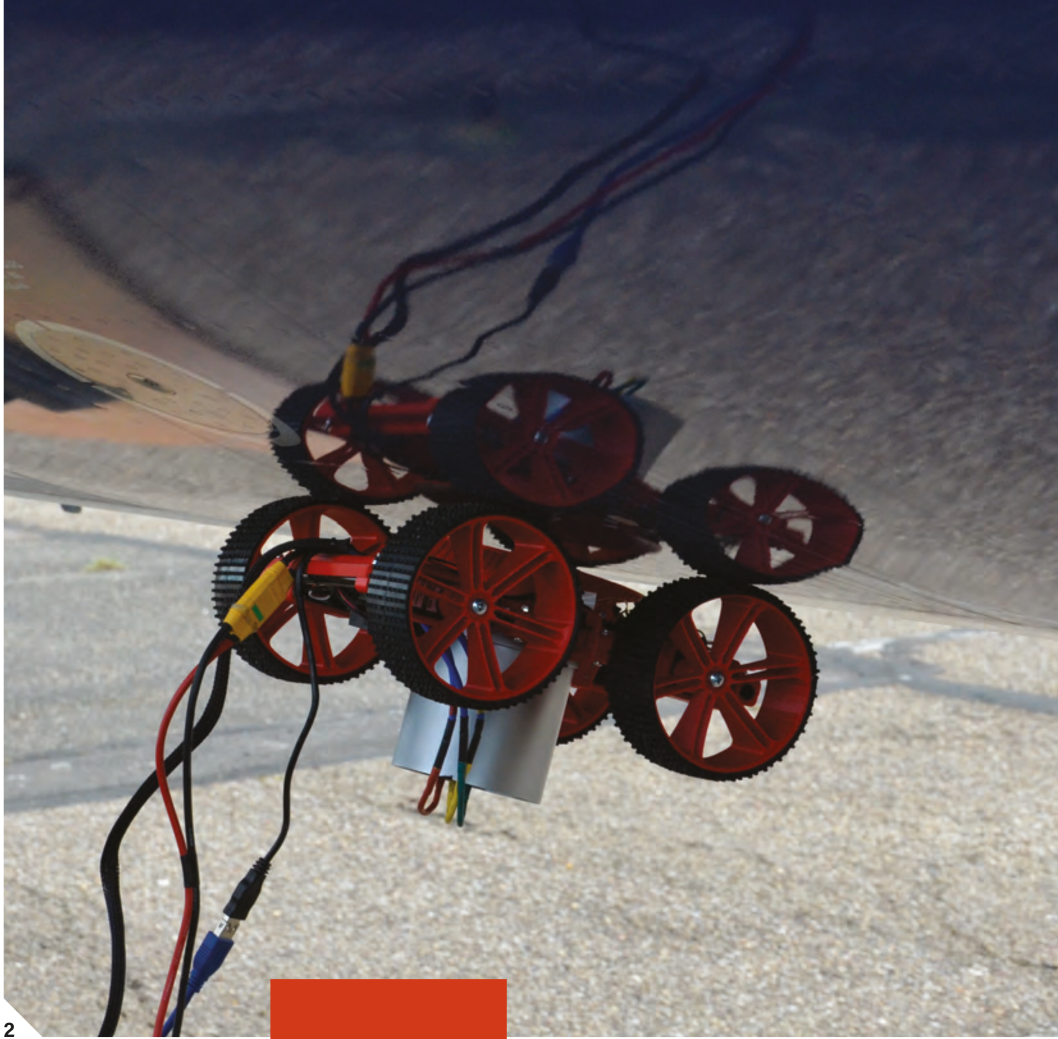
AI-enhanced drones and robots equipped for NDT could form the next generation of testing and inspection tools for aircraft

1 // Airbus developed the Advanced Inspection Drone with its NDT subsidiary Testia *(Photo: Airbus)*



2 // The CompInnova concept: the vortex robot attaches to smooth surfaces and moves in all directions

The use of remotely operated or fully autonomous drones for tasks such as the non-destructive testing (NDT), inspection and certification of aircraft structures is being developed by companies and academia. This is due, in part, to ongoing improvements in a number of the key supporting technologies, including improvements to hardware, wireless connectivity, software and Internet of Things (IoT) capabilities, as well as reliability enhancements.

GENERAL VISUAL INSPECTIONS

Remotely operated drones and robots can be used for NDT inspection in the aerospace industry across a variety of different functions. As Luca Zanotti Fragonara, lecturer in structural dynamics at the Centre for Autonomous and Cyberphysical Systems at Cranfield University, UK, explains, a distinction can be made between in-service inspections and manufacturing applications – each area has a different certification route.

According to Fragonara, one of the most recent developments is the use of drones to assist with general visual inspection between flights. Some MROs are already considering the use of drones and robotic systems to assist in checks. One of the most high-profile cases is the use of drones in the inspections of easyJet aircraft, as part of a partnership with drone company BlueBear. Airbus and Testia have also announced innovations in the field. Additionally, Rolls-Royce has demonstrated a range of robotic inspection and repair tools able to work inside aircraft engines that are remotely controlled.

"The key benefit of using any automated technology for NDT inspection is the repeatability of the process"

"Airlines and airports have to take the lead for these types of inspections, as in the easyJet case. It is the ground personnel that are more involved in such visual inspections and manufacturers do not have much of a role," says Fragonara. "At Cranfield, our research concerns both types of inspections – in-service and manufacturing applications."

At Cranfield there are two major ongoing NDT projects. One is being done in collaboration with Airbus and is using UAVs to inspect metallic wing panels during the manufacturing process. The project aims to replace manual NDT processes with an automatic procedure using the same operational principles. Researchers in this project are also looking at the use of thermography by UAVs for composite structures.

The University is also coordinating CompInnova, a five-year research project with partners including the Luleå University of Technology (LTU) in Sweden, the University of Patras and the University of Ioannina in Greece, and Portuguese company Optimal, which is developing thermography, phased array ultrasonic and a laser repair procedure to inspect, localize, size and repair defects as part of the maintenance process.

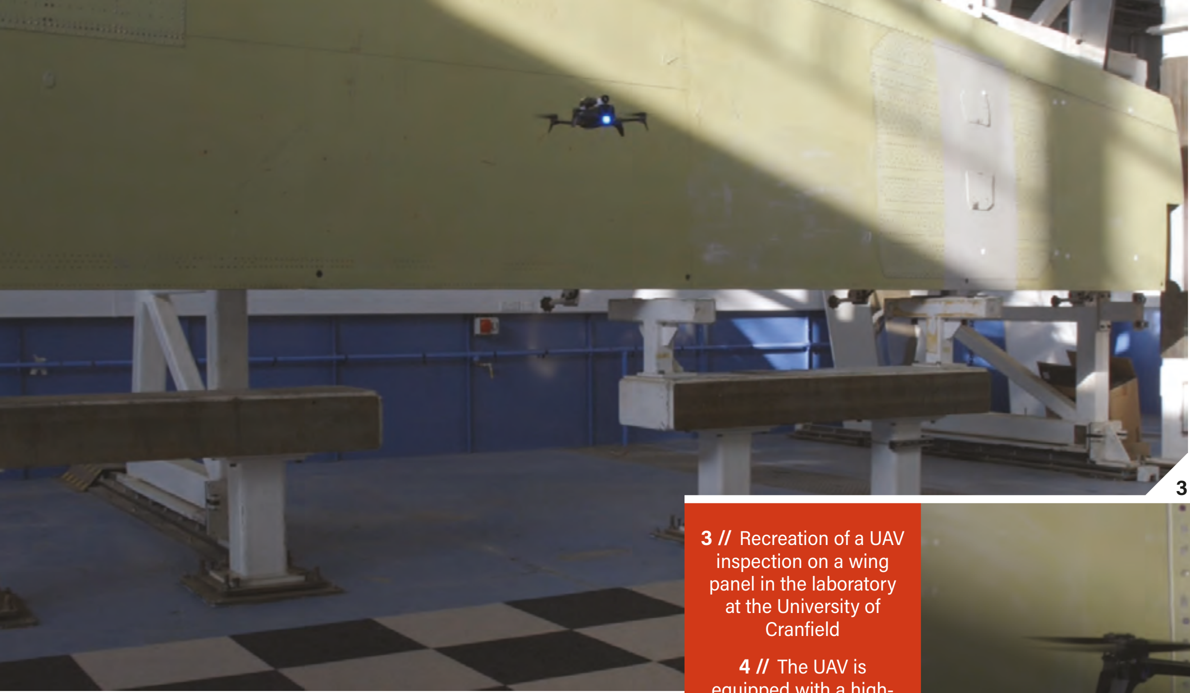
The CompInnova project, which was launched in September 2015, aims to integrate these NDT technologies into the vortex robot developed by LTU and scan the surface of aircraft autonomously and wirelessly. A prototype of the robot was recently successfully tested on a Boeing 737 at the University of Cranfield.

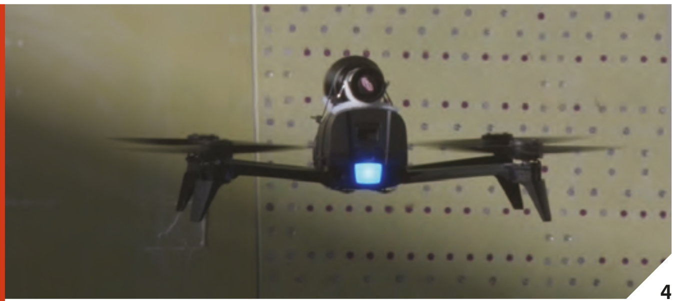
RAPID PROGRESS

Another interesting recent example is the RAPID (Remote Automated Plane Inspection and Dissemination) system developed by UK-based company MRO Drone. RAPID is an automated, drone-based aircraft damage inspection and reporting system that can be used to inspect an entire airframe. The company has tested the system for inspections of appliances, propellers and powerplants.

RAPID uses optical sensors to provide direct visual inspection data that is geo-referenced to the aircraft structure. According to Gavin Goudie, CEO of MRO Drone, the operator requires minimal training and, depending on regulations, no previous experience. "Should a repair be required, the engineering teams can deploy the necessary access systems that have been pre-emptively located and staged near the aircraft," says Goudie.

RAPID has been demonstrated to several OEMs, MROs and airlines that





3 // Recreation of a UAV inspection on a wing panel in the laboratory at the University of Cranfield

4 // The UAV is equipped with a high-resolution camera and a UV light

5 // Dr Luca Zanotti Fragonara, lecturer in structural dynamics at the University of Cranfield

are interested in the deployment of the technology for their operations. MRO Drone has recently supplied its first system to a US-based customer.

REMOVING ERRORS

According to Prof. Antonios Tsourdos, director of research – aerospace, transport and manufacturing at Cranfield University, the key benefit of using any automated technology for NDT inspection is the repeatability of the process. Most current manual inspections rely on the use of personnel to carry them out, who will be more prone to make mistakes than an automated process. Despite the improvements in speed and accuracy offered by automation, Tsourdos admits that a number of challenges remain before aerospace companies are able to fully employ automation in areas such as NDT inspection. He believes that the most significant hurdle to be overcome relates to the navigation of certification routes, which are not yet clearly defined for some disruptive technologies.

"This is more about the way we are going to use the data coming from the inspection, than the technology used for the inspection itself. Data is increasingly being processed by computer vision algorithms based on artificial intelligence technologies such as deep learning architectures or similar," Tsourdos says.

"This is a challenge because AI algorithms are harder to certify than other algorithms. They may perform very well in most circumstances and fail shockingly in some trivial case."

MAKING CONTACT

On average, a commercial aircraft will be struck by lightning at least twice per year, as well as suffer hail and other foreign object damage. NDT inspection is essential to detect and track any damage that may have occurred. Although Goudie at MRO Drone is considering NDT applications for its inspection drone, a potential challenge is that NDT typically requires contact between the tool and the aircraft structure. This may make crawling robot systems more suitable for NDT inspections. Despite the technical challenges, Goudie believes that drones and other autonomous robots offer the opportunity to introduce more automated maintenance processes into the aviation sector. "The main challenge is the fear of change itself. The sector is highly aware of risk because of the safety-critical nature of the operations that are being conducted. The introduction of new technologies such as RAPID will take some time," he says.

"But RAPID is leading the way in this field. We have seen a change in the acceptance of this new technology since the beginning of our development in 2014 – the question from prospective users is no longer 'why would I' but 'how do I' use this technology."

DATA USAGE

In terms of the use of data gathered by drones, and any other autonomous technologies used during inspections, there are potential benefits and challenges. The data collected by the RAPID system is shared via an operator's engineering management system, and being cloud-based can be quickly disseminated regardless of the location of the aircraft or the technical experts.

In addition, post-flight analysis (PFA) software allows individuals to systematically review the captured data sets, and using the embedded image

"One day we could see contactless laser vibrometers carried by a UAV, allowing the use of powerful techniques, such as remote ultrasonic sensing"

6 // The use of drones for inspection is reducing the time an aircraft is on the ground during maintenance *(Photo: Airbus)*

6

"Inspections will eventually become completely autonomous – it is the when, not the if, that is open to discussion"

processing tools, create damage reports that highlight areas that may need some additional investigation.

"By sharing data and working as a team, a whole aircraft can be inspected in one or two hours," says Goudie. "But the automation of the detection of anomalies within measurement and analysis tools is an important step on the route to certification and for the inclusion of the tool into standard aircraft inspection and maintenance processes."

The application of AI-learning algorithms continues to radically improve the effectiveness of computer vision. According to Tsourdos, during the past 10 years, most improvements in object and structural damage detection have been made possible with deep-learning AI.

"Computer vision was considered an impossible task and a dead area around 2005, while nowadays we are able to do what was thought unbelievable only a few years ago. For example, we have object classification algorithms that are able to outperform humans," says Tsourdos.

The digital storage of inspection data also offers the possibility of improving the analysis of things like crack growth, by comparing information between individual aircraft and an entire fleet. "This could help find possible correlations between damage occurring in a particular area and determine if it is due to external factors or not," says Fragonara.

"I think that inspections will eventually become completely autonomous – it is the 'when' not the 'if' that is open to discussion," he adds.

MACHINE LEARNING

Looking ahead, Goudie predicts that the key areas for drone and robotic inspection technology in the coming years will be the integration of expanded sensor payloads, including NDT tools. "The ability to deploy robotic systems, including drones such as RAPID, is an attractive proposition to the industry, not

AIRBUS AND TESTIA PARTNER ON INSPECTION DRONE

One of the leading aircraft inspection drones available has been developed by Airbus and its NDT subsidiary Testia. The Advanced Inspection Drone is used inside hangars, follows a predefined inspection path around an aircraft, records visual data with its integrated camera and then uses analysis software to process the results.

The drone also has a laser-based obstacle detection sensor and flight planner software that has been optimized for inspecting the upper parts of aircraft fuselages. The images are transferred to a PC database for detailed analyses. This allows the operator to localize and measure visual damage on the aircraft's surface by comparing it with a digital mock-up of the aircraft. The software automatically generates an inspection report.

The new system's inspection process is waiting on approval from the European Aviation Safety Agency (EASA) before it can be used.

According to Airbus, the drone-based system enables operators and maintenance providers to reduce inspection time while enhancing the overall quality of reports, improving damage localization, repeatability and traceability.

The inspection process with the drone takes three hours, including 30 minutes of flight to capture images. In contrast, traditional aircraft visual inspection is performed from the ground or using a telescopic platform for the upper parts of the aircraft – a process which could typically last up to a day.

ROBOTS INSPECT INSIDE

One of the major benefits of remotely controlled robotic systems is that they can be used to inspect and even repair the interior parts of aircraft that are otherwise difficult to reach.

An initiative from engine manufacturer Rolls-Royce is developing several robotic technologies for this purpose. Designs being developed by the company and its academic partners include swarming cockroach robots, snake-arm robots and remotely operated probes.

One of the projects which is expected to be made available within the next two to three years is a remotely controlled "boreblending robot". The robot is fixed to the side of an engine and inserts a probe inside of it. A camera on the probe scans the compressor blades for damage and builds a 3D point cloud image. This image is compared to a 3D digital model of the engine to determine damage. An expert at a Rolls-Royce Availability Centre then remotely controls the robot and instructs it to grind away the damaged areas "blending it" to the surrounding area through the borehole, using a high-speed air spindle.

Speaking at the Farnborough Air Show last year, Dragos Axinte, director of the Rolls-Royce University Technology Centre at the University of Nottingham and the research lead, said, "It can be thought of as like a portable CNC machine tool. An unskilled operator can bolt it on the engine so the specialist from Derby can operate and repair the engine."

The robot has been in development for four years. Dr James Kell, Rolls-Royce's on-wing technology specialist, repair technology, said, "It will allow us to service our engines in hours rather than days."

Other robots being developed as part of Rolls-Royce's Intelligent Engine program include sets of miniature "periscopes". These fiber-optic networked cameras are embedded within engines when they are built and would pop-up intermittently to provide visual data to complement the data already gathered by other vibration, acoustic and temperature sensors.

The company is also developing pairs of small snake-arm robots as part of a project called Flare. The robots will be able to travel through an engine and inspect its interior using a proprietary NDT technique, remove damage and then carry out patch repairs on damaged thermal barrier coatings. This project is a partnership between Rolls-Royce, the University of Nottingham and engineering firm Metallisation.

A project with Harvard University is also developing small robotic cockroaches – measuring 4.5 x 1cm (1.7 x 0.4in) and weighing 1.8g each – that are deployed via a long tube inside the engine to perform visual inspections of hard-to-reach parts, such as the combustion chamber.

Sebastien de Rivaz, research fellow at the Wyss Institute, Harvard University, said, "We want to scale it down to fit in borescopes and cameras on it. They are autonomous and transmit images to a central location. Instead of five hours we could carry out an engine inspection in five minutes."

Kell added, "While some of these technologies, such as the swarm robots, are a long way from everyday reality, others are being tested and will be introduced within the next few years."

just in MRO, but also in production, where repetitive but highly detailed quality inspections are required throughout the manufacture of each aircraft," Goudie says. "Software and technology will unlikely ever fully replace engineering expertise. And on that basis we continue to develop RAPID as a tool that can be used to enhance quality and increase process efficiency and reduce costs."

Fragonara argues that the biggest limitation relating to the use of drone technology for tasks such as testing, inspection and certification relates to the sensors that can be installed on the platforms available today. As longer endurance and higher payload-carrying capacity drones are bought to market, the industry will see drones able to lift larger infrared cameras. This will enable engineers to inspect structures not only visually, but also with thermographic techniques.

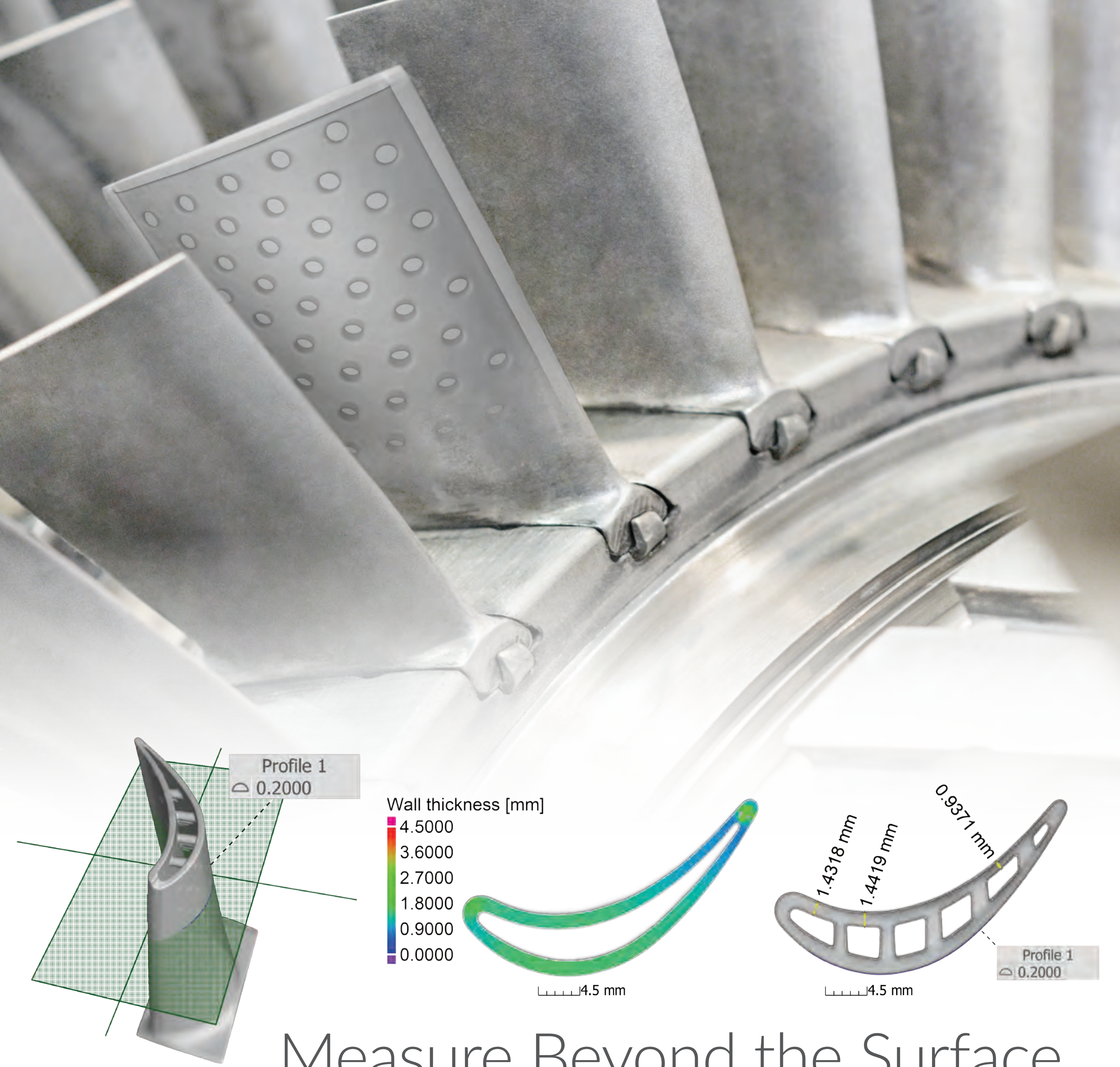
"Potentially, one day we could see contactless laser vibrometers carried by a UAV, allowing the use of powerful techniques, such as remote ultrasonic sensing," Fragonara says.

Ultimately, Tsourdos predicts that there is potential for large operational cost reductions when drones become fully autonomous. However he warns that inspections carried out by such technologies will always need to be closely regulated. He says, "I think that software algorithms and drones will replace existing human expertise over the next few decades. We have seen the disruptive impact of many other technologies in the past on boring, repetitive jobs, and these jobs have all been replaced."

"On the other hand, the technology will offer new types of exciting jobs and drones will need to be designed, manufactured and repaired, too." \\

7

7 // Several airlines have trialled the use of drones for visual inspection of aircraft over the past five years *(Photo: ANA)*


Profile 1
0.2000
Wall thickness [mm]
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Profile 1
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4.5 mm

// BEN SAMPSON

MARK AUBELE FROM THE PERFORMANCE REVIEW INSTITUTE DISCUSSES HOW NADCAP ACCREDITATION IS EVOLVING TO MEET THE NEEDS OF THE SECTOR

Built to

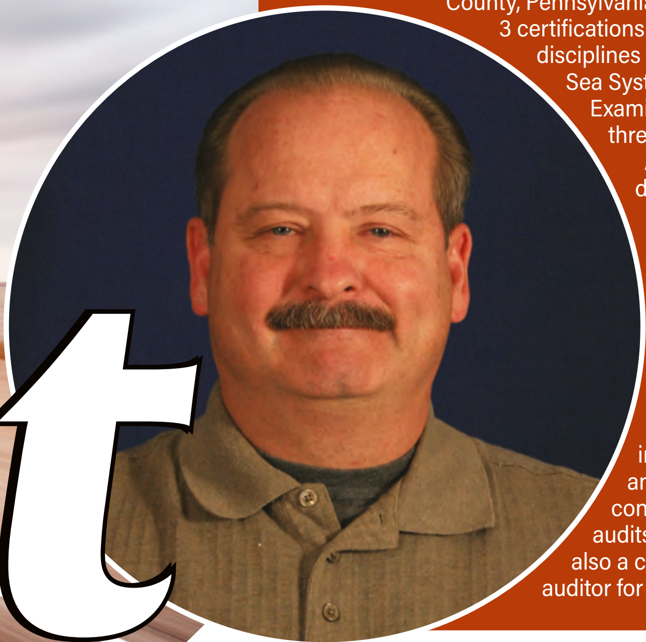
last

MARK AUBELE CV

Aubele's career in NDT began as a US Air Force technician stationed at Pease Air Force Base, New Hampshire in 1978. After four years Mark joined the Air Force Reserves, where he managed an Air Force NDT lab until he retired from the USAF in 2005, after serving almost 25 years.

Aubele has also performed NDT inspections at nuclear power plants, construction sites and fabrication plants. In addition, for 12 years he was a college-level NDT instructor in the evenings for the Community College of Allegheny County, Pennsylvania. Mark has held Level 3 certifications in all five major NDT disciplines and NAVSEA (Naval Sea Systems Command) Examiner certification in three of them.

At PRI, Aubele's duties involve managing multiple special processes including NDT, measurement and inspection, electronics and aerospace quality systems. Personnel in those programs include staff engineers and 85 auditors, who conduct more than 1,900 audits per year. Aubele is also a certified Nadcap Lead auditor for NDT.



1 // The standardization and reporting of testing for NDT reduces the repetition of work and increases value across the supply chain

Standardization of processes is a fundamental part of any successful industrial supply chain. A major part of building and maintaining standards for non-destructive testing (NDT) in the aerospace sector has been Nadcap.

Compliance with Nadcap audits has become a mainstay for suppliers and OEMs around the world since the standard was launched in 1990. Mark Aubele is senior program manager for NDT at the US-based Performance Review Institute (PRI) and talks to *Aerospace Testing International* about how and why the standard has been successful and what future changes to it may entail.

// WHAT IS NADCAP AND WHAT IS ITS ROLE IN THE AEROSPACE SECTOR?

Nadcap is a collaborative industry approach to ensuring compliance with special process industry standards and customer specifications throughout the aerospace and defense global supply chain. All the major aerospace and defense companies work together to identify critical processes that require oversight through the Nadcap audit process. The processes to be checked are established by technically focused task groups made up of experts who approve auditor candidates, develop audit questions and make the final decision on accreditation.

The first and largest of these groups is the NDT Task Group, which accredits the testing processes of magnetic particle, liquid penetrant, ultrasonic, radiography, digital radiography, and remote image and film viewing. There will be questions specific to each area included in the audit checklist.

// HOW DOES NADCAP STAY CURRENT WITH NDT TECHNOLOGIES AND PROCESSES?

We are always at the industry's door and that is how we obtain the latest information on an ongoing basis. This ensures that we meet needs in all areas, including new technologies and processes. Industry input is vital to ensuring that the Nadcap accreditation continues to be relevant and valuable. We also monitor industry trends and share any insights as appropriate.

// WHAT HAPPENS DURING AN AUDIT?

First, let me clarify that there is a significant difference between a Nadcap audit and any other NDT audit or, for that matter, any general quality and/or ISO standard audit. With those types of audits, generic quality questions may be used regardless of the nature of the work being audited.

But the Nadcap audit has been developed by the industry to meet its requirements and that includes questions developed from industry standards like the ASTM, AMS, NAS 410 and others as well as Nadcap subscriber specifications and requirements.

The Nadcap audit is more in-depth than other NDT or quality audits, and every nonconformance initiated requires a thorough response.

Upon arrival at the audit site, the auditor will conduct an opening meeting with key personnel to ensure that the audit scope is understood by everyone involved. A site tour may also be conducted to orient the auditor. On average, an NDT audit takes three days, depending on the number of methods audited, but it may require more than six days.

"Digital radiography has really taken off in the aerospace industry"

The NDT checklists are available free of charge online at www.eAuditNet.com. All auditees are expected to conduct a self-audit using those checklists prior to the Nadcap audit as part of their pre-audit preparation, so there should be no surprises during the audit.

In 2018 we conducted almost 6,000 audits around the world. Approximately half of the audits that take place are conducted in the Americas, followed by Europe and then in Asia.

Of these, almost 1,300 are NDT audits, making non-destructive testing the largest area for Nadcap. With some accreditations being valid for longer than a year, there are currently 1,865 companies holding Nadcap NDT accreditation featured in the online Aerospace Qualified Manufacturers List on eAuditNet.

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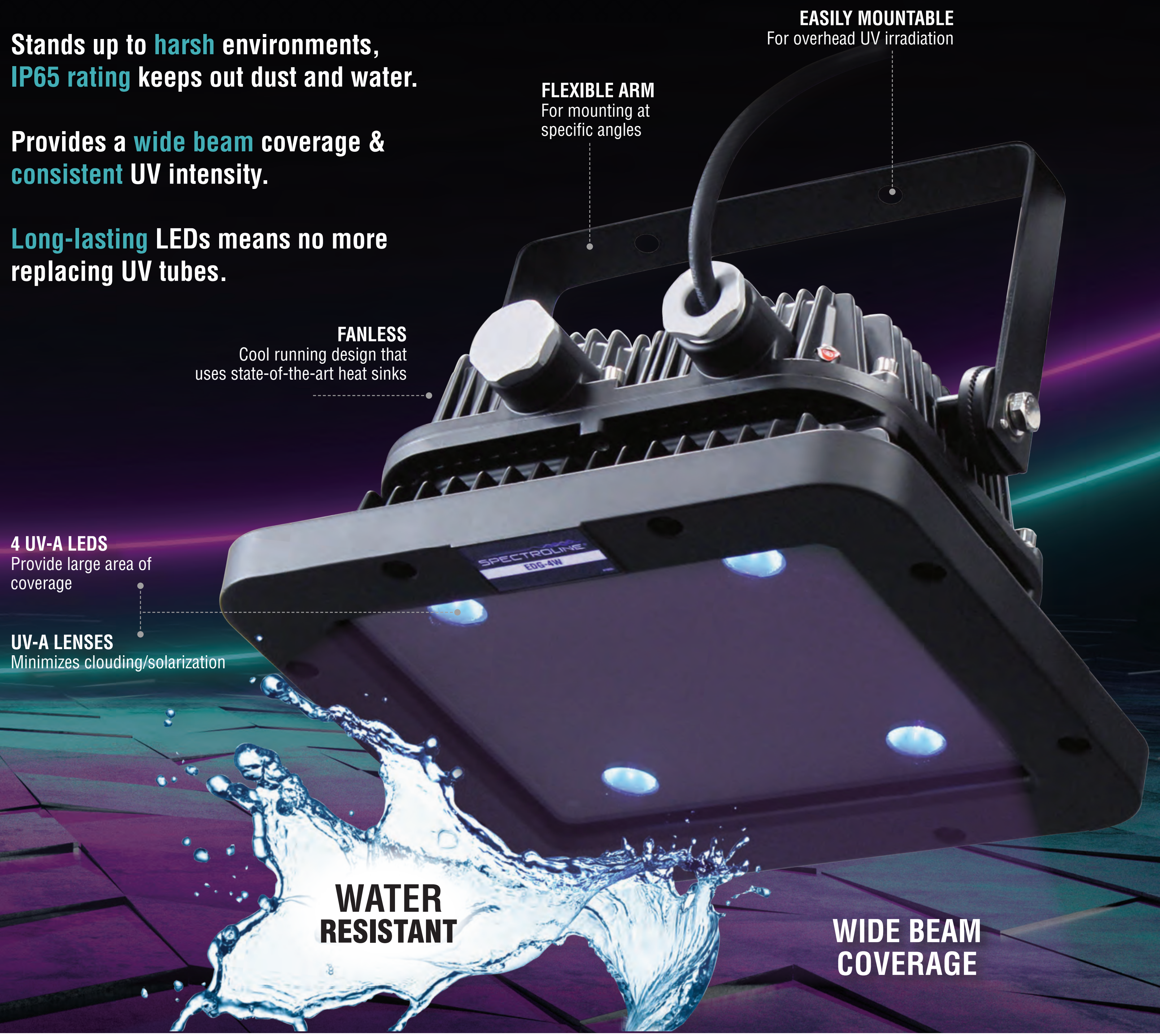

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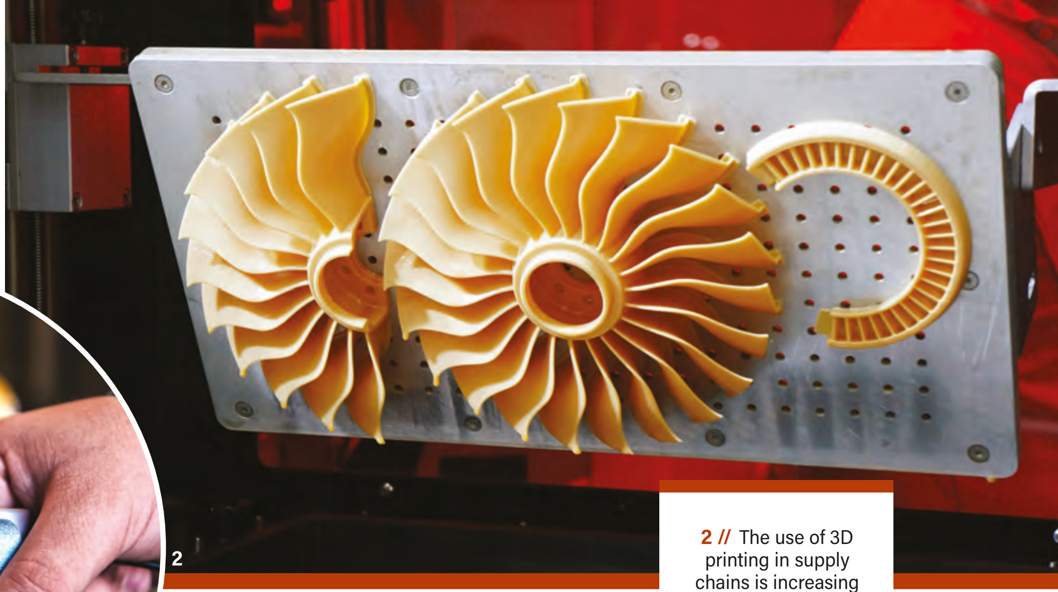
3 // Ultrasonic testing is one of the most common forms of NDT



2 // The use of 3D printing in supply chains is increasing

// WHY SHOULD PEOPLE PRIORITIZE ACCREDITATION?

Nadcap continues to grow in technical scope and global reach. Nadcap accreditation is globally recognized as a key indicator of a company committed to excellence and is a trusted symbol of compliance.

Any company that wants to satisfy its customers, retain and win new business and be assured that its output is of the highest quality holds Nadcap accreditation. Accreditation guarantees that a company will be featured on the online Aerospace Qualified Manufacturers List, which is used by procurement and quality executives, among others, to source suppliers and form part of their risk-mitigation strategy.

// WHAT IS THE MAIN BENEFIT OF NADCAP TO THE INDUSTRY?

There are many benefits and they vary depending on the customer. For the major aerospace and defense companies who subscribe to Nadcap, there is the assurance that their specific requirements will be incorporated into the Nadcap audit checklist. They can retain overall control and oversight while delegating the technical administration of the program, reducing the human and financial resources required to audit and minimize risk.

Nadcap is also able to contract with technical specialists in NDT and other critical areas because of the volume of work in those specific areas. Individual companies are not able to support this, so they typically use generalists across a number of technical areas. They also benefit from shared resources, best practices and knowledge bases, which make for a more technically superior audit than any one company could achieve alone. This is highlighted by a recent survey, which showed that 89% of Nadcap-accredited suppliers believe that the process has helped improve quality.

For suppliers, as well as being featured on the Aerospace Qualified Manufacturers List, there is also the opportunity to input into the audit checklist and network with existing and potential customers. Along with Nadcap subscribers, suppliers are invited to the triannual meetings, which are held free of charge and focus on technical discussions about Nadcap audit criteria. Free training is offered to attendees.

In general, surveys of the Nadcap-accredited supplier base show that 93% believe that accreditation is added value for their company, while 77% think that being Nadcap accredited has helped them win new customers or projects.

Overall Nadcap represents improved universal oversight and reduced costs for the industry. It also reduces repetition of checks, with audits that include industry as well and subscriber specification requirements. Before Nadcap, aerospace companies audited their own suppliers to their own process requirements to verify compliance. For prime contractors this meant duplication of effort, redundant audits, unnecessary administration and, ultimately, higher cost for no added value. It also added unnecessary burden to the supply chain, which was on the receiving end of these duplicate audits.

"The risk of counterfeit parts in the supply chain is high enough that the industry has formed a dedicated committee"

According to our research, 15% of Nadcap-accredited suppliers report increased productivity since gaining Nadcap accreditation, and over 35% report reduced scrap and rework rates. Nadcap has allowed companies who participate in the program to refocus their resource on other activities that deliver value for their business, which benefits the industry as a whole.

// WHAT'S CHANGING WITH THE NDT AUDIT?

The Nadcap NDT Task Group have very recently initiated a program to audit and accredit national

aerospace NDT boards around the world. This accreditation will allow a supplier to pass over many of the questions related to NAS410/EN4179 in our base checklist, AC7114.

One of the biggest changes coming to the Nadcap NDT program is the remote services audit. Until now the only tests that you could seek accreditation for were the ones you did in house under your own roof. This new program will accredit suppliers to work remotely, away from their home base.

"Additive manufacturing is offering challenges to NDT in terms of defect detection"

// WHAT TECHNOLOGICAL TRENDS INTEREST YOU THE MOST IN AEROSPACE AT THE MOMENT?

Probably the increased use of additive manufacturing. Our Welding Task Group has developed audit criteria for this process, but the NDT industry is still working out some of the kinks in how to inspect such objects and what types of defects need to be found.

Digital radiography has really taken off in the aerospace industry and the Nadcap NDT program has developed audit criteria for both digital detector arrays and computed radiography.

// WHAT ARE THE MOST CHALLENGING NDT PROCESSES TO USE?

They are all challenging in their own way. Additive manufacturing though, because of the way the parts are made, is offering some challenges to NDT in defect detection and evaluation. Soon after the industry – our customers – decides that a technology is warranted for use, Nadcap audit criteria will be developed so that we can monitor the quality of the suppliers of that will be using the technology.

// WHAT'S A TYPICAL DAY AT WORK FOR YOU?

I spend quite a bit of time simply managing the programs and the staff engineers who run them. I still also spend a fair amount of time reviewing NDT audit reports, speaking to customers and ensuring that our subscribers receive value from the Nadcap program.

The most satisfying part of my job is speaking to suppliers and being able to help them through difficult audit processes. I also get numerous calls from auditors on-site who want a clarification or direction regarding a possible nonconformance. It is truly rewarding any time I can help someone's day go a bit easier.

// WHAT DO YOU SEE AS THE MAJOR CHALLENGES FOR THE AEROSPACE INDUSTRY IN THE FUTURE?

There are a number of well-documented and significant challenges that the aerospace industry must address in order to continue to be the well-respected, technology pioneering leader that other industries benchmark themselves against. We all know that a qualified personnel shortage has been looming for some time. The baby boomers who grew up in the era of the space race, when investment in aerospace and defense was high, are starting to retire and there has not been enough investment in education, training, recruitment and retention to maintain the workforce in its current numbers or at the current level of expertise.

Another of PRI's programs, eQualified, uses the Nadcap industry-collaborative model to develop technical bodies of knowledge. They are published free of charge online, to support and encourage companies to think about the technical expertise they need to function and develop their staff accordingly.

Globalization, with its many benefits, also brings challenges. Ensuring the correct interpretation and application of technical specifications in traditionally non-aerospace areas, and the rise of counterfeit part production, are by-products of the need for ever greater cost savings and efficiencies.

While Nadcap can help with regard to the need to maintain effective oversight at a distance, the risk of counterfeit parts in the aerospace supply chain is high enough that the industry has formed a dedicated Counterfeit Avoidance Management Committee, to run a program focused on mitigating the risk of introducing counterfeit parts into the supply chain.

// WHAT DOES THE FUTURE HOLD FOR NADCAP?

Nadcap will continue to support the aerospace and defense industry by providing a cost-effective, technically superior mechanism to ensure the compliance of the supply chain to industry requirements and expanding into new technologies as appropriate. Nadcap will also continue to be a highly regarded program that acts as a model for other critical industries where safety and quality are shared values. This is already the case for the medical device manufacturing industry, which has based its MedAccred supplier accreditation program on Nadcap. \\

4 // Careful equipment calibration is as important for simple micrometers as it is more complex tools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ENGINE TESTING
// BEN SAMPSON

FUTURE *proofing*

GE Aviation has upgraded its testing facilities to deal with the challenges of next-generation engine development

1

1 // The Passport engine under test at GE Aviation's Peebles facility in Ohio *(All photos: GE Aviation)*


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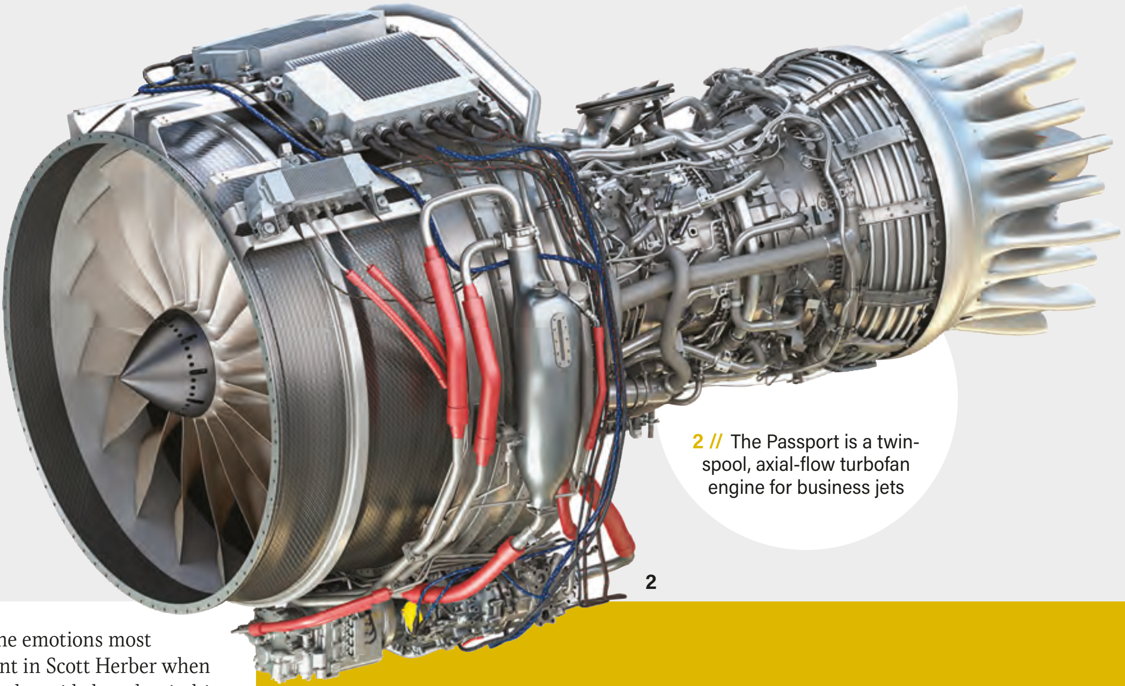


2 // The Passport is a twin-spool, axial-flow turbofan engine for business jets

One of the emotions most apparent in Scott Herber when talks is the pride he takes in his work. Herber is the evaluation and test engineering manager at GE Aviation at its Evendale headquarters in Ohio. Evendale celebrates its 70th anniversary this year and is the center of GE Aviation's testing operations. It's testing facilities have seen significant investment recently in equipment and laboratories to enable engineers to test the latest engines and deal with challenges in areas such as thermal management, acoustics and emissions. The GE Aviation testing team has never been busier – both with internal projects and the development programs of external customers.

> ***"I'm excited about the direction we are moving in. We've a lot of exciting products in development"***

PASSPORT TO SUCCESS

GE Aviation's Passport entered service at the end of last year with Bombardier's Global 7500 business jet. The ultra-long range, 16,500 lbf-thrust (73kN) business jet engine comprises a design which blends the engine and cowling nacelle together. Other features include a 52in-diameter (132cm) titanium fan blisk, the first time a blisk of this type has been used in an engine of this size and a core scaled down from the Leap airliner engines.

The engine took almost nine years to develop and was tested at Evendale and GE Aviation's site in Peebles, Ohio. Twelve Passport engines and a dedicated team were used in the rigorous ground and flight test program. Herber says, "The first time you see an engine you worked on take flight is a humbling experience. It's thrill that gives you the continued motivation to develop the next product.

"It reminds you that people are depending on you to develop a safe, lower cost, high performance product."

UNDER PRESSURE

Another major development program within GE Aviation currently is the GE9X, the world's largest jet engine, which will be used on Boeing's 777X aircraft. The engine, which will have thrust of 105,000 lbf (470kN), and is 14.5ft (4.7m) wide. The GE9X started flight testing in March 2018 and is due to be flown on the 777X this year.

3 // The supersonic Affinity engine will be developed at the Evendale facility

4 // Cell A19 at Evendale

"It's taken several decades to build everything we have at Evendale"

5 // GE's 747 testbed is used to flight test earlier in development

6 // The supersonic Affinity engine will be used by Aerion

The development of the GE9X required the construction of new test facilities at Evendale, notably the A20 combustion test cell, because of the overall pressure ratio is very high in the engine. This US$120m cell provides realistic combustor inlet conditions of 1,000psi and 1,475°F (800°C), the same as would be found if the combustor was already installed within the engine. The cell is around 20ft (6m) wide, 200ft (60m) long x 30ft (9m) high.

Herber says, "The combustor is in the heart of the engine, so it can be very difficult to take measurements in a fully assembled aircraft engine. It can also be difficult to vary the parameters that govern combustion performance and efficiency in an aircraft engine."

The A20 cell enables engineers to vary the conditions the combustor would see during operation and tune different aspects of the combustor and the combustion system to meet requirements for durability and emissions. The design of the facility also enables the collection of data that is impossible or very difficult to collect in a full engine test. It is used early in the engine development cycle to adjust the combustion and so that more-informed hardware choices upstream and downstream of the combustor can be made. "We use it to investigate and duplicate any issues found in the field to validate fixes and to validate and explore new combustion spaces in new engine designs," says Herber. "We test various designs and materials, as well as different cooling and purging schemes and different fuel nozzles and cases in it."

THERMAL MANAGEMENT

Alongside the A20 test cell, another recent addition to the facilities at Evendale is the VESIL (Vehicle Energy Systems Integration Laboratory). The VESIL lets engineers simulate and test different thermal systems and energy transfer mechanisms that would be found on an aircraft. This allows them to prove the reliability of systems before flight tests and tweak aspects of the design to improve thermal efficiency. "In order to reach the next level of performance, people are optimizing the aircraft and power plant systems as a whole. The VESIL lab allows us to simulate not just the engine but also all the systems that are on an aircraft and would be involved in heat transfer," says Herber.

1,000PSI
Overall pressure ratio of GE9X

14.5FT
Width of GE9X engine

US$120M
Cost of A20 test cell built for GE9X development

7 // Cell A20 at Evendale during a rig test

The large VESIL laboratory contains lots of color-coded pipes and valves. It has a combustion section to simulate aircraft-engine levels of heat generation and several auxiliary rooms that contain different heating and cold fuel systems and an electrical substation to enable the testing of electrical devices. Components can be tested independently, system by system, or integrated as a whole. There is a fuel tank that engineers can pre-chill or preheat depending on the test. In addition, the laboratory contains air cycle machines, vapor cycle machines oil heating and cooling machines and electrical heating and cooling machines. Herber says, "Anything that could be a sink or source of thermal energy in an aircraft we can simulate. When we have a highly integrated system installed and we are testing multiple heat transfer aspects, it's difficult to identify where the test article is because different pipework and pieces are connected so intimately."

VESIL is proving useful in both civil and defense sectors as all-electric and more electric aircraft are being developed. Like the A20 cell, the VESIL's aim is to solve thermal issues early on in the development process, before flight testing. "The more efficiently you can move heat around the better. You can solve a problem with additional cooling, but that comes at a price in weight or efficiency of the engine's operation.

"By the time you get to a flight test that process can be expensive. Whereas a ground test in VESIL helps you avoid repeating expensive tests," says Herber.

OUTSIDE THE LAB

One of GE Aviation's highest profile pieces of testing equipment is its 747-400, which is based at its Flight Test Operations center in Victorville, California. The location was selected for partly because it has some of the calmest and driest weather in the USA.

The 747-400 has most recently been used to flight test the GE9X, so that engineers can test it alongside the known performance envelope of the three GE CF6 engines already fitted to the aircraft. The 747-400 started life as a standard passenger aircraft. GE bought it and retrofitted it. When an engine is being tested it is swapped out for the standard CF6 in the number-two engine position using a specially-designed pylon and interfacing hardware, which links onboard instrumentation to measure pressure, temperature, strain, clearances and deflections. Herber says, "The aircraft cabin has been heavily modified. There are racks and racks of data acquisition equipment and interfacing equipment that allows the aircraft to talk to the different engine as if they are the engine that should be on it.

"A ground test in VESIL helps you avoid repeating expensive tests"

"A CF6 is very different technology from the development engines we are testing. The ability to integrate the test engine's communications and control interfaces with the 747 is one of our flight test team's core strengths."

GOING SUPERSONIC

One of the most recent partnership announced by GE Aviation is also one of its most interesting. Last October, it was revealed GE Aviation is developing the Affinity engine for one of the leading companies of the new cadre of supersonic aircraft developers, Boeing-backed Aerion. The Affinity engine is a twin-shaft, twin-fan turbofan. It will be used on the company's 12-passenger AS2 business jet. Aerion plans to be flight testing a prototype of the AS2, which is designed to fly at a cruising speed of Mach 1.4, in 2023.

It's likely the bulk of testing for Affinity will be conducted at Evendale, says Herber, a project the site is prepared to perform. The company has considerable experience with supersonic engines for jet fighters.

"We are ready to test supersonic engines like Affinity," says Herber. "Engines for supersonic aircraft aren't new to GE, although it has been a while since a civil supersonic design was considered. We are entering a rebirth of civil supersonic transport.

"There are additional technological questions and issues to be resolved. Civil has different requirements from a military aircraft. The experience of our design engineers, as well as our testing personnel and facilities, will enable us to deliver it."

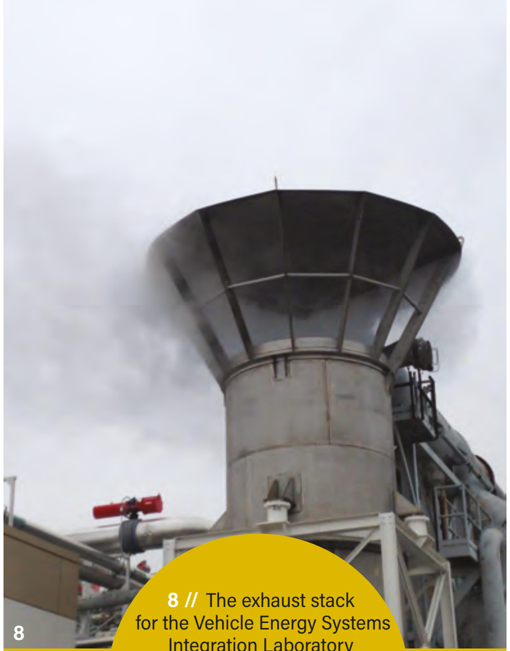
The bottom line is that supersonic passenger aircraft won't be going anywhere without supersonic engines. That what will likely be one of the first of these engines will be developed by one of the largest and oldest industrial companies in the world is proof of the efforts GE Aviation has gone to nurture innovation. "We purposefully encourage innovation internally and that comes from leadership. We're encouraged to make mistakes early and learn from them and move on; to take bigger risks," says Herber. "The development of the LEAP engine is one of the best examples of how this has worked for us.

"I'm excited about the direction we are moving in GE Aviation. We've got a strong installed base and a lot of exciting products in development, which will keep us busy in test and will enable the next generation."

Innovation may be a requirement for survival, but GE Aviation's reputation is also built upon a pride in the work and its products that one suspects carries down from leadership through the rest of the testing team. It's a reputation that means Evendale is hosting several projects for external customers and is always looking to partner with more external companies.

"We have a proven track record of safely and efficiently running these tests and have some unique capabilities. It's taken several decades to build everything we have at Evendale. We're fortunate to have had the sustained high level of support from the company to place us in that position" says Herber.

"Others could develop those facilities, but it would be expensive and time-consuming for them to do so. We can offer access to the capabilities that our facilities offer, along with our expertise to anyone interested. We're open for business." \\



8 // The exhaust stack for the Vehicle Energy Systems Integration Laboratory

"People are depending on you to develop a safe, lower-cost, high-performance product"

9 // Single cup combustor rig for GE9X test at Evendale

SPACE TECH EXPO | USA

Watch this SPACE

TESTING TO-DO LIST

Monday, May 20
- Electric Propulsion Workshop, including EMC/EMI testing

Tuesday, May 21
- Exhibition floor opens with access to more than 30 testing companies. Keep an eye out for our Testing Space Trails, which we will publish closer to the show
- Technical testing session in the morning on the Open Tech Forum
- Technical testing 360 Sessions in the afternoon

Wednesday, May 22
- Future Mission Enablers day on the Space Tech Conference, including the Taking Additive Manufacturing to the Next Level: Ensuring quality control for future spaceflight session with ASTM International, Lockheed Martin and Siemens participating, among other organizations.

2019 OPENING HOURS

Monday, May 20: 10:00am-9:00pm
*(Workshops open to industry trade visitors: 10:00am-4:15pm
VIP reception, invitation only: 4:30-8:30pm)*

Tuesday, May 21: 9:00am-5:00pm
(Conference and exhibits open to all industry trade visitors)

Wednesday, May 22: 9:00am-4:00pm
(Conference and exhibits open to all industry trade visitors)

VENUE DETAILS

Pasadena Convention Center
East Green Street, Pasadena, California, 91101

Space Tech Expo is a global event. On November 19-21, 2019, Space Tech Expo Europe will be held in Bremen, Germany

NOW IN ITS EIGHTH YEAR, SPACE TECH EXPO & CONFERENCE CONTINUES TO GROW AT ITS VENUE IN PASADENA, CALIFORNIA

Space Tech Expo USA is the country's engineering and manufacturing meeting place for space technology. This free-to-attend exhibition showcases the very latest technology from testing companies, designers, manufacturers, and component and subsystem suppliers, through to systems integrators for civil, military and commercial space.

Now in its eighth year, Space Tech Expo 2019 promises to be the biggest yet, with 3,500 visitors expected. The event provides a platform for senior leadership, decision makers and engineering professionals for various technologies and systems from US DOD organizations; space agencies; Primes and Tier 1 system integrators; subsystem suppliers; components, parts and assembly suppliers; and startups.

More than 250 exhibitors have booked to appear at the Space Tech Expo this year. Exhibitors include NASA's Jet Propulsion Lab, Northrop Grumman, Element, NTS, Novawurks, Go Engineers and Amphenol.

TESTING: WHAT NOT TO MISS THIS YEAR

The latest developments regarding testing for space and aerospace applications will be highlighted at this year's Space Tech Expo 2019, from NDT and environmental testing to electrical test and measurement and real-time simulation.

One trend impacting testing professionals is the increasingly shorter time-to-market: space organizations want to ensure that their production time, as well as cost, is reduced.

In her presentation on the Open Tech Forum on Tuesday, May 21, Leah Rafaelli, system thermal analyst at Lockheed Martin, will discuss the optimization of multidisciplinary analyses and system models to achieve cost-effectiveness and sustainability. She will highlight various methods of optimization in her presentation and will also discuss why they are an improvement on existing testing methods. She says, "System analysis can improve the cost/profit ratio. Software tools have developed to the stage where system-level simulation is a feasible methodology to rapidly and continually fine-tune the entire product system in a virtual environment well before physical assembly and testing."

The Open Tech Forum will also highlight advancements in the area of environmental testing, including vibration testing. In his presentation, Benjamin Shank, R&D engineer at Thermotron Industries, will discuss the limits of mid-field pyroshock on electrodynamic shakers. He says, "ED shakers have largely been overlooked as a tool to replicate pyrotechnic events and launch shocks. This talk gives a review of shock characterization through the Shock Response Spectrum [SRS] and summarizes efforts to generate pyroshock-like transients on a range of ED shakers with meaningful SRS content up to 10kHz."

OVER US$16BN INVESTED IN SPACE STARTUPS GLOBALLY SINCE 2000

(Bank of America Merrill Lynch)

SPACE TECH CONFERENCE HIGHLIGHTS

The Space Tech Conference returns to Pasadena this year with a two-day agenda, packed with presentations from 40 industry-leading experts giving insights and opinions on technology trends sure to stimulate lively discussion. The agenda is designed to support commercial, military, government and academic organizations to navigate the opportunities and challenges of doing business in the increasingly complex space industry.

The comprehensive not-to-be-missed program includes these highlights:

- Day 1 features a number of two-hour, pre-conference workshops. These include a workshop by Dr John Brophy, engineering fellow and principal engineer for electric propulsion at NASA's Jet Propulsion Laboratory, who will be taking a "deep dive" into the future of electric propulsion. Topics to be covered include: an overview of the different types of electric propulsion, and the current standards and certifications for electric propulsion.

- After keynotes from Jim Bridenstine, administrator at NASA, and Eric Stallmer, president of the Commercial Spaceflight Federation, the conference starts at 10:00am with a panel session on how to accelerate the process of technology development, moderated by Ellen Chang, CEO of Lightspeed Innovations. Participants include Col. Steve Butow, director of the space portfolio from the Pentagon's Defense Innovation Unit, and Tess Hatch, investor from Bessemer Venture Partners.

- The second panel of Day 1 at 3:15pm focuses on investment and technology for low Earth orbit. Moderated by Mike French, senior VP of commercial Space at Bryce Space and Technology, speakers include Mike Lewis, chief innovation officer, NanoRacks; and Miki Sode, commercial innovation program manager, International Space Station National Laboratory.

- Day 2's focus, Future Mission Enablers, features an opening session at 8:45am on propulsion technologies with three speakers, including Beau Jarvis, CEO of Phase Four.

- The conference concludes with a panel session ensuring quality for additive manufacturing processes moderated by Dr Mohsen Seifi, director of global additive manufacturing programs at ASTM International. Speakers include Max Hoat, CEO of Launcher, and Quan Lac, head of additive manufacturing in the Americas for Siemens.

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Speaker Interview

CHRIS JOHNSON

instrumentation engineer, Experior Laboratories

EXPERIOR BOOTH 3018

WHAT DOES YOUR JOB ENTAIL?

I spend the majority of my time developing, testing and operating custom-automated test and measurement systems to suit our customers' needs in test applications. These range from mission-critical, high-pressure confidence testing of pneumatically operated propulsion components, to long-duration extreme temperature thermal vacuum cycling of spacecraft electronics.

WHAT ARE SOME OF THE CHALLENGES YOU ENCOUNTER IN YOUR JOB?

Test programs usually involve moving the test article through a sequence of simulated loads and environments, such as vibration, SRS shock and thermal vacuum. A big challenge can be designing a test stand that can successfully operate in all these cases and accommodate any changes or test article failures that are common when going into test.

HOW HAS TESTING OF SPACECRAFT CHANGED RECENTLY?

We have witnessed a much shorter time-to-market approach by our customers, and test schedules are key for success. Our management and staff understand that need. Second and third shift, as well as weekend work, have become part of the status quo.

WHAT DEVELOPMENT HAS STOOD OUT TO YOU IN THE PAST YEAR?

The boom in commercial space has been really exciting to watch, literally. I currently live in Santa Barbara, California, and often see launches from Vandenberg Air Force Base. The most memorable was SpaceX's first attempt at landing its Falcon 9 booster back on the original landing pad.

Chris presents Optimized Pneumatic Test Assemblies for Qualification and Production Testing, at the Open Tech Forum on Tuesday, May 21

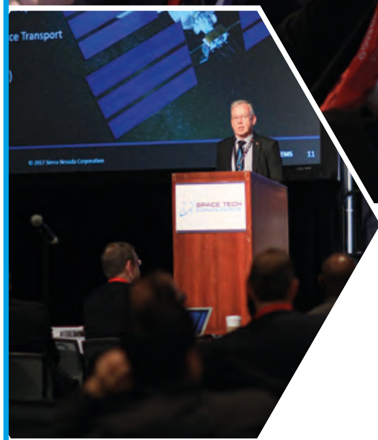
ADVANCED SENSING TECHNOLOGY

DYTRAN BOOTH 7028

An industry leader in sensor technologies for product development testing and embedded solutions, Dytran specializes in designing and manufacturing custom high-end sensors, including piezoelectric and DC-MEMS accelerometers, dynamic force and pressure transducers, USB accelerometers with software included and digital bus-based sensors.

Dytran sensors have been used by flight test engineers in fixed-wing aircraft, rotorcraft, launch vehicle and spacecraft flight test programs since the 1980s. Today, the company continues to provide high-quality sensors and accessories that reliably operate in extremely harsh environments. The company offers a variety of solutions including low outgassing and low-noise sensors for space flight applications, ultra-high temperature products for turbine and engine test cell environments, as well as cryogenic sensors that survive the most demanding conditions.

At its booth, Dytran will be showcasing its latest innovations including its digital machinery diagnostics platform CAN-MD (Controller Area Network – Machinery Diagnostics). CAN-MD sensors incorporate powerful microprocessors that allow data reduction and algorithm processing to migrate to the sensor location rather than reside in a remote box somewhere else on the vehicle. Be among the first to discover how CAN-MD can transition your vibration testing to an all-digital format with high-level, broadband vibration data.



The conference at Space Tech Expo will include the topic of testing in numerous sessions, including the Taking Additive Manufacturing to the Next Level: Ensuring quality control for future spaceflight session, which takes place on Wednesday, May 22. Led by Mohsen Seifi, director of global additive manufacturing at ASTM International, this session explores the future of additive-manufactured components for spacecraft, together with speakers from Lockheed Martin, Siemens, Launcher and Additive Rocket Corporation.

Those interested in measurements and certifications around electric propulsion and issues around EMI/EMC testing might like to attend the Electric Propulsion Workshop on Monday, May 20.

Also on the exhibition floor this year will be a number of Space Trails, where a representative will take you around the testing booths.

See the box *Testing To-do List* for a summary of the must-see testing-related items at Space Tech Expo 2019.

CHANGE MANAGEMENT

The space industry is currently undergoing a transformation where new partnerships and business models are implemented to make sure business becomes more agile, fast and cost-efficient. This approach will affect space system development, technology requirements for future missions and new processes for supply chain management.

Space Tech Expo 2019 reflects these changes through the coverage of various focus areas including: Industry 4.0; space systems; components, parts and assemblies; and testing. The conference represents these industry sectors and will kick off with high-level industry challenges going all the way through to new technology implementation within the supply chain and on the manufacturing floor. \\

CT INSPECTION: FROM THE LAB TO THE PRODUCTION FLOOR

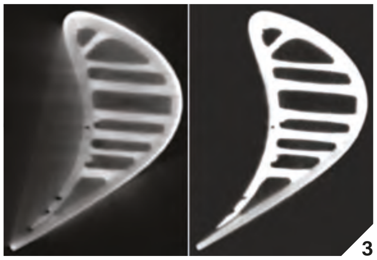
Recent developments in remote visual inspection and computed tomography aim to improve the probability of detection, while reducing reliance on human interpretation

Remote visual inspection is now widely used to examine complex aero engines. The Mentor Visual iQ videoprobe from BHGE Inspection Technologies is the first HD 3D measurement-enabled video borescope and uses an optical measurement technique. This involves projecting line patterns onto a surface, capturing the patterns with a video camera, and processing the images using algorithms to produce a point cloud 3D map of the entire surface, using a single tip.

All inspection data can be shared, stored and managed as the new videoprobe also features Menu Directed Inspection (MDI) and remote collaboration functionality, eliminating the need for note-taking. This combination of features enables the new probe to reduce typical engine inspection by more than two hours, with the assurance that the probability of detection (POD) is greatly increased.

Computed tomography (CT) was confined to the laboratory for many years, but has now emerged as a production floor tool, for example in blade or additive part inspection. The latest developments have seen the introduction of the v|tome|x c HS, which uses cone beam technology instead of a fan beam. This has been made possible because of GE's scatter|correct technology, a hardware and software combination that automatically removes the majority of unavoidable cone beam scatter artifacts from the CT volume. This provides image quality similar to fan beam scanning, but at imaging speeds that are up to 100 times faster. For instance, high-pressure turbine blades can be scanned in less than five minutes.

Another innovation incorporated in the v|tome|x c HS is a proprietary family of flat panel x-ray detectors, which combine 100µm pixel size with a unique photodiode design, improving efficiency and sensitivity by up to ten times compared with conventional detectors and allowing twice the resolution without impacting on cycle time. Furthermore, the inspection process chain can be fully automated with a component gripper mounted beneath the turntable. This enables blade manipulation from a box inside the cabinet without the need for a robot arm.



1 // The new Mentor Visual iQ inspecting an engine

2 // The v|tome|x c HS system

3 // Turbine blade inspection without (left) and with (right) scatter|correct

CT is also proving invaluable as a dimensional metrology tool. This is especially the case where complex parts like metal printed components with difficult-to-access internal surfaces need to be measured. Where conventional measuring methods fail, CT can be used to carry out nominal-actual CAD comparisons, remaining wall thickness analysis and dimensional measurements. Such CT inspection can prove invaluable on the production line to flag the necessity for tool changes or adjustments.

Long-term storage, traceable handling and communication of data are vital components of any inspection procedure. Rhythm RT from GE is a software platform that is fully DICONDE compliant, so operators are not constrained by current proprietary formats, eliminating the need for future data conversion and simplifying data integration from other NDT information sources.

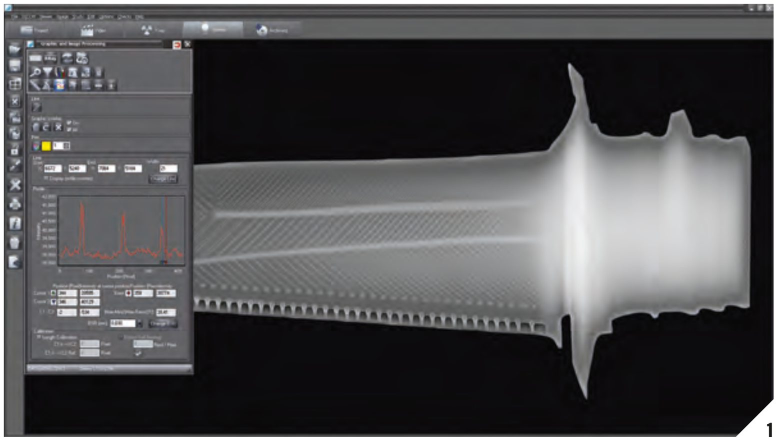
The data from tagged images gathered by Rhythm is analyzed in Rhythm Review and can be stored and archived in globally accessible company networks with Rhythm Archive. Furthermore, the tagging of each image facilitates any database searching.

Accurate, reliable, traceable and fast inspection and metrology is vital in aerospace. Developments in NDT technology are meeting these challenges, to ensure that airplanes are built as efficiently as possible and continue to fly as safely as possible. \\

FULLY AUTOMATED WELD INSPECTION OF TURBINES

2

Digitization of x-ray inspections offers engineers the opportunity to save time and money



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The digitization of x-ray technology continues to expand in the NDT inspection world. Many manual inspection tasks can now be fully automated. The main benefits are an increase in productivity and efficiency, as well as higher end-product quality.

In this regard, a leading aerospace manufacturer has been seeking improvements to its inspection workflow in order to reduce the time required to perform the detailed inspection of welded cylindrical drums used in its aircraft turbines. The use of digital image acquisition was the central way to realize these efficiency goals. After extensive preliminary assessments, the capabilities of the available digital methods such as computed radiography (CR) and digital detector array (DDA) were approved internally by the manufacturer.

The objects to be inspected are cylindrical drums built up step-wise with segments attached using electron beam welding. The drums can be up to 1m (3ft) in diameter and require a maximum of 11 weld inspections, which are up to 3.2m (10ft) in length each.

An additional requirement from the manufacturer was that the automated inspection process should be compatible with different types and sizes of drums – so a flexible and easily configurable solution was crucial. Furthermore, quality assurance required inspection to be performed after each assembly step.

With the customer requirements in mind, Dürr NDT's local dealer proposed a complete turnkey solution to the customer. This automated solution combined the technology and expertise from three international companies.

X-RAY WorX provided a micro-focus rod anode x-ray source with a customized head. Bosello designed and provided a CNC-controlled manipulation system to move the drum, with the weld centered between the x-ray tube and the DDA. The x-ray projection is carefully controlled to a specific magnification in order to reach the basic spatial resolution requested by the customer. Dürr NDT provided the software integration solution for the multi-manufacturer system, which allows the viewing and analysis of the segmented digital weld images for scrutiny by Level 2 and 3 x-ray inspectors.

The software provided by Dürr NDT uses the DICONDE (Digital Imaging and Communication in NDE) standard, which guarantees a future-proof solution for image format stability and interoperability with software and tools from different vendors.

Furthermore, a Dürr NDT HD-CR 35 CR scanner was also installed to provide ultra-high-resolution inspection capability in cases where this is required if the material thickness is below a certain value. As the inspection techniques for this application are based on the 2013 ISO 17636-2 standard ('Non-destructive testing of welds – x- and gamma-ray techniques with digital detectors'), penetrated thicknesses of 1.5mm (0.05in) and below require a minimum basic spatial resolution (BSR) of 40µm – the HD-CR 35 exceeds this requirement and is certified down to 30µm. For any resolution requirements below 30µm, the Dürr NDT DR 7 digital detector is more suitable as it can achieve a 25µm basic spatial resolution.

1 // D-Tect software for x-ray imaging and analysis

2 // Enlarged view of four weld segments with slight overlap

3 // HD-CR 35 NDT computed radiography scanner

4 // DR 7 NDT CMOS x-ray detector

This fully automated solution has been in operation for over four years and has successfully reduced the inspection burden associated with examining numerous large welds of a single complex part – the time now associated with examining 11 welds has dropped from the length of an eight-hour shift to just one-and-a-half hours.

With this end-to-end solution, aerospace turbine manufacturers can implement a digital x-ray inspection process that offers full data management and integration using industry standards.

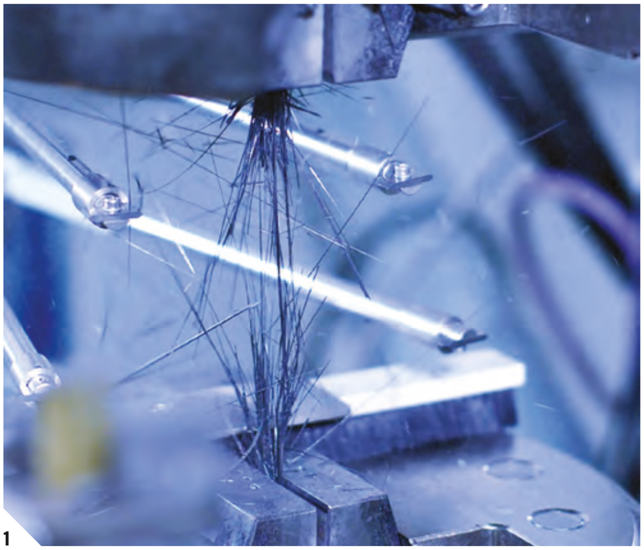
Any inspection workflow where conventional x-ray film is used to perform weld inspection during the manufacturing process can benefit from huge time and labor savings by using a fully automated solution. An additional benefit is the seamless digitization of the inspection data. This digitization enables further analysis for part optimization and future development purposes. \\

3

4

INTEGRATED AEROSPACE PROTECTION

The role of the traditional aerospace inspection service provider is evolving



1 // Destructive testing services performed in a MISTRAS lab in Germany

2 // Finishing services performed at a MISTRAS lab in the USA

When it comes to the typical aerospace manufacturing chain, adhering to strict schedules is of the utmost importance. But outsourcing inspection, testing, machining and finishing operations to multiple vendors can lead to delays that impact every step of the process.

Enter the fix: MISTRAS Group, a leading, global OneSource provider of asset protection solutions.

As a complete asset protection solutions provider, MISTRAS can provide high-quality solutions throughout aerospace manufacturers' production cycles and their assets' operational and recurring maintenance phases. Performing quality assurance and quality control for aerospace components and composite materials, MISTRAS simplifies aerospace production logistics by performing multiple services at convenient locations, helping to ensure production remains on-time and on budget.

Traditionally, the role of aerospace inspection providers has been confined to performing non-destructive inspection (NDI) services on pre- and post-forged components. The same company often inspects the same batch of components at various points throughout the production process. But with the current backlog of engines that need to be built, the need to optimize production cycles is greater now than ever before. The MISTRAS OneSource approach to aerospace protection provides a solution: a global, multidisciplined lab network capable of performing multiple services throughout the production process.

MISTRAS is evolving the role that an inspection partner can play. The company's lab network provides pre-machining, finishing, and destructive testing (DT) services – in addition to ultrasonic testing (UT), penetrant testing (PT), magnetic particle testing (MT), and other NDI solutions, helping its clients to keep up with the demands for faster turnaround times while maintaining high levels of quality.

Integrated aerospace protection provides many benefits for aerospace manufacturers, primarily in regard to optimizing production cycle logistics. For example, since many parts may be too rough from the initial forging process to perform UT on, they may need to be polished prior to inspection. Traditional NDI service providers often have to send these parts away for polishing and bring them back for inspection, creating multiweek lead times. With MISTRAS's extended laboratory network, which is capable of performing polishing and NDI services, these times are significantly reduced.

Centralizing to a minimal amount of service providers may not only enhance time efficiencies, but may also enhance inspection and testing quality. For example, macro etch and fluorescent penetrant inspection (FPI) are common testing and inspection processes for aerospace components, but are often performed by separate providers. This can cause extended delays in between the etching and inspection processes. As FPI is most effective when performed immediately following macro etch, these delays potentially increase the chances of not detecting manufacturing flaws and wear-related defects that can affect safe operations.

Through its manufacturing division, MISTRAS develops technology that its laboratories use to increase inspection and testing accuracy and productivity, by enabling robotic equipment to autonomously conduct inspections while technicians focus on higher-value tasks. These automated inspection technologies significantly reduce human error and inspection times compared with traditional techniques.

Additional inspection and maintenance will be needed once components have been operating in high-stress conditions. In addition to expanding the role that traditional NDI service providers play during the aerospace production cycle, MISTRAS partners with its clients to provide field inspection services and offers a full range of ultrasonic testing and acoustic emission inspection systems. This enables the operators to discover cracks, flaws, delamination and other discontinuities in new and aging aerospace components, with technical support from the same company that initially worked on the components. \\

PRECISE, REPRODUCIBLE AND FUTURE-PROOF

Test chambers that combine climatic and vibration testing can precisely simulate extreme conditions for aerospace components

// The ShakeEvent environmental test chambers are able to simulate dynamic processes as well as thermal loads

The ShakeEvent test chambers from Weiss Technik enable the precise simulation of dynamic processes in combination with thermal-climatic loads acting on components and devices.

The chambers are an important tool for research, development and quality-control departments in the aerospace sector. They can test components that are exposed to intense vibrational forces during real-life operation and at the same time undergo extremely rapid temperature changes in very different climates. They also enable the stress limits of such components to be investigated to ensure safe flying operations.

The ShakeEvent series has been redeveloped recently with the main aim of ensuring they produce reliable, precise and reproducible test results. Just as important has been the inclusion of a modern user interface and a modular device structure that makes ShakeEvent suitable for use with many vibration systems. It can be used to fulfill numerous testing standards and to carry out long-term tests.

Weiss Technik has optimized the airflow and temperature distribution in all the new ShakeEvent models. The air to be tempered is drawn off at the lower end of the test space, passed through heat exchangers and heater coils, and blown in again from the top. This way, the test specimen is fully surrounded and evenly reconditioned by the tempered air. This also works in shaker mode. Due to the powerful air-recirculating fans, the shaker has only a minor impact on the reconditioning of the test space.

The ShakeEvent vibration test chamber's user interface has been redesigned with enhanced usability and connectivity in mind. The latest web-based interface, which is called WEBSeason, can be used to program, control and monitor tests. In addition, it enables the control of the device at any time and anywhere, and can be used on a tablet or smartphone. Language and units can be set to suit the user and the settings can be saved.

WEBSeason has already been successfully implemented in other Weiss Technik test chambers, such as ClimeEvent and TempEvent.

The ShakeEvent test chamber can be used for a wide range of tests. Floor elements can be replaced manually, while its adapted seals ensure an airtight connection. With these various floor elements, tests in vertical and horizontal excitation directions, as well as with a closed floor element, can be performed.

For horizontal tests, the floor has a sliding table with a rectangular duct, off-center of the test space floor and heated all around. Vertical tests are possible with a head extender, direct installation or head expander. For vertical vibration, the floor comes with a round or square port, centered in the test space floor and also heated all around. The closed floor element is designed without a port. In this way, ShakeEvent can be extended to a ClimeEvent test chamber for even more extensive testing.

// The test chambers can be adjusted and customized to run a variety of tests

Other customization options include an electric height adjustment system for the test space, reaching up to 2.2m (7ft) to test extra-tall test specimens. A mobile test chamber can be designed by tracks combined in 1.5m or 2m (5ft or 6ft) grid lengths – left and right, as well as backward and forward.

With the redesign of the Shake Event series, Weiss Technik also took into consideration the EU's current F-gas regulations. According to these regulations, refrigerants with a high global warming potential (GWP) used in climate chambers need to be replaced by less harmful variants. Therefore, in all ShakeEvent vibration test chambers, Weiss Technik uses the new eco-friendly R449A refrigerant. Its GWP value of just 1,397 ensures the safe use of the chambers and the refrigerant will not have to be replaced. \\

WIND TUNNEL TESTS FOR MARCO POLO CLASS CAPSULE

A study of the re-entry process of rocket launcher stages offered an opportunity for one of Europe's leading wind tunnel operators to show its expertise

1

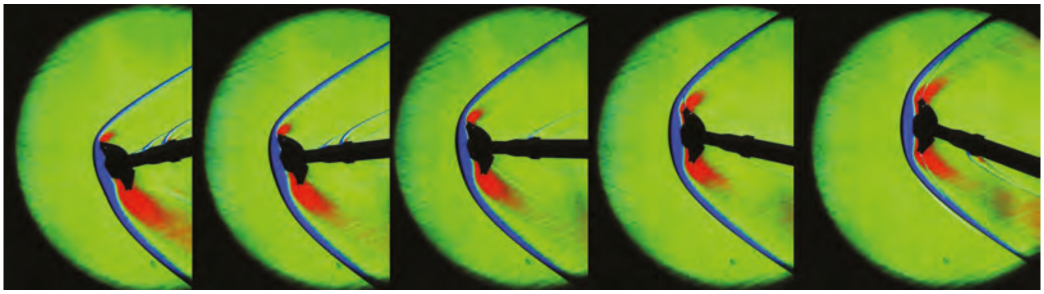
Romania's National Institute for Aerospace Research, Elie Carafoli in Bucharest, operates a 1.2 x 1.2m (4 x 4ft) supersonic wind tunnel. The tunnel is a blowdown type, with a high level of performance and a good flow quality. Supporting the operation of the wind tunnel is a team of experts who have carried out nearly 150 test programs and over 9,000 test runs for national and international clients over the past 40 years.

The tunnel is a pressurized facility capable of extremely high Reynolds numbers exceeding 100,000,000 per meter (31,000,000 per foot) chord. The facility may operate from low subsonic compressible regimes up to Mach 3.5, using solid walls and interchangeable porous test sections. The transonic tests at continuously varying Mach numbers between 0.5 and 1.4 are carried out in the transonic test section, which has variable porosity walls with 60° inclined perforations, while subsonic and supersonic tests from Mach 1.4 up to 3.5 are carried out in the solid wall test section downstream of the flexible nozzle.

The recent Demise Observation Capsule (DOC) project aimed to enable initial developments aimed to help INCAS prepare for the ESA's Future Launchers Preparatory Programme (FLPP).

DOC was focused on acquiring aerodynamic loads on a Marco Polo-like capsule, for a wide range of angles of attack (25° to 180°) and Mach numbers from 0.3 to 3.5. The scale of the model was selected after a series of CFD analyses was performed on the Marco Polo shape to check the blockage and load estimation. The CFD analysis is based on in-house code that uses a series of high-order finite volume schemes to simulate flows from the incompressible to the hypersonic, in laminar, fully turbulent or laminar-turbulent transition conditions. For the meshing strategy the newly implemented overset (chimera) mesh that is now available for most of our solvers, turbulence models and numerical schemes was used.

The turbulence modeling for steady and unsteady cases is based on the turbulence model family of k-omega SST (shear stress transport), the industry standard due to its accuracy and robustness in predicting wall-bounded turbulent flow. However, for unsteady cases where there are large separations in the flow, it is arguable that URANS (unsteady Reynolds averaged Navier-Stokes) modeling based on the k-omega SST fails to predict the broadband turbulence spectrum and becomes too diffusive for the transport of vortex structures. This shortcoming can be alleviated through the use of hybrid RANS-LES (Reynolds averaged Navier-Stokes large eddy simulation) models based on the k-omega SST.



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1 // Schlieren visualization versus CFD. Left is wind tunnel testing at Mach 2.5; right is CFD at Mach 2

2 // Schlieren visualization for the Demise Observation Capsule model at Mach 2.5 and angles of attack of 145°, 155°, 160°, 170° and 180°

During the wind tunnel testing (WTT) campaign, a series of four models were made. The four models were chosen to cover the whole range of angles of attack that the DOC capsule may encounter during flight, without the cases that had already been tested in similar developments in Europe. For each model, a custom-made adaptor between the balance and the capsule was designed, manufactured and used.

The WTT campaign was completed and the data extracted was corrected by means of CFD for support (sting) and Reynolds effects. The CFD was validated from raw WTT data and then used in corrections. The corrected WTT data matched data available in the literature and can be a starting point for future development in this area.

It was a challenge to cover the wide range of angles of attack in the WTT and a compromise was found in using CFD to correct for the sting interference. Simulations were performed to calculate aerodynamic coefficients in the supersonic regime, which are used as input for the trajectory computations that require the aerodynamic drag coefficient, lift coefficient and pitching moment coefficient and also to complement the aerodynamic database of Marco Polo class capsules with aerodynamic coefficients for angles of attack higher than 25°. \\

BREATHING SPACE

The reliability of components such as pressure transmitters is tested to extremes within the International Space Station's vital oxygen recycling unit

The HTV supply vessel containing the ACLS (Advanced Closed Loop System) module for the International Space Station (ISS) was launched on September 22, 2018, by a Japanese H-IIB rocket. The ACLS 'recycles' CO_2 from the air in the spacecraft and generates fresh oxygen for the crew by means of electrolysis.

Keller für Druckmesstechnik has developed and manufactured highly reliable absolute and differential pressure transmitters to regulate these processes.

The International Space Station orbits the Earth at some 400km (248 miles)above its surface. As barely any oxygen is present at this altitude, it must either be supplied from the ground or generated on board the ISS. Bringing oxygen to outer space is expensive, with transportation costs for a 1kg (2.2 lb) payload coming in at around €33,000 (US$37,000). It is therefore a good idea to try to process the air exhaled by the astronauts in order to generate oxygen that can be inhaled again.

Airbus developed the ACLS on behalf of the European Space Agency. In the ACLS cycle, oxygen is generated by the carbon dioxide from the cabin air being turned into methane and water using hydrogen obtained from splitting water molecules and adding energy. The electrolysis process extracts breathable oxygen from the water. According to Airbus, the system is designed for a crew of three astronauts and saves 450kg (1,000 lb) of additional water load per year. At full performance, each day the ACLS extracts 3kg (6.6 lb) of CO_2, supplies 2.5kg (5.5 lb) of oxygen, and produces 1.2kg (2.6 lb) of water.

The ACLS requires extremely reliable components to ensure that these processes run safely. Swiss pressure measurement technology manufacturer Keller, based in Winterthur, won the contract to develop the pressure measurement technology.

1 // The International Space Station uses pressure measurement technology for applications run under extreme conditions

2 // Rocket H-IIB before launch at Tanegashima Space Center, JAXA Japan Aerospace Exploration Agency

3 // Launch rocket H-IIB carrying a payload for the International Space Station on September 22, 2018

The project posed some extreme challenges, because at 400km above the earth's surface, components cannot be replaced within a reasonable period of time if they fail.

Keller's contribution to this mission comes in the format of absolute and differential pressure transmitters that work in the range of 50mbar to 20 bar at 0-110°C (32-230°F).

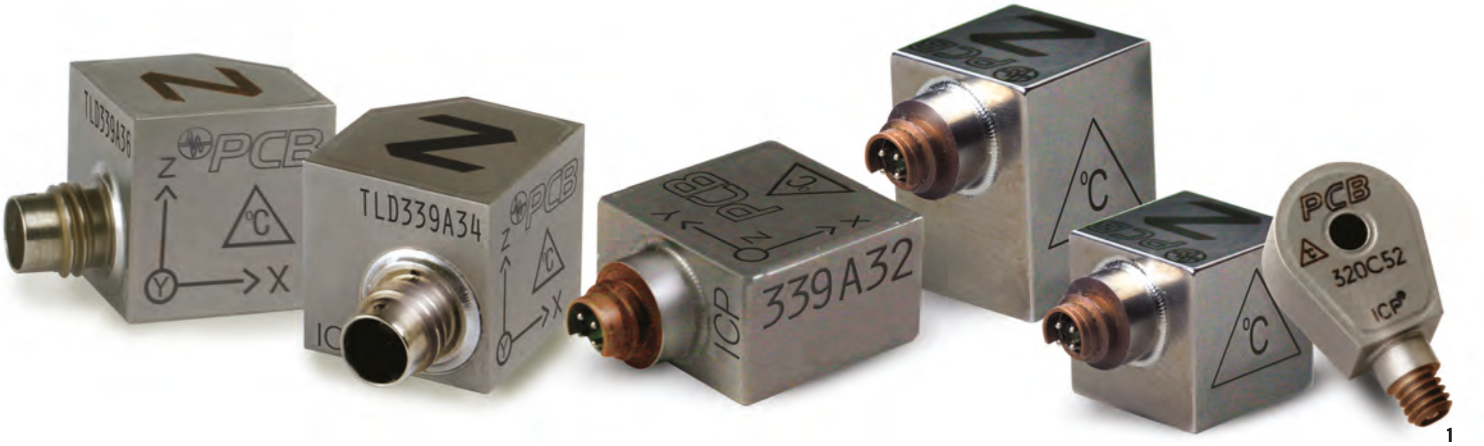
"With its pressure transmitters that can undertake the most varied tasks in numerous types of aircraft and contribute to the security of all manner of systems thanks to their reliability, Keller has proved that the demands imposed on sensor lifetimes in actual operations are many times greater than they need to be," says Jürg Dobler, managing director of Keller für Druckmesstechnik.

"Needless to say, our initial sensor projects for the aerospace industry incorporate our many years of experience in aviation, but of course also in industrial applications.

"In addition, we are naturally expecting our findings from the aerospace projects to feed back into our broad range of pressure sensors at Keller," explains Dr Günther Kaden, consultant for aerospace sensors at Keller. \\

LOW THERMAL COEFFICIENT ACCELEROMETERS

When testing involves extreme temperatures and temperature swings, accelerometers must be thermally stable to guarantee reliable results



1

Many aerospace testing environments require specialized accelerometers that are designed to withstand wide temperature variations while maintaining a stable vibration output.

Typical vibration measurement applications for accelerometers include component testing in environmental chambers, on engines and during flight testing.

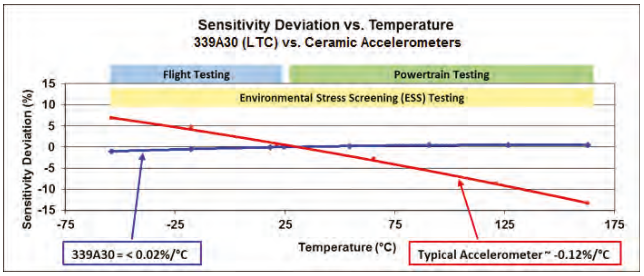
When conducting these live tests, measurement data is collected at the extreme temperatures found in winter, desert and high-altitude conditions. In addition to extreme temperatures, these environments often have very high random vibration levels that can result in high frequency overload of the accelerometer.

To help solve these common measurement problems, PCB Piezotronics (PCB) developed a Low Thermal Coefficient (LTC) series of accelerometers that have significant advantages in applications subjected to drastic temperature swings.

These accelerometers feature thermally stable construction and wide operating temperature ranges. The specification of interest, temperature coefficient of sensitivity, is the percentage change in sensitivity per degree change in temperature, measured as %/°C. The design of these accelerometers results in a very low change in their sensitivity during temperature gradients.

During use on a live test, accelerometers can experience thermal expansion or contraction of their internal parts that apply a preload to the sensing element.

This preload results in some level of signal change on the test article. Figure 2 illustrates how temperature can affect the sensitivity deviation of piezoelectric accelerometers. The data shows how an LTC accelerometer such



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as Model 339A30 is much more stable across a wide temperature range, with a temperature coefficient less than 0.02%/°C compared with ceramic designs.

Random vibration testing often results in high-frequency mechanical inputs, caused by metal-to-metal impacts on the test article. These impacts are not part of the vibration measurement of interest, but can cause accelerometers to enter into an overload recovery state (saturation), during which time acquisition of meaningful data is not possible. Amplifier saturation occurs when an accelerometer is excited outside its recommended measurement range when approaching its resonant frequency.

To alleviate the effects of these high-frequency overloads, a low pass filter has been incorporated into LTC accelerometers to help ensure accurate data in the frequency range of interest and to minimize the possibility of amplifier saturation. The low pass filter passes signals with frequencies lower than a specified cut-off frequency and attenuates signals with frequencies that are above the cut-off value.

PCB's LTC accelerometers feature sensitivities from 1mV/g to 50mV/g, frequency range between 1Hz and 10kHz, and operating temperatures of between -73°C and 163°C (-99°F to 325°F). The accelerometers are hermetically sealed in titanium housings in a number of convenient mounting configurations such as stud, adhesive and through-hole versions (Figure 2), making it easy to get the exact type of mounting desired for any vibration application. \\

1 // PCB's Low Temperature Coefficient accelerometers

2 // How temperature can affect the sensitivity deviation of piezoelectric accelerometers

HIGH-RELIABILITY DATA RECORDING

Data recorders should have reliable failsafes and backups as well as multichannel capabilities and multiple amplifier variations for important tests

1

The LX-1000 series of instrument data recorders is designed to provide multichannel and multiple amplifier variation recording solutions for the testing and monitoring requirements of aerospace, defense and industrial-acoustics/vibration-based applications. TEAC has been providing data recorders for the aerospace testing market since the reel-to-reel tape era and the company continues to develop and provide machines that use the latest and most reliable technologies.

In the past, PC storage capacities were small and data transfer rates were slow. In aerospace testing many signals are recorded at high sampling rates, but earlier computers did not have a high enough performance level to record such volumes of data. Instrument data recorders were therefore the main data acquisition system and the files created were analyzed on a computer after the testing was completed. Now the ubiquitous PC is the front end of the acquisition system, analyzing the data in real time, while the instrumentation data recorder has become the important backup system.

The TEAC LX-1000 series has features that enable it to provide reliable data recording with protection from catastrophic data loss, including a wide dynamic range and high resolution. A unit can have 64 channels and synchronization between four units enables 256 channels to be recorded. The LX-1000 offers a longer recording time than is possible with tape recorder technologies.

Moreover, it's possible to use, add and change multiple amplifier variations, such as PA (DC-switchable), AO, strain, thermocouple amplifier and CAN. Additionally the LX-1000 has pulse input and GPS input.

Connection to sensors is eased by support for the transducer electronic data sheet (TEDS) standard, while data is stored on a reliable recording medium using a large-capacity removable SD card (SDXC/SDHC). If you need video recording too, it's also possible in synchronization with TEAC visual data recorder VR-24.

To ensure failsafe recording, the LX-1000 closes the data file after every predetermined time interval while recording. Even if a power outage occurs, the recorded data is saved from the minute before the power loss and is available for playback after the event.

1 // Remote control unit

2 // The LX-1000 main unit

3 // 48-channel model with PA, AO, strain, thermocouple amplifier and CAN

TEAC data recorders have been used for developing Japanese rocket engines. Vibration testing and analysis is one of the most important parts of development. If levels exceed certain thresholds, vibrations might lead to decreased engine efficiency and damage. The test data collected can increase the reliability and durability of components. But they have to be performed under the same conditions as encountered in flight, such as extremely low temperatures, high nozzle pressures and high rotation forces when the rocket is launched. The considerable time and cost that is involved in this kind of testing requires dependable and secure data recording.

2

Turbomachinery and jet engine makers use the data recorders when testing for rotational balance to lessen shaft vibration, and they are also used during inspections.

These applications employ TEAC data recorders with a PC front-end system running real-time analysis software. The recorded raw data is transferred to a PC via gigabit Ethernet in real time and to the LX-1000 to ensure the safe backup of data.

The forthcoming LX-1000 will be released in summer 2019. \\

3

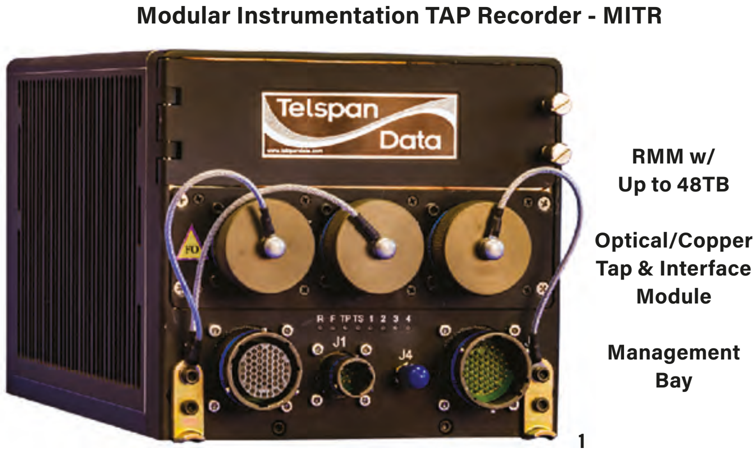
MULTIDISCIPLINED DATA RECORDER

System-on-a-chip technology has enabled the development of data recorders such as the MITR with multidisciplined architectures and major performance improvements

Traditionally recorders were single-purpose boxes that stored data in proprietary formats. The Modular Instrumentation Traffic Recorder (MITR) is a high-speed/high-capacity IRIG 106 Chapter 10 compliant recorder and publisher with a removable memory module (RMM), TAP and interface module (TIM) and management bay. MITR is suitable for recording everything from Ethernet DAU's (data acquisition units), to avionics databuses, radar, high-speed video and data from any other LRUs (line replaceable units).

MITR's management bay extends the capability beyond that of a traditional recorder with an integrated layer 2/3 managed Ethernet switch providing four external ports and 11 internal ports on the switched data fabric (SDF). A transformer or optic-coupled MIL-STD-1553 provides remote terminal, bus-monitor operations or 1553 recording. A bidirectional PCM (pulse-code modulation) link provides a gateway between the recorder and the ground telemetry station by encoding/decoding published IRIG (Inter-Range Instrumentation Group) 106 Chapter 10 or Ethernet traffic. The PCM link supports the IRIG 106 Chapter 4 and 7 formats as well as HDLC (high-level datalink control), an encapsulation method for serial links.

Providing an interface to cockpit control panels, the management bay also includes multiple programmable discrete I/O for event, status and control (enable, record, fault, erase, declassify, etc), in accordance with IRIG 106 Chapter 10. An internal GPS receiver is provided to seed the internal hardware clocks. One to four hardware-based IEEE-1588 Precision Time Protocol time engines with Grand Master capability can be configured for master/slave, ordinary, boundary or transparent. The IRIG time code generator produces IRIG-A/B/G time for recording/publishing, produces



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1 // The MITR has a multidisciplined architecture to enable it to be adapted to different test environments

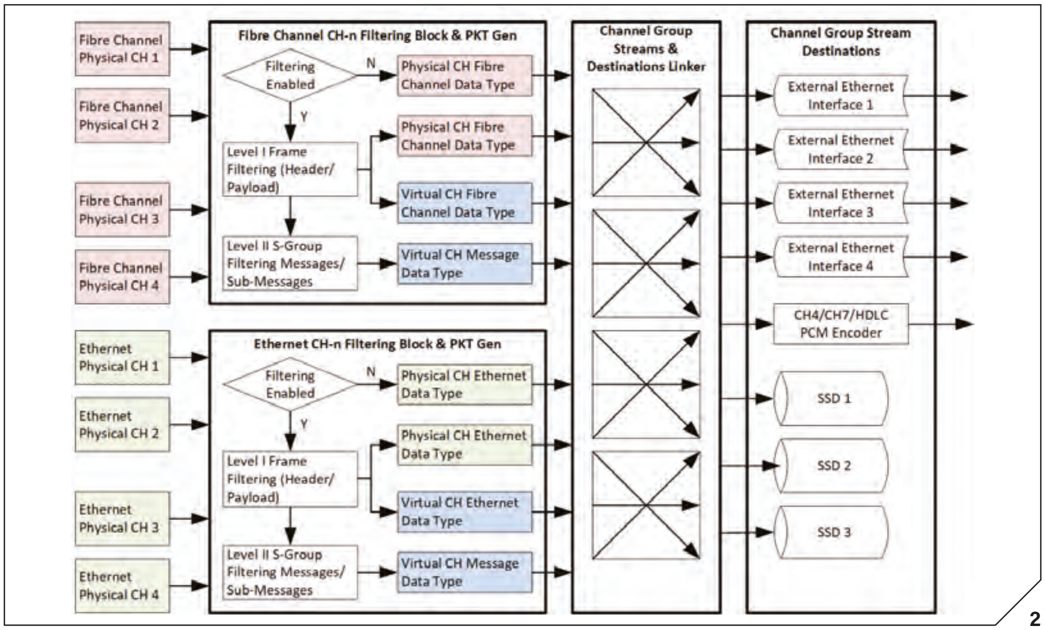
2 // Diagram showing the MITR's channels, filtering, streams and destinations

IRIG-A/B/G external time outputs and provides a 1PPS Output.

The RMM (Removable Memory Module) consists of up to three drives in a single carrier. With data security and throughput in mind, three independent data paths (from inputs to disks) allow individual data channels to be written to individual drives. Recording bandwidths from 1.5GBps (SATA) to 9GBps (NVMe) and up to 48TB, supports recording from any source. Each carrier includes a built-in power and a 10GE download port eliminating the need for expensive, standalone debrief stations.

Since the MITR is often installed and isn't always easily accessible, the operator is able to load firmware (TIM protocol configuration) as well as MITR's setup/configuration files directly on the RMM. Using a TMATS (Telemetry Attributes Transfer Standard) setup record, the operator defines the TIM type and channels, number of recording drives and configuration of external Ethernet and discrete interfaces for command/control. Individual channels, filtering policies (inclusive and exclusive), channel groups (streams), and stream destinations (drives and publishing interfaces) are also defined via TMATS. Once the RMM is reinstalled, MITR is setup accordingly.

The TAP and Interface Module, (TIM), is available with optical and/or copper



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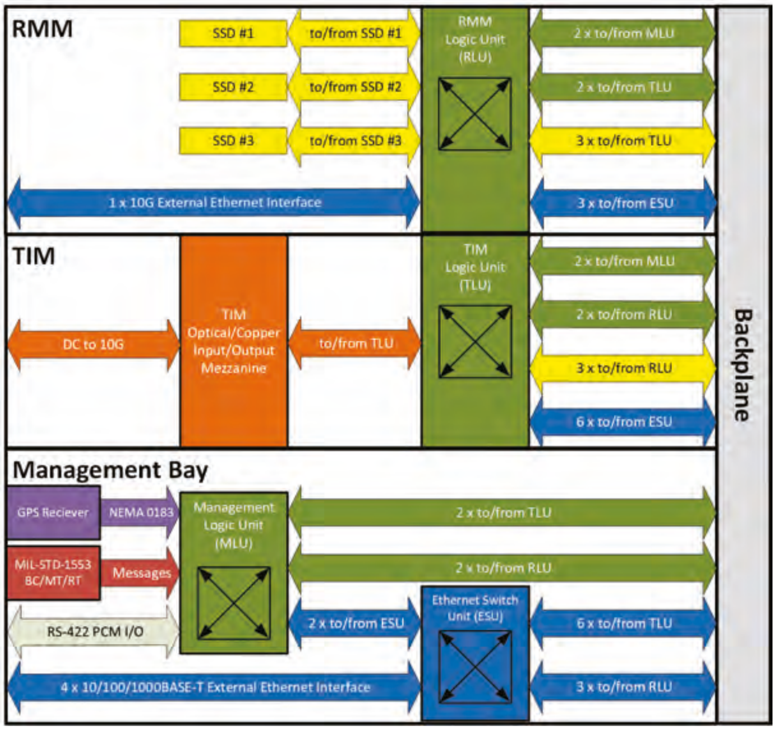

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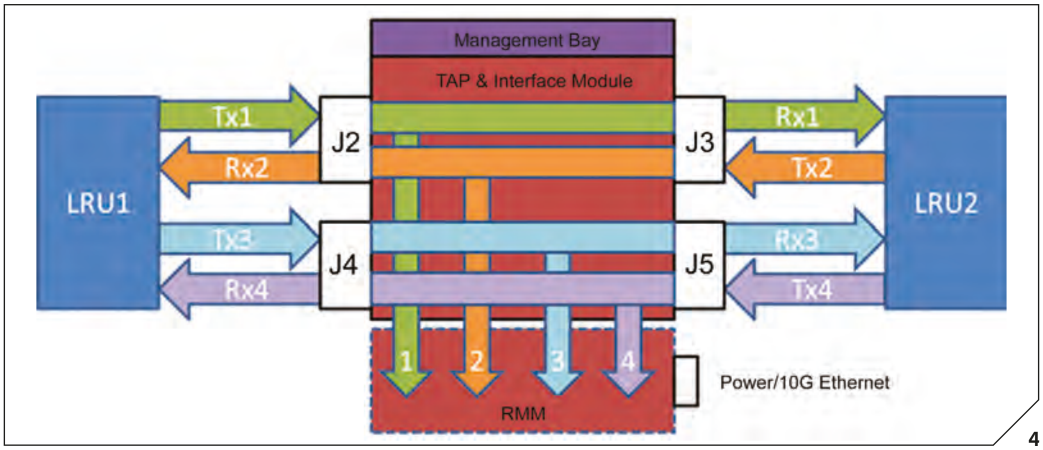

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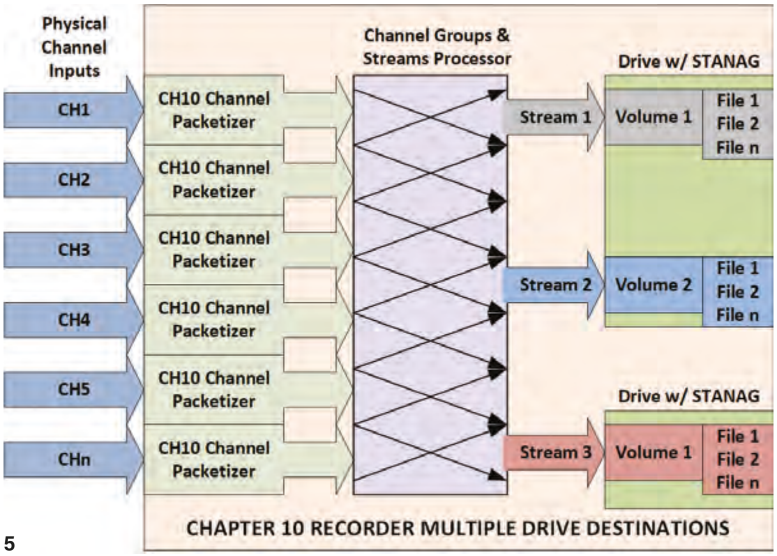

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3 // The MITR's switch data fabric provides 230Gbps of bandwidth

4 // Diagram of Optical Tap and Interface Module set up with two LRUs

5 // Diagram showing the MITR set up with multiple drive destinations

interfaces. The optical TIM provides up to 12 channels of DC-10G protocol independent transceivers as an in-line TAP or up to 24 channels of receive end-points. The copper TIM is available with 8 channels of 1G copper Fiber Channel or up to 12 channels of 10/100/1000BASE-T.

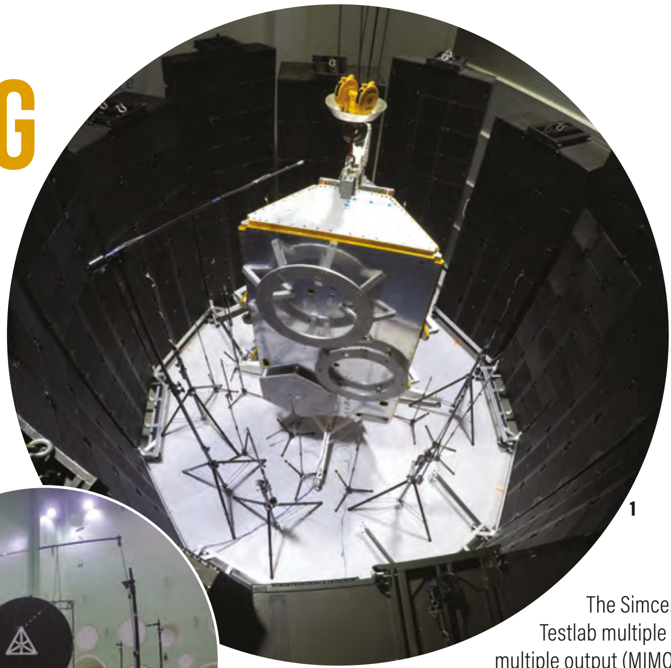
The signaling protocols reside within the logic fabric for Ethernet, optical/copper Fiber Channel, Firewire, Serial Front Panel Data Port (sFPDP) and several others. Since the transceivers are protocol independent, the TIM channels can be configured for all of one protocol or mixed and matched. This mixing of protocols and of physical channels offers the greatest flexibility to adapt to many different FTI (Flight Test Instrumentation) and avionics bus configurations.

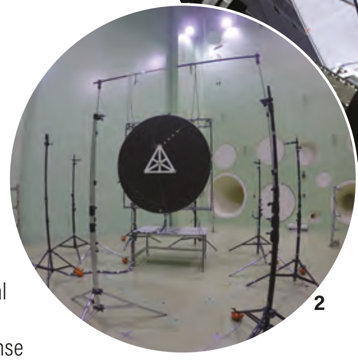
MITR contains a logic-based Switched Data Fabric (SDF) between the TIM, management bay and Removable Memory Module (RMM). The high-speed SDF currently provides 230Gbps of bandwidth across its data lanes which allows line speed filtering, processing, recording and publishing of incoming high-speed signal data. Inclusive/exclusive filtering setup consists of conditional frame level, Upper Protocol Level (UPL), and data content level from all physical channels as well as multiple virtual channels.

User programmed channel groups can consist of physical channels from the TIM and/or Ethernet switch interfaces along with virtual channels derived from the physical inputs. The channel groups are then linked to destinations across the fabric to include individual or all RMM drives, IRIG 106 Chapter 10 data streaming publish ports in the Ethernet switch and PCM encoded serial outputs. This allows both "truth" data to be recorded and filtered "quick-look" data to be recorded and/or simultaneously published. \\

DEDICATED TESTING SOLUTIONS FOR END USERS

Safe environmental testing solutions that integrate years of expertise and end-user feedback are critical in aerospace testing





Space mission success must not be threatened by spacecraft design and workmanship anomalies. It is important to know how to increase confidence in the survivability of spacecraft during launch without damaging the flight hardware during testing and without overrunning the verification program cost and schedule.

Simcenter Testlab's solutions consolidate years of expertise and end-user feedback from leading companies in the space industry that share these same objectives.

Over-testing of the various dynamic environmental tests generates a number of risks for hardware. Simcenter Testlab's space industry end users are extremely critical of the reliability of control applications for the qualification of their hardware. They use intensive internal validation procedures before upgrading to a new software release, which will provide increased value to their facilities. Such procedures are closely followed by Siemens Industry Software's experts, ensuring that the end user can safely and fully exploit the functionality of our control software.

The primary goal of vibration testing is to expose the space hardware to a low-frequency environment and verify that it performs as expected after being exposed to this dynamic input. Simcenter Testlab Sine Control is a closed-loop control solution for swept sine vibration tests. Together with Simcenter SCADAS hardware, it provides an integrated feature for force and moment limiting. Simcenter Testlab Sine Control can realistically notch spacecraft resonances and limit responses to protect the spacecraft structure and hardware from exceeding design strength capabilities.

Simcenter Testlab Random Control provides all the features necessary to define and control a random vibration excitation that matches a predefined power spectral density profile. Among several safety features, this solution offers response limiting and sigma limiting. The implementation of a phase optimization algorithm for sigma limiting – with no amplitude distortion and out-of-band noise – is an added value, compared with traditional sigma clipping algorithms.

Shock qualification consists of assessing the shock control capability of the space hardware to withstand an induced shock environment. Simcenter Testlab Shock Control is a time-domain control solution that can use a previously measured pulse as reference waveform, a classical waveform such as a half-sine pulse, or the result of a synthesis for control. Simcenter Testlab Shock Control offers a shock response spectrum (SRS) limiting algorithm for test specimen protection. It also offers online SRS calculation with a wide range of post-test data analysis capabilities.

Environmental acoustic testing methods make use of reverberant or direct fields to replicate acoustic loading. Simcenter Testlab Acoustic Control is a closed-loop control solution for the operation of reverberant rooms. A robust PI control algorithm ensures spatial uniformity of sound pressure level in $^1/_3$ or full octave bands. To avoid over-testing, three layers of safety checks are integrated: at individual microphones in octave bands, at overall sound pressure levels, and in terms of structural responses through user-defined abort profiles.

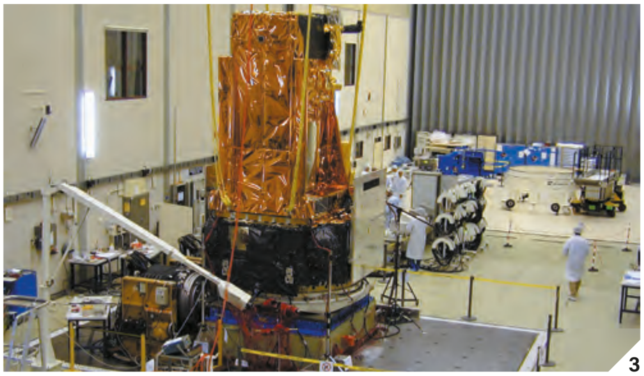
The Simcenter Testlab multiple input, multiple output (MIMO) random control for direct field acoustic tests is a closed-loop control solution to replicate acoustic loads with loudspeakers. Adaptive MIMO control ensures a safe, time- and energy-efficient workflow. Furthermore, narrow-band operation enables line-by-line abort checking with tolerances that are defined by the user, limiting for acoustic and vibration responses, and overload prediction for the signals driving the loudspeakers.

Simcenter Testlab Space Release is the outcome of a customer-centric philosophy. The software package integrates the latest features with updated feedback, as well as the legacy from the leading companies in the aerospace sector. Its periodic release is a continuous commitment to our customers, striving for safety and reliability. \\

1 // Direct field acoustic excitation can be used for satellite and components qualification *(Photo: Thales Alenia Space)*

2 // Vibration testing safely exposes flight hardware to the dynamic launch environment *(Photo: Thales Alenia Space)*

3 // Acoustic testing in reverberant rooms is safe, reliable and accurate *(Photo: ESA)*



DATA FUSION AND SIGNAL CONTROL

A test setup with multiple cameras and data streams demands an integrated and advanced solution

1 // Phantom cameras can integrate with data acquisition modules to digitize and synchronize analog input signals with images

When designing a test setup for high-speed aerospace applications, data fusion and signal control are key elements to consider. Conventionally, various data-streams emanate from one experiment – for example, frames from cameras, voltages from sensors, timecodes from function generators – and are collected and analyzed on separate platforms.

As a result, it requires that all the data is later combined and synchronized, and only then can it be properly analyzed. This process is time-consuming, often complicated and error prone. For these reasons, Vision Research's Phantom cameras enable users to achieve data fusion and signal control in the freely downloadable Phantom Camera Control (PCC) software.

To achieve data fusion and signal control, Phantom cameras integrate with National Instruments' (NI) USB data acquisition modules to digitize and synchronize analog input signals with images captured by a Phantom camera. Users can choose to measure a single datapoint per frame, or increase the sampling frequency of the DAQ to collect multiple datapoints per frame. This method serves as an excellent means for synchronizing any signal from your experimental system and/or camera, including the trigger signal, f-sync, strobe, and/or any imaginable analog inputs from sensors embedded in the experimental system.

As a simple example, synchronizing light sources such as pulse lasers and/or flash lamps with microsecond precision traditionally requires an oscilloscope. Instead, all signals in the system can be fed into the DAQ module, automatically synchronized with video, and then visualized in the PCC software. To demonstrate this, a single LED light was powered using the strobe-out signal (a TTL pulse train 0-5V) exiting the camera.

Naturally, a strobe-powered LED light is out of sync with the integration periods of the camera because the integration process (or light gathering for a frame, indicated by the yellow areas in graphs B & D in diagram 2) occurs when the strobe signal is low, and the LED is powered when the signal is high (+5V).

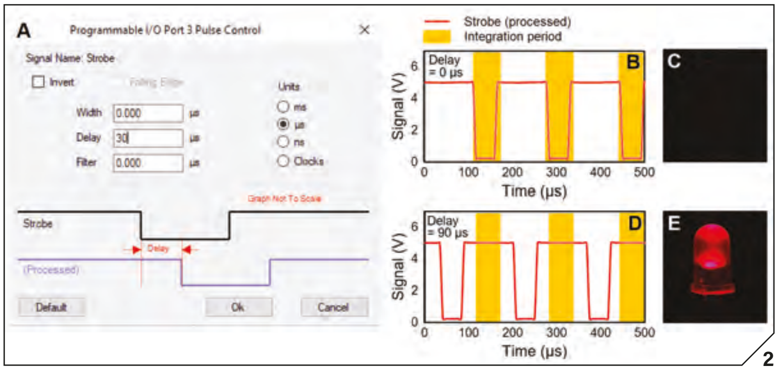
By measuring the strobe signal using the DAQ unit and using the programmable I/O of the camera (see schematic A in diagram 2), the strobe signal can be systematically delayed so that the integration period coincides with when the LED is powered on, all while being visualized in the PCC software (see schematic B-E in diagram 2). Images C and E in diagram 2 show what the camera sees when the LED is out of and in sync with the integration periods, respectively.

In addition to data fusion, Phantom cameras can automatically trigger and/or send external signals based on motion detected between frames. This feature is referred to as Image-based Auto Trigger, or IBAT, and is based on coding of a field programmable gate array (FPGA) integrated directly into the image sensor. The FPGA can process a frame, perform a logic step such as a frame comparison, and then trigger the camera, provided the user-defined criteria are satisfied – all within the time it takes to collect a subsequent frame.

Furthermore, the Phantom camera also provides an output signal when IBAT-criteria are satisfied, thus permitting the opportunity to trigger other devices.

Some operators are using multiple Phantoms, aligned orthogonally along x, y and z axes, and all focused to a single point. When the airborne object moves through the focal point of all three cameras, IBAT triggers all three cameras simultaneously.

Phantom cameras not only provide high-quality image data for high-speed aerospace applications, but also serve as a complete solution for applications involving multiple data streams that demand highly advanced data fusion and signal control modalities. \\



2 // Visualization of an LED light powered using the strobe-out signal (a TTL pulse train 0V to 5V) exiting the camera

WHAT'S SO SPECIAL ABOUT 5,000µW?

Most UV-A lamps on the market are set to provide 5,000µW/cm² at a distance of 38cm, but why?

The physics of light intensity follows an inverse-square law. If there's a bright lamp that's 1m (3.3ft) away and it is moved out to 2m (6.6ft), the light from the lamp won't be half as bright; it will be a quarter as bright. Going out to 3m (9.9ft) drops it down to one-ninth the original intensity. The intensity of the light also works the same way as the source moves closer to the surface. The same lamp will be four times as bright 50cm (20in) away, and 16 times as bright 25cm (10in) away. For non-destructive testing (NDT), this means that the distance to the lamp is just as important as light intensity.

The NDT industry has set a standard distance of 38cm (15in) as a benchmark to compare the light intensity of UV-A lamps in fluorescent testing. The standard distance is used to compare performance differences of available lamps.

UV-A irradiance is required to make penetrant and magnetic particle materials fluoresce, making them visible to the human eye. The more UV-A available, the brighter the fluorescence will be, but there are limits. UV-A light is defined as wavelengths between 320nm and 400nm, and visible light is defined as wavelengths between 400-760nm.

In the dark environment of an inspection booth, human vision can perceive some UV-A light. Even though fluorescence increases with increasing UV-A, there are diminishing returns as far as what is seen. Too much UV-A can overpower a fluorescent indication, which is called 'veiling glare'.

Studies on the effect of UV-A intensity on fluorescence have demonstrated that the dyes and pigments used in penetrants and magnetic particle materials can degrade with long exposure to intense irradiation. Exposure to high levels of UV-A over time will decrease the amount of fluorescent light produced – described as 'fluorescent fade'.

Maximum UV-A intensities are defined in standards to guard against both veiling glare and fluorescent fade. The details vary with industry standard, OEM and application. Many authorities permit UV-A intensities up to 10,000µW/cm², but exposure time must be limited to prevent fluorescent fade. The maximum intensity of 5,000µW/cm² according to ISO 3059 is commonly accepted as safe for extended exposures.

NDT inspectors have a standard distance of 38cm due to the way that light works and have a maximum intensity of 5,000µW/cm² due to the way human vision and fluorescence work. It is easy to use those two figures together: 5,000µW/cm² at 38cm. With so many different light sources available, that combination doesn't work in all cases.

A UV torch that delivers 5,000µW/cm² at 13cm (5in) is useful for close examination of bores and tight spaces. However, at the standard 38cm, the intensity would be less than 560µW/cm². In the same way, an overhead lamp delivering 5,000µW/cm² mounted 0.76m (2.5ft) above the inspection surface would be nearly 10,000µW/cm² at the standard distance.

1 // Working distances need to be considered when selecting a UV lamp

2 // UV torches of 5,000µW/cm² are useful for examining tight spaces

In these examples, the torch and the overhead fixture have wildly different intensities at the standard distance. When they are used as intended they are perfectly acceptable, because ISO 3059 set the maximum intensity limit of 5,000µW/cm² at the examination surface, not at a standard distance of 38cm.

Many overhead lamps are designed to meet inspection lamp specifications while mounted at a distance from examination surfaces, giving the inspector ample room to work. For example, to deliver enough UV-A to perform examinations while mounted up to 36in (0.9m) away, an overhead lamp would need to deliver 7,000µW/cm² at the standard distance of 38cm. When working to Rolls-Royce and Airbus specifications, that translates to a minimum working distance of 61cm (24in). Therefore, the working environment and mounting location need to be taken into consideration when selecting either a stationary inspection LED UV lamp for fluorescent NDT. \\

CHOOSING THE RIGHT CAMERA

High-speed cameras are one of the most useful tools in a laboratory, but what is the best approach when selecting a new one?

1

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High-speed cameras facilitate the detailed analysis of projectile flights, missile launches, combustion processes, engine performance, fuselage durability, material strength, flow/particle movement and more. They do so by providing engineers with super-slow-motion video of high-speed events.

There are several companies that manufacture high-speed cameras, so how do you decide which one to buy from and which model of camera to buy? Wichita State University's National Institute for Aviation Research (NIAR) has found success in using Photron high-speed digital cameras in its Virtual Engineering Laboratory.

Laboratory director Gerardo Olivares has four cameras in the lab, two of which are color plus two monochrome models. The lab uses high-speed cameras in a variety of testing applications, such as high-impact dynamic events. Olivares says the flexibility of the frame rate and excellent image resolution make Photron high-speed cameras ideal for their testing processes.

Recently Photron cameras were used during a drop test of an airplane fuselage. The test was done as research for the FAA, to examine the behavior of composite materials when used for main aircraft structures. In this case, the materials were a honeycomb structure covered by a carbon-fiber laminate.

The 10ft (3m) section of composite fuselage was brought into the lab and filled with appropriate ballast to simulate the 1,500 lb weight (6,800kg) of an operational fuselage. Extensive accelerometers and strain gauges were attached, with two high-speed cameras placed on either side of the test area. Two monochrome cameras were set up to record the entire width of the fuselage and two color cameras were placed on the other side, focusing primarily on the emergency exit door area. The test represented a pure vertical crash at 30ft (9m) per second.

A laser beam was used to trigger the cameras and instrumentation so that image collection would begin when the fuselage was about a foot away from impact. Set to record at 20,000fps and using the Photron camera's pre- and post-triggering feature, 25% of the images were captured prior to impact and the remaining 75% during and after impact. Using digital image correlation (DIC), researchers were able to see levels of deformation and performance of the composite materials on the fuselage.

The FAA is studying the results of the test to support future regulations on the use of composite versus metallic materials in 14 CFR PART 25 commercial aircraft.

Olivares also uses high-speed cameras for diverse tests such as airbag deployment, airline seat airbag studies for bulkhead seats, and a variety of crash test applications in research for industry and government. The camera's ability to achieve high frame rates up to 20,000fps without losing resolution makes it suitable for the lab's testing studies.

1 // Photron cameras were used to study deformation in composites in a fuselage drop test *(Image: Wichita State University)*

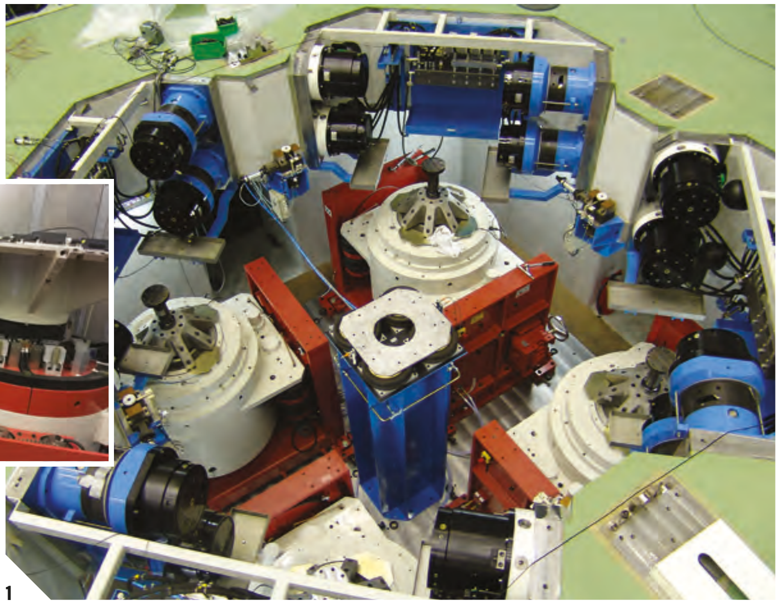
2 // Photron cameras can achieve frame rates up to 20,000fps without losing resolution

When Olivares was looking into high-speed cameras, it became apparent that a number of factors were highly important, including the frame rate, light sensitivity, minimum exposure and data offload.

Aerospace testing environments can be challenging for high-speed camera suppliers. To guarantee the successful implementation of high-speed cameras within such environments it is important to select an experienced supplier that can provide a range of highly reliable cameras and exceptional customer support. Likewise, it is essential to verify datasheet information and product claims by testing a camera in its intended environment and application before committing to buy that model. \\

KEEPING THE NOISE DOWN IN A QUAD-SHAKER SYSTEM

Engineers have improved data quality by installing a drive-signal isolator that lowered the noise floor in a shaker system



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The vibration testing market is becoming more refined. High-force tests are required to test the limits of expected performance, but as the test requirements become more stringent, the accuracy of the system as a whole must increase. There is a growing trend toward testing with very low-*g* input levels. Signal noise for such low-*g* input is defined as the system's background vibration in milligravities (*mg*), sensed by the accelerometers while there is no drive signal applied by the controller. Current background noise for a typical quad-shaker system with cable lengths of approximately 40m (131ft) has been measured at around 30-45*mg*. This means that the signal noise levels on typical quad-shaker installations are too high to align with evolving market requirements. This is not an acceptable signal-to-noise ratio.

To solve this problem, the acceleration background noise needs to be reduced without adversely affecting existing performance characteristics. In a recent project, engineers worked with a system of four Brüel & Kjær LDS V984 shakers providing a combined vertical sine thrust of 640kN. The noise reduction was achieved by installing a drive-signal isolator on the quad-shaker system. The selected isolation transformer, which has a liner a response of 5-200Hz and galvanic isolation, can reject noise by as much as 125dB. The addition of the transformer provided a reduction of ground noise present in the system or cabling, resulting in a cleaner drive signal to the amplifier and a noise reduction of approximately 54% of the original noise floor.

The isolation transformers underwent rigorous testing and characterization prior to on-site installation. The testing was performed at the vibration test system's manufacturing plant in Royston, UK. Testing was carefully monitored by engineers, and product specialists verified the expected system performance and ensured that the solution was robust and worked well under all operating conditions.

Customer measurements taken at their installation site to profile their quad-system's noise characteristics and provide a base level for referencing provided proof of concept. Their quad system of V984 shakers, before isolator installation, showed noise levels of 23.9*mg* in shaker V1, 26.5*mg* in V2, 19.3*mg* in V3 and 19.0*mg* in V4. After isolator installation, noise was reduced to 12.5*mg* in V1, 12.2*mg* in V2, 11.1*mg* in V3 and 12.2*mg* in V4. These results align with the predicted noise reduction and follow the direct improvement seen on their quad-V984 system.

The resulting background noise is historically the lowest level achieved in the customer's setup. This enables it to make more realistic, reliable and accurate predictions during self-checks for very low-level test runs and lowers the self-check levels. This improves operational flexibility in the very low-*g* excitation range for its quad-shaker system. Most importantly for the customer, the reduction of noise in its system setup provides the most important product – better data. \\

3

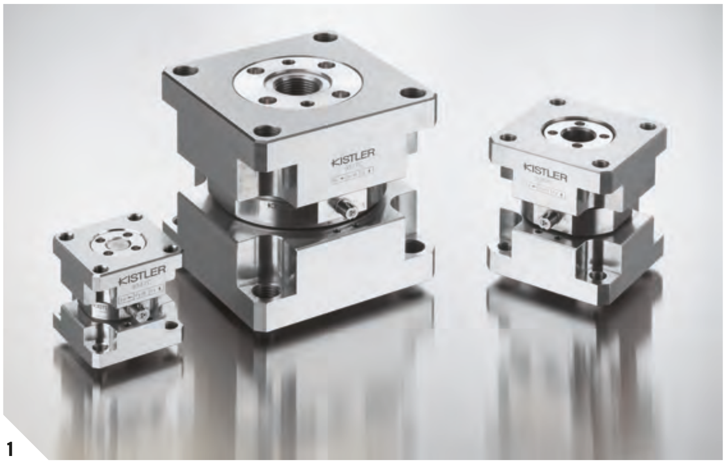
1 // The quad-shaker setup used to confirm the isolation results *(Photo: ESA/ESTEC)*

2 // Isolation testing performed at Brüel & Kjær's Royston, UK, facility prior to on-site installation

3 // A Brüel & Kjær LDS V984 Shaker used in the isolation testing

ENVIRONMENTAL VIBRATION TESTING OF SPACE PAYLOADS

Engineers ensure payloads such as satellites will not malfunction with extensive, but carefully limited, vibration testing

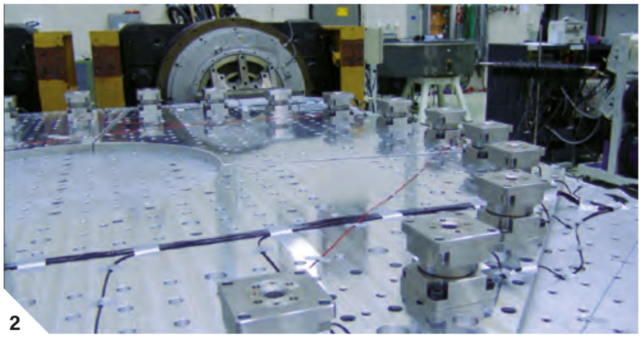


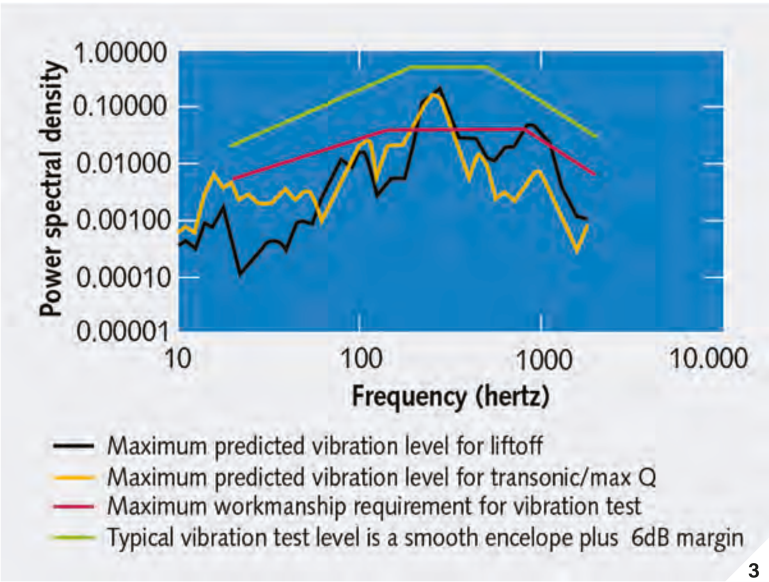
Satellites undergo a stressful journey from the launch pad until they reach their final orbit. A failure in any component may result in malfunctioning of the satellite, which is expensive and will delay the program for years. Furthermore, there is no repair service currently available if a satellite is damaged. This makes it vital for all space systems such as satellites to undergo an intensive program of prelaunch tests.

These laboratory tests include force limited vibration tests (FLVT). This type of testing, conducted at ground level, involves subjecting the satellite to all the vibrations that are likely to occur during its flight from ground to orbit. If a problem arises, corrective actions can be taken.

Vibrations are generated during the following flight phases: launch, due to acceleration and engine operation; transonic flight, when the sound barrier is broken; and near orbit, when the protection cover is removed from the launch vehicle. Each of these phases creates specific vibration spectra.

Figure 3 shows a typical spectrum of vibrations created at lift-off and during transonic flight. The light green curve depicts the test level. It is slightly above the expected levels, but should not lead to overtesting. The FLVT aims to be a realistic test that simulates real conditions. However, there is a problem. The shaker and the launch vehicle each display different dynamic behaviors – the mechanical impedance of the shaker is very high at its resonance. This may lead to overtesting at the shaker's resonance frequency. The dynamic forces acting on the test object can be far too high, so the force must be limited. This is achieved by positioning force sensors between the test object and the shaker.





1 // Types 9347C, 9367C and 9377C are very common examples of force links for FLVT

2// Shaker table set up for satellite testing

3 // Typical vibration spectrum of a launch

The force sensors limit the maximum vibration at the shaker's resonance, which is the main objective of an FLVT. The FLVT was introduced by Terry Sharton at NASA's Jet Propulsion Laboratory in 1990.

Force sensors for FLVT must be rigid and require a wide measuring range. Therefore the NASA Handbook 7004C states: "The high degree of linearity, dynamic range, rigidity, and stability of quartz make it an excellent transducer material for both accelerometers and force gauges."

The ring configuration is a very common layout. Multiple force links are mounted between a ring-shaped top plate and bottom plate. It is used most often because the configuration provides a flexible layout for a large variety of test objects. \\

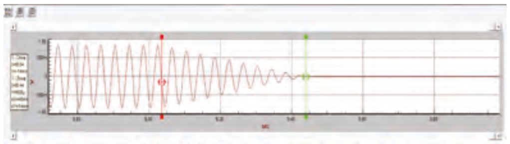
SAFE TESTING WITH A SAFE SHUTDOWN

Spacecraft qualification requires high-level vibration testing of valuable and sometimes irreplaceable flight hardware. Preventing damage from unexpected events during test is critical.

In general practice, safety systems are designed to shut down tests quickly in the event of an over-test condition or system failure. The resulting 'hard' shutdown, unfortunately, can subject the test article to potentially damaging transient shock due to rapid deceleration.

Recent advances in vibration testing systems, pioneered by Data Physics and Team Corporation, solve this problem with a safe shutdown system that integrates comprehensive monitoring of conditions during test with a controlled ramp-down of the system in a test abort.

The system was employed at NASA's Goddard Space Flight Center for testing the James Webb Space Telescope. In addition to continuous monitoring of vibration and force levels on the test article, the safe shutdown system used at NASA monitors facility power, safety interlocks and other critical subsystems. Given detection of a failure event, the system automatically initiates an abort sequence that leverages specially modified power amplifiers to ensure smooth ramp-down of the shaker systems – even with complete loss of facility power – to protect the high-value test article. \\



EDDY CURRENT ARRAY PROBES AND APPLICATIONS

An eddy current array (ECA) is a series of discrete sensors arranged in a specific pattern, enabling the coverage of a large area in a single pass.

ECA probes eliminate the conventional raster scanning necessary when using pencil probes. This has an impact on inspection speeds and coverage. Multiplexing through the coils ensures complete coverage of the surface area and minimizes interference between coils close to one another.

Coil modules can be tailored to an application and comprise flexible arrays, rigid arrays, independent, spring-loaded coils and more. The ECA from UniWest is a handheld scanner that contains a replaceable probe module, allowing many configurations of coils for specific applications. Encoded wheels on the scanner enable precise location and scaling to ensure complete coverage of the surface area and recall of data for enhanced analysis.

Data is displayed in a color C-scan to aid interpretation and characterization. When using an ECA, large surface areas can be examined in a single pass and yield a high-resolution scan. The technology reduces the complexity of robotic and mechanical scanning systems. Intricate shapes can be easily examined by employing probes to the profile of the part. Additionally, C-scan imaging helps in enhancing flaw detection and sizing. Compared to liquid penetrant testing and magnetic particle testing an ECA can reduce inspection time by up to 95%. \\

LOW NOISE FLEXIBLE CABLE

The Endevco model 3076 is a low noise, flexible cable assembly designed for use in high-temperature environments. It has the temperature capacity of a high-temperature mineral-insulated hardline cable yet is extremely flexible like a softline cable. It is ideal for installations that require flexibility for cable routing, low noise and temperatures up to 1,000°F (538°C).

The 3076 cable assembly provides a number of advantages over the traditionally used mineral-insulated hardline cable. It is highly flexible, with a threefold improvement in bend radius.

Additionally, mineral-insulated hardline cables are limited in the number of bends that can be made in one location before damage can start to occur. Because of its construction, this 3076 has no such limitation.

Furthermore, because of its flexibility, the 3076 can potentially improve the dynamic response of the cable and sensor system compared with a hardline cable. Depending on installation factors, a rigid hardline cable connected to a sensor can often induce strain onto the body of the sensor and affect its dynamic response. The 3076's flexibility minimizes this impact while still being able to withstand extreme temperatures.

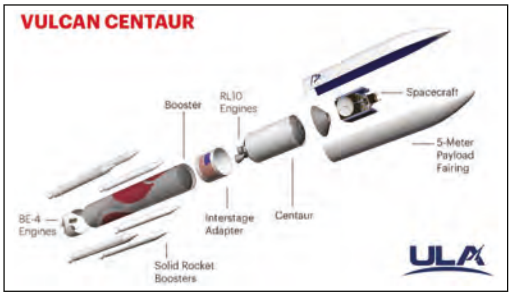
The 3076 has rugged 10-32 hex connectors on both ends. The cable is removable and has lock-wire holes for secondary retention when mated to the accelerometer. Additionally, it is insulated between the connector backshell and the stainless steel outer sheath to prevent inadvertent grounding. \\

MANUFACTURING SUPPORT

The aerospace and defense industry has always been at the forefront of product, process and material innovation. Today, in addition to technical challenges, cost challenges are influencing the dynamics of the industry. Cost is a critical factor in the development and implementation of solutions to technical challenges. Best value tops many aerospace project/process/product requirements lists.

As aerospace companies seek to address technical and cost challenges, they continue to look for innovative solutions for efficiently and cost effectively accomplishing their development, process, production and operational goals. Outsourcing project management, project planning and integration, process improvements, lean initiatives and process analysis is a cost-effective solution to address labor spikes without incurring excessive overhead and resources when the project is complete. Outsourcing also introduces a host of out-of-the-box thinking, fresh eyes and ideas and new challenges to the status quo, which can potentially increase innovation, resulting in new features, processes and cost-reduction ideas.

Jacobs is helping its aerospace clients meet these challenges by offering manufacturing support services with a wide experience base, including process modeling and simulation, industrial and manufacturing process improvement, highly complex facility work, and technical services for space, defense and commercial industry customers. The United Launch Alliance (ULA) engaged Jacobs to assist with process operations, planning and preparations for the upcoming Vulcan and Centaur program.



Jacobs applies best practices from more than 70 years of experience to provide engineering services to help its aerospace and defense clients increase operational efficiency and productivity to cost-effectively deliver superior products in an increasingly cost-competitive environment. \\

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HIGH-SPEED TESTING: VERSION 2

Test-Fuchs has been designing, manufacturing and servicing aerospace test equipment since 1946. It has been developing generator test stands since 1950 at pace with technological developments.

Today, speed is an essential component in our fast-moving world, not only with road and rail transport, but also in air travel and its associated maintenance and repair. MRO is a streamlined and fast-moving activity. Greater speed often requires new technologies and an interaction of many science and engineering sectors. In line with this, we now expect a reliable, faster and higher-quality testing, to deliver the operational product.

For the testing of electrical generators, Test-Fuchs has designed a modular concept that provides the opportunity to test many units under test on one test stand. Enhanced with the newly developed quick-fastening system, test engineers profit from a much reduced setup and startup time.

The most innovative test stand subassembly is the direct-drive solution that replaces the traditional gearbox. The overall rig solution reduces complexity, noise and power loss, and results in less maintenance, faster turnaround and more reliable lead times. In combination with the universal voltage regulator, time is saved and the cost of an external controller is eliminated.

Intuitive software keeps your operator in control. The easily programmable and adjustable test sequences create customized reports in the most flexible way.

The company has also developed a new interface that enables remote connection to the test stand data from an alternative location to the testing. With Data Solutions an IoT gateway is available for real-time monitoring and analysis.

The Test-Fuchs generator test stand is the choice for the new faster-moving aerospace MRO industry. \\

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TEST FUCHS

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EQUIPMENT AND SERVICES FOR TESTING REQUIREMENTS

Marposs, supplier of precision equipment for measurement and control in the production environment, such as tooling, fixtures, machine monitoring systems and automatic inspection machines, believes that good quality and reliability remain the most important goals to ensure the safety of air passengers.

Research and development provide the path at a low production scale, but when moving to mass production, process control, 100% inspection and data gathering during the manufacturing process are needed to ensure quality and reliability. Like aircraft and engine systems where redundancy and close monitoring ensure proper function, these same concepts are applied in manufacturing.

Behind the scenes, aerospace companies are looking to optimize manufacturing while reducing costs to stay within budget. Many of them believe a solution is to tackle high-precision measurement and process control on their own. But this can often mean they lose control of the optimization and cost reduction initiatives they set out to achieve.

To help its customers avoid this, Marposs has dedicated solutions designed to take on the task. The company's measurement and inspection systems provide a way to reach the quality and reliability needed to meet industry requirements with the desired speed and cost-effectiveness measures.

Systems such as in-machine probing, laser inspection, machine monitoring and process control provide the inspection and control environment needed to manufacture components at large scale that are 100% compliant with requirements.

Marposs understands the importance of timeliness and quality in aerospace programs. The company works closely with each company to ensure its inspection and process control needs are met. It supplies solutions to aerospace customers worldwide, including tooling, fixtures, machine monitoring systems and automatic inspection machines. \\

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AIRCRAFT NOISE AND CERTIFICATION

Since 2001 ANOTEC (Aircraft NOise TEChnology) has provided consulting and engineering services to help reduce aircraft and airport noise. A private and independent company, it offers impartial solutions optimized from both a technical and economical point of view to engine manufactures, aircraft operators, design organizations, authorities, airports and their communities.

Its consultants have decades of experience in noise certification applicable across a wide range of aircraft.

A noise certificate may be needed as part of the approval of a new design or for the modification of a helicopter, a propeller or a jet aircraft, whatever the changes' size or purpose. Several means of compliance exist, from a small desktop analysis, up to an extensive flight test campaign.

ANOTEC has a comprehensive suite of solutions to cover the whole range of means of compliance and offers its customers an efficient way to obtain its noise certificate.

A fully equipped mobile laboratory is available for noise flight tests anywhere in the world. Test equipment and data analysis software have been approved by the major civil aviation authorities worldwide.

ANOTEC's 360º aircraft noise certification solution covers all stages of the aircraft noise certification process, covering from the initial discussions with authorities on the compliance demonstration plan up to the delivery of the noise certificate. \\

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ANOTEC ENGINEERING

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THE GREATEST EXPERIMENT

The arduous and ambitious development of Concorde has provided inspiration to aeronautical engineers since its maiden flight 50 years ago

On the afternoon of March 2, 1969, in Toulouse, France, more than 600 journalists and hundreds more technicians, engineers and onlookers cheered Concorde 001 into the sky. Two years after the prototype was revealed to the public, and three years behind schedule, the maiden flight of the world's first supersonic passenger airplane lasted 29 minutes and did not exceed 305mph (490km/h) – it wouldn't break the sound barrier until its 102nd test flight in October 1969.

Meanwhile, Concorde 002 was being built in the UK. That aircraft's maiden flight took place on April 9, 1969, from Filton Aerodrome to RAF Fairford, Gloucestershire, and lasted just 22 minutes.

Development work had begun on Concorde seven years earlier and included many innovations, such as electronic flight controls, the first cockpit side-stick to anti-skid braking system and the movement of fuel around the aircraft to adjust its center of gravity.

The first test flights with the prototypes aimed to expand the flight envelope as quickly as possible to validate the design and predicted performance. In the UK, this was conducted at RAF Fairford and in France at Toulouse. After the prototypes achieved Mach 2.0 in November 1970, testing was focused toward certification to Technical Supersonic Standards, which were devised to cover the areas where existing standards were inadequate. Route proving using production aircraft started in May 1975 and concluded in August the same year with the French Concorde 203. UK-based route-proving flights using Concorde 204 were conducted between July and September 1975.

In all, it took seven years of testing after the first flight to certify Concorde as safe for commercial use. The first commercial flight was on January 21, 1976, from Paris to Rio de Janeiro. Concorde operated commercially for 27 years before it was retired from service in October 2003, its fate sealed by a crash at Gonesse, near Paris, in 2000.

Only recently have aircraft manufacturers started to consider again that a passenger supersonic aircraft is a commercially viable proposition. Companies such as Boom, Spike and Aerion look likely to return supersonic aircraft to the skies. They will build on Concorde's successes and learn from its failures. Concorde's other legacy was political: the project, although not without disagreement, showed that the UK and France could cooperate on large aviation projects and laid the foundations for the creation of Airbus.

Concorde was a costly experiment. In 1962, the aircraft was projected to have cost £160m (about £3.5bn or US$4.6bn in today's money). In 1975 it was estimated to have cost at least £1.2bn, the equivalent of around £26bn (US$34.4bn) today.

Despite the high cost and project delays, the aircraft pushed the boundaries of aeronautical engineering and helped shape today's aerospace industry. Even 50 years on from its first flight, Concorde still provides inspiration. \\

MAR 2,1969
First flight

001
Model number pictured

84FT
Span

202FT 4IN
Length

173,600LB
Gross weight

1,354MPH
Top speed

1,341MPH
Cruising speed

4,488 MILES
Range at full load

60,000FT
Ceiling

38,050LBF
from each of the four Olympus 593 Mk 610s

20
aircraft built, including four prototypes

120
passenger capacity

Watch the Airbus video commemorating Concorde:
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SIEMENS
Ingenuity for life
Simcenter Testing Solutions
Drive innovation and productivity in test-based performance engineering.
In the digital era, it is crucial to test, validate, and optimize real-world designs under the constraints of increasing test complexity, growing product diversity, and shortened test schedules. Simcenter Testing Solutions integrate multiphysics data acquisition with a suite of data collection, analytics, and modeling software, in the core fields of vibration, acoustics and durability. Our solutions deliver critical insights to innovate smart products under tight schedules. They increase productivity, enhance team collaboration, provide engineering flexibility, and lower cost of ownership.
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