DECEMBER 2018

Aerospace TESTING INTERNATIONAL

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Measurement of parts and components is changing rapidly thanks to advances in x-ray technology, cloud computing and automation

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// TESTING TALK
Danish defense company Nammo's test center manager reveals the secret life of weapons and ammunition test engineers

Boom or bust?

Discover how engineers plan to silence the boom and return commercial supersonic aircraft to our skies

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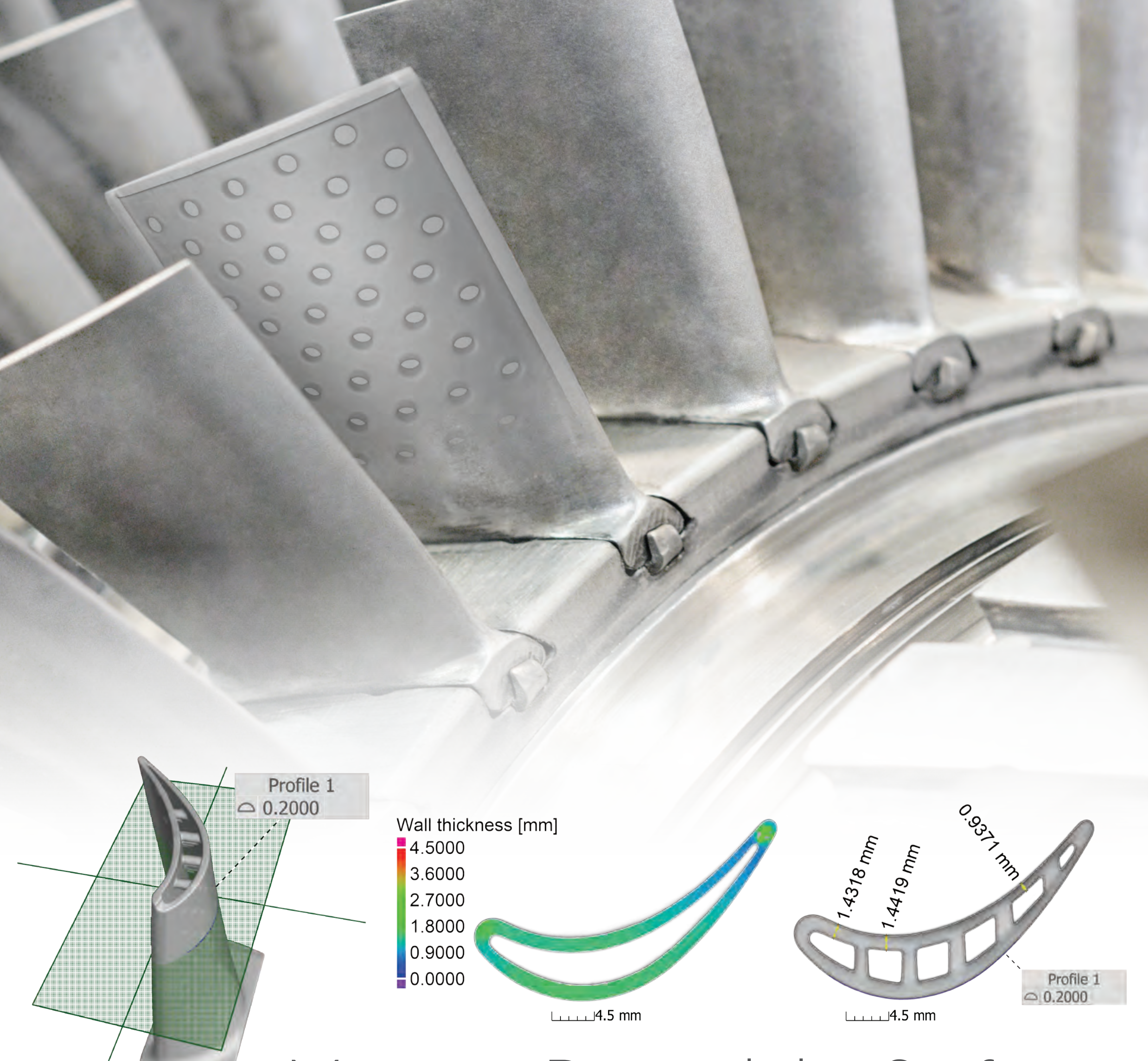

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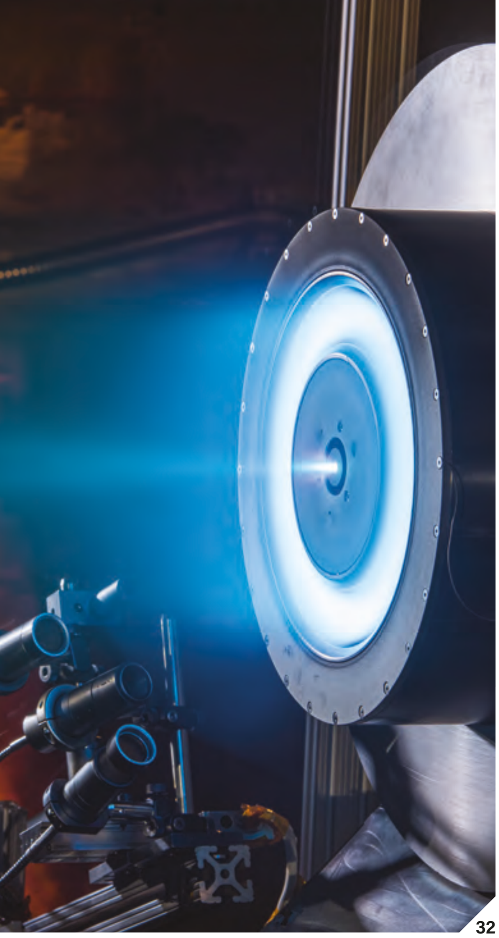
Global briefing



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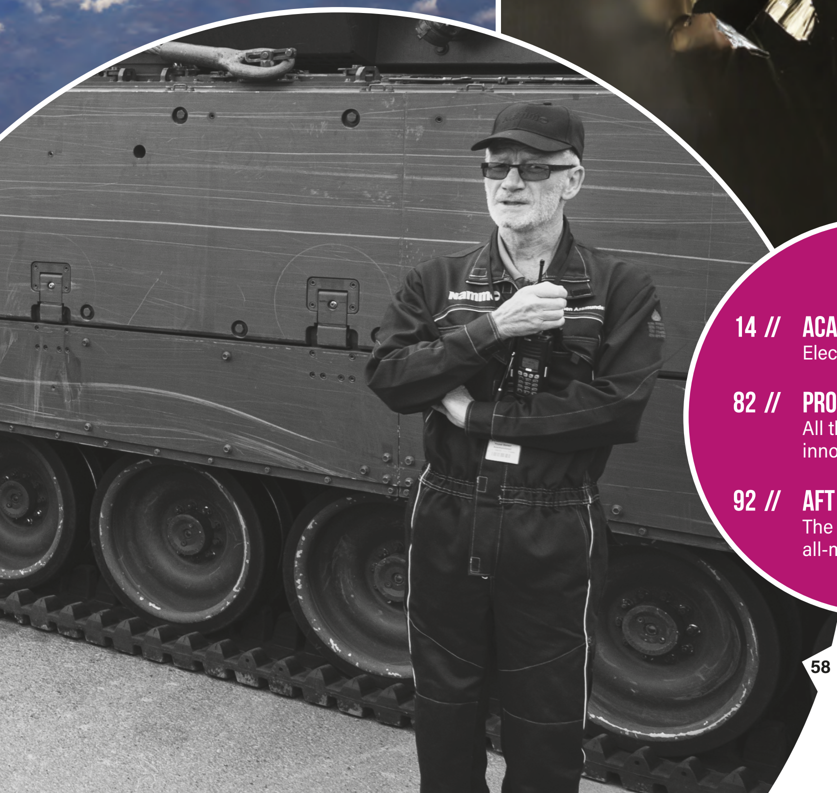

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Inside this issue

// Marijuana versus metrology

This issue of *Aerospace Testing International* covers the full gamut of aeronautical engineering. Flick through its pages and you'll find people leaping out of aircraft to test jet-propelled wingsuits, designing supersonic aircraft, fatigue testing helicopters and improving manufacturing methods using laser-scanning metrology solutions.

The wide scope of the magazine should come as no surprise. The aerospace sector is experiencing one of its most innovative and divergent phases ever, fueled by a combination of factors, not least the ever-present drive to improve the speed and reliability of transport while reducing its impact on the environment.

To deliver those aims requires innovation, which in turn has created a slew of fast-moving startups and prompted companies from other sectors to enter the aerospace sector. Whether the technology being developed is supersonic, electric, autonomous or simply lower cost, it's clear that the industry is undergoing massive change. But it's not just the technologies that are changing, it's also the culture of the sector.

A symptom of this culture change was displayed recently by one of the most controversial figures in the industry: Elon Musk. The entrepreneur and engineer behind Tesla and SpaceX, and one of the world's highest profile CEOs, allowed himself to be broadcast over the internet drinking whiskey and smoking marijuana during a podcast interview in September.

As well as the expected outrage and subsequent reaction against that outrage, the public display of Musk's personal relaxation methods has reportedly prompted NASA to review workplace safety at SpaceX and Boeing. As part of NASA's Commercial Crew Transport Program, the two companies are supplying the spacecraft that US astronauts will use to travel to the International Space Station next year. SpaceX is also a launch provider for NASA.

The review will take months and involve interviewing hundreds of employees. Clearly as a federal organization NASA takes a dim view of marijuana use. It also clearly has a responsibility to its astronauts to transport them to and from orbit as safely as possible.

On the other hand, a corollary of an increased amount of competition and innovation in the sector should be an increase in the amount of diversity within it. Should NASA be more tolerant of the eccentric industrialist?

It's easy to see that spaceship designers, wingsuit enthusiasts and test and manufacturing engineers are completely different sets of people. But they do have something important in common – apart from featuring in this magazine. They are all engaged in testing to ensure safety while flying: running experiments, measuring and recording, collecting and analyzing data, validating designs, and working to meet certification requirements and standards. Although the types of flight are very different, the goals, methodologies and tools they use for testing will not be dissimilar. As long as the ethos driving that part of aerospace's culture is unchanged, perhaps there should be room for more diversity and innovation.

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COVER IMAGE: Boom Technology

WORLD *test update*

// NASA SCHEDULES CREWED SPACE MISSIONS

NASA has announced that the first test flight of SpaceX's Dragon spacecraft will take place on January 7, 2019, with the Boeing CST-100 Starliner's maiden flight to follow in March.

The US space agency's updated schedule for its Commercial Crew Program then plans the first crewed test flight of the Dragon capsule during June 2019 and the Starliner vehicle in August. The first operational missions with crews should launch in August and December.

As part of the Commercial Crew Program, SpaceX and Boeing are contracted to develop and fly space transportation systems to and from the International Space Station. Six flights will run between 2019 and 2024.

Following the test flights, NASA said it will review the performance data and resolve issues as necessary, to certify the systems for operational missions.

Florida, USA

READ MORE ONLINE

// KING STALLION STIRS UP A STORM DURING DUST TESTS

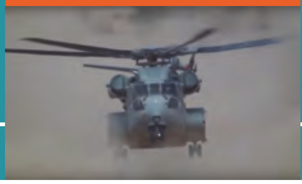
The CH-53K 'King Stallion' heavy-lift helicopter has been undergoing degraded visual environment (DVE) testing at the US Army Yuma Proving Ground.

The tests have involved the helicopter creating massive clouds of dust in the landing area, which was regularly plowed to create the most extreme dust situation possible for this flight test.

The DVE course recreates the potentially catastrophic consequences of brownouts.

The Sikorsky CH-53K has been developed for the US Marine Corps and features three 7,500hp engines, composite rotor blades, and a wider cabin than previous variants. The helicopter's first flight took place in October 2015 and the first CH-53K was delivered in May 2018.

Arizona, USA



// BALLOON TEST FOR MILITARY COMMUNICATIONS

Airbus has successfully flight tested a stratospheric 4G/5G communications platform for defense applications on a high-altitude balloon in Canada.

The stratospheric balloon flew at altitudes up to 21km (13 miles) above Earth, carrying Airbus LTE AirNode communications equipment to create a high-altitude airborne cell site 30km (19 miles) wide for secure communications.

The test team, which was equipped with two vehicles and two drones, tracked the balloon over 200km (125 miles). While the team tracked the balloon, the engineers exchanged 4K video between the vehicles and drones, to simulate real-time transmission of data during a military mission. The data was sent via a private network at speeds of 0.5-4Mbps, which is comparable to 4G/5G mobile communication.

The test was part of Airbus's Network for the Sky project, which aims to offer a full operational capability by 2020.

Ontario, Canada

WATCH THE VIDEO ON OUR WEBSITE

// BELUGA XL LANDS IN BREMEN, GERMANY

Airbus's massive transportation aircraft, the Beluga XL, has been moved to the company's site in Bremen, Germany, to perform loading and unloading tests as part of its certification.

The Beluga XL is a modified version of the A330 freighter. Airbus is making five of the aircraft to carry completed sections of aircraft from production sites around Europe.

The Beluga XL's flight test campaign began on July 19, 2018 from the Airbus Toulouse, France, headquarters. It is expected to start regular operations before the end of 2019.

The Beluga XL will replace the Beluga STs the company currently uses, which have been in service since 1995.

With a length of 63m (206ft), the Beluga XL is approximately 7m (23ft) longer than the Beluga ST and incorporates a highly enlarged cargo bay structure and modified rear and tail section. The Beluga XL fleet will increase air transportation capacity for the company's industrial network by about 30%, said Airbus.

Bremen, Germany

// LAUNCHERONE ALMOST READY FOR ORBIT

Satellite-launch company Virgin Orbit has conducted the first successful test flight of its LauncherOne rocket.

The carbon-fiber, two-stage rocket was carried under the left wing of Cosmic Girl, the company's customized 747 passenger aircraft, on November 18, after it took off from a test facility in Victorville, California.

Virgin Orbit CEO Dan Hart described the 80-minute test flight as "picture-perfect and a major step forward in our quest to bring a new capability to small satellite launch".

The 'captive carry' test flight marks the start of a new phase in Virgin Orbit's test program.

The flight crew assessed the take-off, landing, and low-speed handling and performance of the integrated system during the flight. The next tests will prove the robustness of the modified 747, the LauncherOne carbon-fiber rocket itself, and the performance of its onboard avionics and flight computers.

Victorville, California

// INDIA'S TRAINER AIRCRAFT IN A SPIN

Defense and aerospace firm Hindustan Aeronautics Limited (HAL) is spin testing its HTT-40 basic trainer aircraft.

The testing, which started on November 9, 2018, was conducted by two test pilots: Group Captain (Retired) KK Venugopal in the cockpit, and Group Captain S Chaki in the rear. It started on November 9. Stall testing has already been completed.

The two-person HTT-40 is 10.5m (34ft) long with a wingspan of 11m (36ft) and is powered by a Honeywell Garrett TPE331-12B turboprop engine. The HTT-40 has a top speed of 400km/h (249mph), a range of 1,000km (621 miles) and a ceiling of 20,000ft.

Development of the HTT-40 began in August 2013 and the aircraft made its first flight in May 2016. The Indian Air Force is to buy 70 HTT-40s from HAL.

HAL's Aircraft Research and Design Centre (ARDC) has also conducted wind tunnel testing and mathematical model analyses to arrive at the spin characteristics of the aircraft.

Bengaluru, India

READ MORE ONLINE

// CHINA DEVELOPING HIGH-ALTITUDE PERSISTENT DRONE

Chinese aerospace developer, the Aviation Industry Corporation of China, has tested a prototype solar-powered drone that will be able to stay in the air for months.

The Morning Star prototype drone made its first test flight in September 2018. The drone has a 66ft (20m) wingspan. It attained and then cruised at an altitude of more than 66,000ft, said the Aviation Industry Corporation of China (AVIC).

"With the development and first flight, in addition to a great number of ground, wind tunnel and scale model tests, a solid foundation has been laid for follow-up development.

"We will move quickly toward large-scale, heavy load and long-endurance solar-powered UAVs," the company said.

The main wing structure has a "superlight" weight of 18.9kg (42 lb), AVIC said, thanks to the development of a new material.

Beijing, China

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1

POWERED WINGSUITS SET FOR TAKE-OFF

3

1 // Gravity Industries' Jet Suit is regularly displayed at airshows

2 // Lightweight materials are used in the Jet Suit

3 // Version two of Jarno Cordia's Jet Wing design

Engineers and enthusiasts are flight testing jet-powered wingsuits in a bid to achieve truly independent human flight. Two projects, one in Holland being run by a team of skydivers, and another in the UK, which is a development of the jet suit design pioneered by Gravity Industries, are developing prototype jet-powered suits.

Wingsuits, which were first developed in the mid-1990s, increase a skydiver's lift while they descend. The fabric suits feature ribbed 'wings' between the wearer's arms and torso, and between the legs, which inflate with air like square parachutes.

Both powered wingsuit concepts involve wearing jet engines on the body and using them to create lift and control while in the air.

The concept of a powered wingsuit was first explored by Finnish skydiver Visa Parviainen in October 2005, by attaching jet engines to his boots. That concept has been further developed by Dutch wingsuit pilot Jarno Cordia, who has been working with Parviainen since 2010 and earlier this year conducted several successful test flights of the Jet Wing in Holland, reaching speeds of up to 120mph (200km/h).

Cordia said, "At around 75% thrust, I'm flying level. With 100% thrust, the climb rate is comparable to that of a small airplane. With the half-fuel load I'm using during test flights, I have around two-and-a-half to three minutes of flight time. When flying with full tanks, I should be able to fly for around five or six minutes."

The main enabling technology for the Jet Wing are the small gas turbines, supplied by Dutch company AMT Jets, attached to the wingsuit's boots. Cordia said, "I'm developing a second version of the same setup, with the engines mounted on small struts attached to the parachute system. We hope to do the first test flights with this second version in June next year."

Cordia is also looking for sponsors and funding for the project.

Gravity Industries intends to start testing its modified suit this month. Its approach is to advance the Daedalus jet suit developed by Richard Browning, which consists of six micro-jet engines, two on each arm and a pair on the back, linked by a metal frame worn over the body

The first modification, due to be flight tested this month, will place a tail wing made from flame-resistant material onto the suit, while future planned changes will look at including arm wings.

Dr Angelo Grubisic is a lecturer and researcher in astronautics from the University of Southampton in the UK, and jet suit pilot and developer for Gravity Industries. He said he is integrating research he has done on wing suits into the jet suit. "We're taking it a step at a time. So far we've mastered vertical flight; now we want to manage the transition to horizontal flight and master that," he said.

Grubisic believes that a modified Daedalus can morph into a propulsion device that will fly further and faster than the Jet Suit. "When you go fast in the suit it feels like skydiving, and I employ the skills and techniques I know from skydiving," he said. "You use your body as an aerodynamic control surface. You produce drag as you go faster, but you also produce lift if you angle your body in the right way. We're learning all the time about how to go fast." \\

2

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// The first ever shipborne rolling landing is carried out with an F-35B Lightning II on board HMS Queen Elizabeth

F-35B FINISHES ROYAL NAVY SEA TRIALS

Two months of trials examining how the F-35B fighter jet performs when operating from the Royal Navy's HMS Queen Elizabeth aircraft carrier have been concluded off the east coast of the USA.

The deployment started in late September and has written the so-called 'operator's manual' to enable the fighter jet to fly from her deck on frontline operations.

The F-35B Lightning II is the short take-off and vertical landing (STOVL) version of the fighter. The two F-35B fighters and four test pilots that participated in the flight testing departed the ship in late November 2018 to rejoin the Integrated Test Force (ITF) at Naval Air Station Patuxent River in Maryland.

During the trials, the two aircraft performed 200 short take-offs, 187 vertical landings and 15 rolling landings – a technique that enables a Lightning to return to the carrier without having to jettison fuel or payload – and dropped 54 dummy bombs.

RAF Squadron Leader Andy Edgell, ITF chief test pilot, said, "This has been one of the most comprehensive flight trials at sea ever conducted."

ITF scientists recorded data about the weather, humidity, pitch and roll of the ship, and aircraft weight to determine the operational limits at which the Lightnings can safely launch from and land back on HMS Queen Elizabeth. Various configurations of bombs and missiles were also loaded onto the Lightnings during the tests, using the ship's automated munitions magazine. \\

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STRATOSPHERIC PROBE REACHES NEW HEIGHTS

1 // The Hidron is launched into the stratosphere using a helium-filled balloon

2

3

4

Flight testing has begun in Europe of a new type of unmanned drone that is launched by balloon into the stratosphere to conduct atmospheric research. The Hidron aircraft ascends through the atmosphere on a weather balloon, is released once it reaches its target altitude and then glides slowly to a pre-programmed landing zone. The drone collects data using a payload of sensors and instruments for meteorologists and climate scientists.

The developers, drone-development firms Uavos and Stratodynamics Aviation, believe the drone will open up new research applications in the stratosphere because it is cheaper and able to produce more, and better, data than other methods. The single-use balloon campaigns used by researchers in those areas often result in the loss of the equipment.

Hidron is made of composites and has a wingspan of 3.3m (11ft). It does not use engines or propellers, although there is a battery to power the telemetry, payload, autopilot and servo drives for the ailerons and tail rudder.

The drone's maiden flight, which took place in November, lasted for 1.5 hours. It reached an altitude of 20,000ft and its vertical speed as it descended was 2m/s (6.5ft/s) – slower than a parachute descent. The drone landed autonomously without releasing a parachute.

During the flight, engineers gathered performance data about the aircraft's primary radio communications link and the backup satellite communications system, the release system, the stabilization and controllability of the aircraft after release, and how the UAV's controls dealt with the icing conditions.

The next flight tests, which are due to take place this month, will see the drone rise to an altitude of 82,000ft and take three hours to descend. Engineers will trial automatic upstream processing software designed to increase the descent time depending on the weather conditions.

Gary Pundsack, founder and CEO of Stratodynamics Aviation, said, "The next phase of testing centers on the continued instrument performance in BVLOS [beyond visual line of sight] flights. We'll also be integrating a sensor package from one of our scientific partners from the USA."

"We're breaking new ground in BVLOS. Part of our mandate is to generate flight data that will help to inform policy for BVLOS in Canada. It's very exciting because we are flying in the stratosphere, which in so many ways is an undiscovered country."

Aliaksei Stratsilatau, chairman of Uavos, said, "One of our main objectives is to stabilize the transmission of data, the interaction of the autopilot with the payload and the control of Hidron in the stratosphere. We are also practicing how the drone interacts with air traffic control organizations. A challenge has been coordinating with the licensing organizations for flights, because the aircraft ascends as a meteorological probe, but descends as a UAV."

"Many from the scientific community are interested in Hidron," added Pundsack. "Opportunities to access the stratosphere are few and far between and require a large investment. Most balloon lift-and-drift platforms offer no guarantee that the payload will be retrieved and are at the mercy of the weather, time of day and time of year.

"Hidron disrupts the model with its versatility, control and quick lead time to launch." \\

2 // The drone's progress can be tracked using GPS

3 // The system can be reused, unlike existing weather balloons

4 // The stratospheric altitudes reached by the drone are high above other air vehicles

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READ IN-DEPTH ABOUT QUESST TESTING ON PAGE 40

// Production of the first part for the X-59 in Palmdale California *(Photo: Kevin Robertson/Lockheed Martin)*

PRODUCTION STARTS ON NASA'S SUPERSONIC TEST AIRCRAFT

Lockheed Martin has started manufacturing NASA's X-59 Quiet Supersonic Technology (QueSST) aircraft, which will be used to test new ways of quietening sonic booms. The first part of the aircraft's structure was milled at a Lockheed factory in Palmdale, California, last month.

The X-59 will provide NASA engineers with data about how effective its design is at reducing supersonic jets' boom noise. The aircraft has been aerodynamically shaped to reduce the noise heard on the ground to a quiet sonic 'thump' using computer simulations and wind tunnel testing conducted at the Langley Research Center in Hampton, Virginia.

Once airborne, which should be from 2022, flight tests will be conducted to assess the acoustic signature of the aircraft, both in the air and on the ground. The X-59 will be flown over a number of communities in the USA so that NASA engineers can also collect data on how the public responds to the noise. Regulators will use the data to potentially change the rules that currently ban supersonic flight over land.

Future testing will assess other barriers to the reintroduction of supersonic flights over land. Peter Coen, Nasa's Commercial Supersonic Technology project manager, said, "We're focusing on the sonic boom problem for now, but we've not taken our eyes off take-off and landing noise and emissions. We've already made progress in those areas and when we finally break the sonic boom problem, we'll turn our full attention to those." \\

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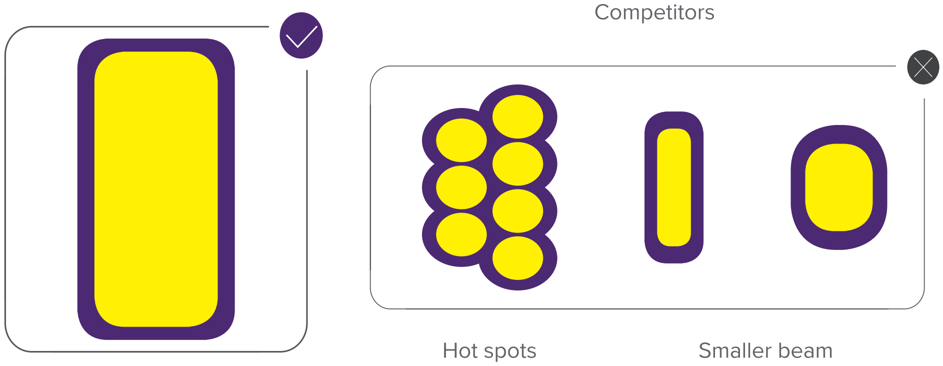

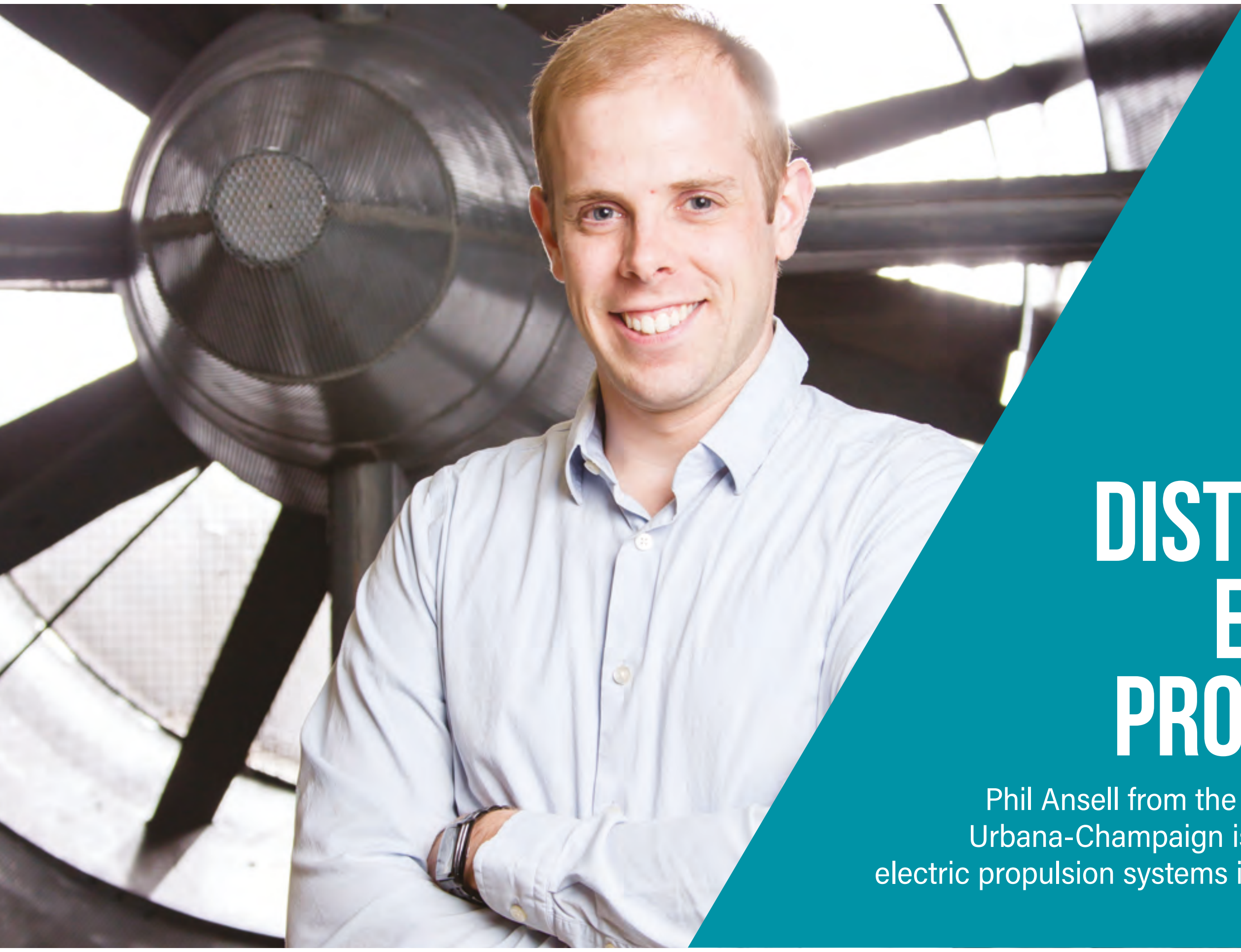

DISTRIBUTED ELECTRIC PROPULSION

Phil Ansell from the University of Illinois at Urbana-Champaign is testing how different electric propulsion systems interact with airframes

Many researchers and aviation groups are actively considering more electric propulsion schemes to improve future aircraft efficiency, safety and operational flexibility. One of the benefits of propulsion electrification is the increased freedom in the placement and the interaction that the propulsive devices can have with the aerodynamics of the airframe, leading to significant aero-propulsive interactions. Fundamental aspects of these interactions in a distributed electric propulsion (DEP) configuration, as well as the cross-coupling between propulsors, are not well understood.

To resolve these interactions, a series of experiments were conducted in a low-speed, low-turbulence wind tunnel at the University of Illinois at Urbana-Champaign. The results show that aero-propulsive coupling effects produced by an overwing DEP system are significant, to the point where classical aerodynamic theories are no longer applicable. The influence of the fans was observed to produce a global change in the airfoil flow field, far beyond simply producing a thrust vector oriented at the local fan inclination.

Our results show a considerable circulation-induced influence of the propulsion system on the airfoil aerodynamic performance and pressure distributions, indicating a variation in the airfoil trailing-edge boundary condition induced with changing fan efflux speed. The fan cowling pressure distributions were also observed to vary with throttle setting, and the upstream boundary layer entering the fans was observed to thin with increasing fan RPM. These results indicated the important role of the fan inlet streamtube in shaping the effective airfoil contour and dictating the aerodynamic performance of the airfoil section.

Cases of asymmetric throttle were also tested to simulate fan-out scenarios. The configuration produced a highly three-dimensional flow field as expected, although cases with failure of a centrally located fan across the array were less detrimental to the aerodynamic performance than the failure of a fan at the edge of the array.

Overall, the study provides a new understanding of aero-propulsive interactions for future air-vehicles, particularly those that use DEP systems. For example, asymmetric throttle is often thought of as a means to provide rudderless directional control of an aircraft by introducing a thrust difference across the aircraft centerline, resulting in a yawing moment. However, our results indicate that the throttle setting of an overwing ducted fan has a direct link to the airfoil lift-curve slope, such that increasing the throttle also increases the net lift of the wing section, which would act to also introduce a rolling moment in such an asymmetric throttle scheme.

This case would require careful mixing of throttle inputs to prevent this rolling moment. However, this interaction could also be used favorably during coordinated turns by simultaneously introducing a rolling moment and a proverse yawing moment, without the need for aileron or rudder input.

During the next stages of this work we plan to further improve our understanding of aero-propulsive coupling and propulsion-based vehicle control through wind tunnel testing of a full 3D aircraft model with an overwing DEP system, as well as through a flight testing campaign of an unmanned, subscale DEP aircraft platform. \\


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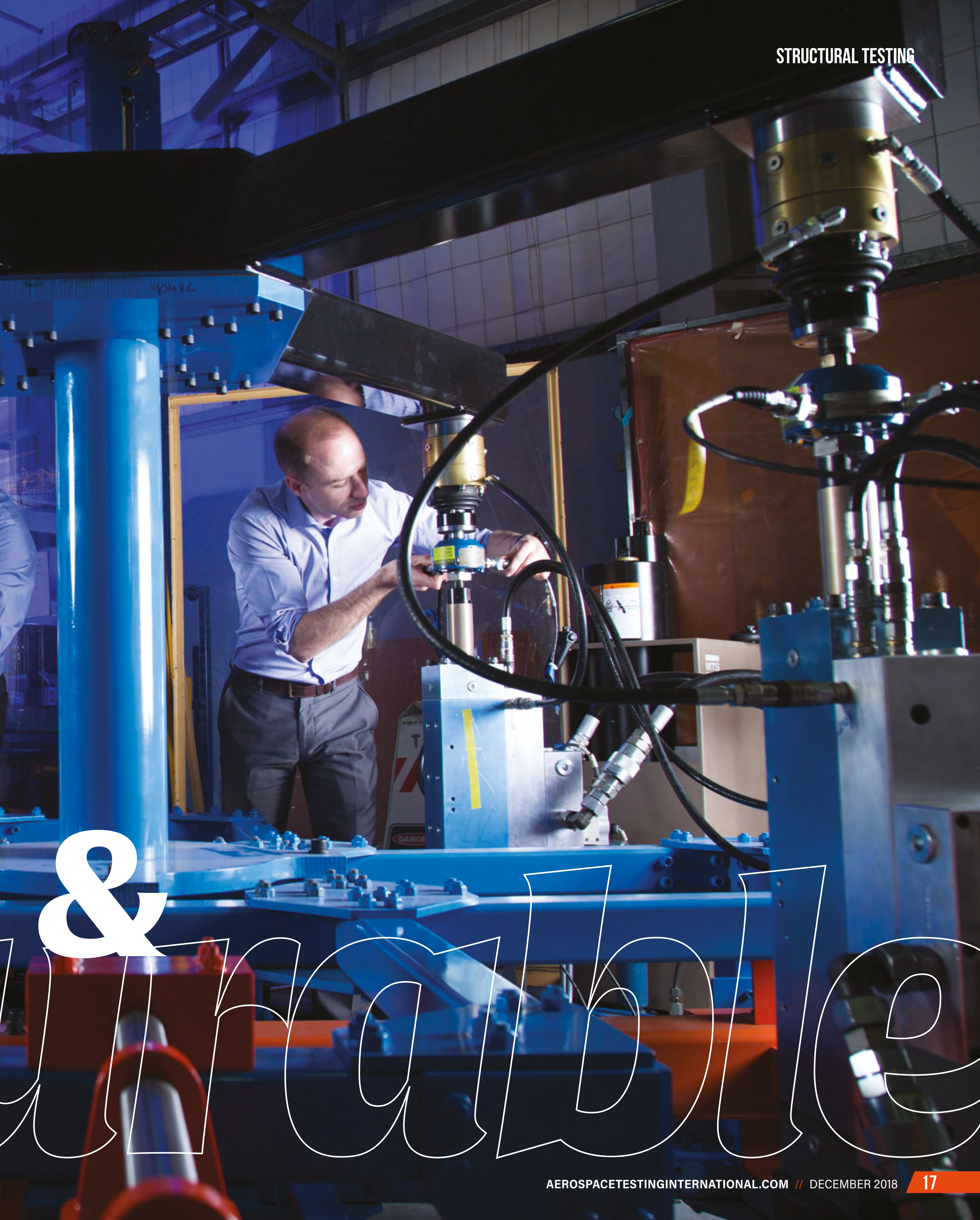
// NIGEL PITTAWAY

1 // Engineers adjust the prototype helicopter fatigue test rig

Research being conducted by Australia's Defence Science and Technology Group aims to slash the duration of full-scale fatigue testing

Predictable measu



& urable

2 // The US Navy has supplied a retired MH-60R airframe to help develop the test rig

Australia's Defence Science and Technology Group has embarked on a study aimed at developing novel techniques to slash the time it takes to conduct the full-scale fatigue testing of helicopters. The project also has the potential to revolutionize the way fixed-wing full-scale fatigue testing is performed.

Known as the Helicopter Advanced Fatigue Test – Technology Demonstrator (HAFT-TD, pronounced 'Half-Ted'), the major five-year project also involves the Royal Australian Navy (RAN) and the US Navy's Naval Air Systems Command (NAVAIR) at Patuxent River in Maryland.

The work is being performed at the Defence Science and Technology (DST) Group's facility at Fishermans Bend in Melbourne, Australia, and is due to be completed in 2022. The research will be used to inform the US Navy's proposed Service Life Assessment Program (SLAP) for the Sikorsky MH-60R Seahawk 'Romeo' helicopter. If successful, the results of the HAFT-TD program could reduce the downtime for inspection and structural repair of the MH-60R's airframe, greatly increasing the flight hour limit and increasing availability throughout the helicopter's service life.

200 YEARS
Time it would take to replicate all the loads on a Seahawk helicopter using current fatigue testing methods

2 YEARS
Length of time to which the HAFT-TD project aims to reduce full-scale fatigue testing for a Seahawk helicopter

> **"We hope to conduct the full-scale fatigue test of a helicopter within two to five years"**

TESTING GOALS

Although a helicopter's dynamic components – such as its main and tail rotor assemblies, engines and drive train – are all subjected to rigorous testing by the OEM, full-scale fatigue testing of the airframe is not traditionally conducted. Knowledge of a helicopter airframe's structural integrity is for the most part built up from years of operation and corrective maintenance.

The main and tail rotor blades of a helicopter generate a huge number of high-frequency loading cycles on the airframe as they pass over or across it – as many as tens of thousands of cycles per flying hour. Traditional methods of testing use hydraulic actuators to induce loads on an airframe test article at a maximum of one cycle per second. Several studies have shown that replicating all of the loads required on an MH-60R airframe using current methods would take over 200 years.

HAFT-TD is exploring ways to increase the rate of hydraulic actuator cycling and to identify which loads are important to replicate and which can be safely ignored. The ultimate goal is to reduce the full-scale fatigue test of the Romeo airframe significantly to between two and five years.

"On one hand we have fixed-wing full-scale fatigue testing, where we rely heavily on the prognostic capability that the current method gives us, and on the other we have the helicopter, where we currently rely heavily on analytical methods. We don't really have any test validation data for them," explains Loris Molent, acting research leader for DST's Aerospace Division at Fishermans Bend.

"So it's not surprising when cracking is discovered on in-service helicopters. A helicopter may spend quite a long time during its service life on the ground having

MORE TESTS FOR SEAHAWK

The Helicopter Advanced Fatigue Test Technology Demonstrator project is not the only involvement that Australia's DST Group has with the Seahawk helicopter – in terms of both the Romeo and its predecessor, the S-70B-2.

The Small Engine Test House (SETH) at its Fishermans Bend facility is being upgraded to accommodate a GE T700-401 engine from an SH-2G(A) Super Seasprite, donated by the Royal Australian Navy.

The work on the SETH facility will be finished in June 2019. The DST Group will then use it to research engine performance using alternative fuels and to develop engine health technologies. Researchers will also look at technologies such as novel engine sensors (for example, wear debris sensors) and develop and validate vibration algorithms.

The DST Group also has a long history in corrosion management and monitoring technology and is working on improving sensors initially developed by the US Navy. A corrosion monitoring system has recently been developed for the Seahawk airframe that measures a full set of corrosion-inducing parameters in addition to temperature and humidity. The system is currently being tested on one of the Australian Defence Force's NHI MRH-90 Taipan helicopters and later trials will involve the MH-60R.

cracks in the fuselage repaired. We think we should be able to do better."

“A full-size test rig will be built to apply loads to a real MH-60R airframe in a predictable, measurable and representative manner”

DEVELOPING A FULL-SIZE RIG

The HAFT-TD program is focusing on two areas to reduce the time it takes to conduct full-scale testing. Researchers at Fishermans Bend are exploring ways to increase the cycle time of hydraulic actuators and the ability to control them precisely, using a specially designed six degrees of freedom (6DOF) demonstration test rig. If this proves successful, a full-size test rig will be built and used to apply loads to a real MH-60R airframe in a predictable, measurable and representative manner.

Second, a loading spectrum reduction activity is underway to conclusively identify the most important loads on the helicopter. "Part of the research is trying to determine if they occur in the hover, when it is banking, or a combination of maneuvers." Molent says. "The aim is to reduce the spectrum from many millions of load lines to maybe several hundred thousand. That would enable testing to be done in a shorter time.

"Coupling that with a cycling rate of up to 10Hz, we would hope to be able to conduct the full-scale fatigue test of a helicopter within two to five years.

"That's the main objective and it's quite a difficult challenge we have set for ourselves."

US NAVY PARTNERSHIP

The HAFT-TD project has came about thanks to the very close relationship that has existed between the Australian Defence Force (ADF) and the US Navy for many years. The DST Group and NAVAIR have partnered on a number of mutually beneficial projects, including the Boeing F/A-18A/B Hornet strike fighter program.

The Royal Australian Air Force (RAAF) has operated the Hornet since the mid-1980s, albeit from land bases rather than aircraft carriers. The service also operates several other US Navy aircraft types, including the Boeing F/A-18F Super Hornet, EA-18G Growler and P-8A Poseidon. In coming years the RAAF will also acquire the Northrop Grumman MQ-4C Triton unmanned maritime patrol platform and the Royal Australian Navy is already a major operator of the MH-60R helicopter. The DST Group was also a major partner in the Hornet

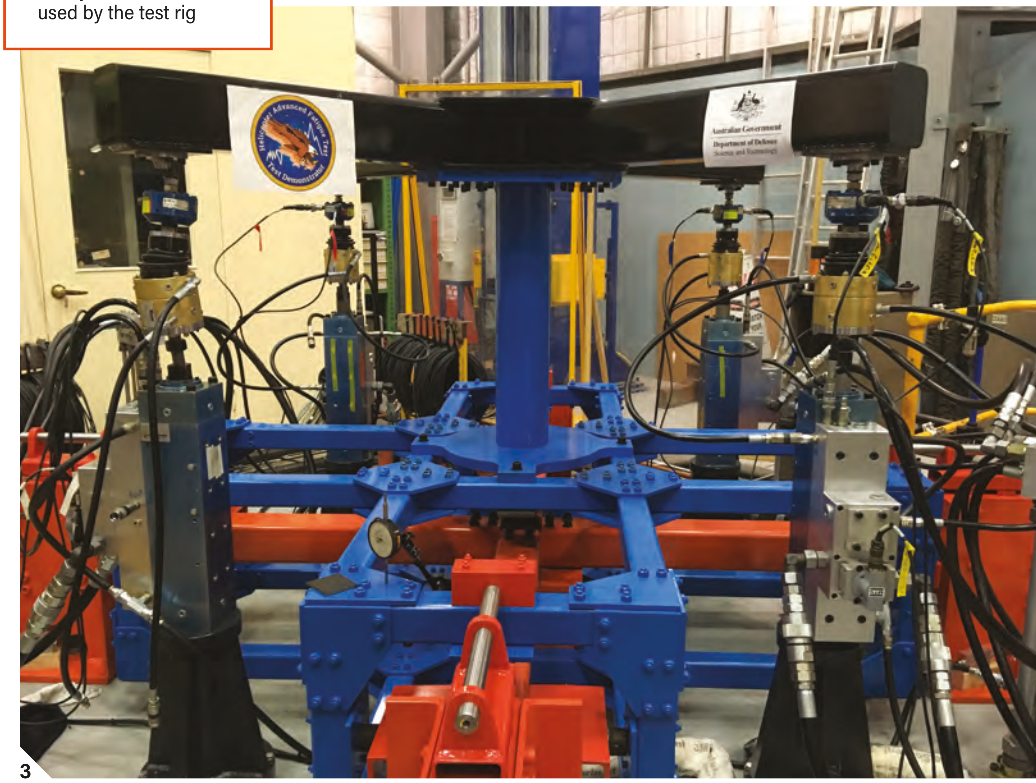
AWARD-WINNING TESTING

The DST Group's prior work on the Hornet International Follow On Structural Test Project (IFOSTP) was the first time aerodynamic buffet loads had been superimposed on steady-state maneuver loads. The program provided a wealth of information for the management of Hornet fatigue issues.

Canada and Australia both operate their Hornet fighters from land bases in a similar manner. IFOSTP was a joint venture between the two countries to establish the fighter's safe economic life. Under the agreement, Canada conducted testing of the Hornet's center fuselage and inner wing, while DST's focus was on the aft fuselage and empennage. A new structure was purchased from the assembly line for the purpose.

At the time, the IFOSTP was the largest structural test program undertaken by engineers at the DST Group. Full-scale structural testing began in 1995 and involved 24,000 hours of representative test flying. Loris Molent took over as project manager of the program in 2000 and the following year the DST Group, the RAAF and the Institute for Aerospace Research, National Research Council, Canada, were jointly awarded the Von Karman Award by the International Council of the Aeronautical Sciences.

According to the DST Group, "Many new test techniques were pioneered and an invaluable set of operational data was collected to support the aircraft for RAAF service."



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3 // Researchers in Australia are increasing the cycle time and improving the control of the hydraulic actuators used by the test rig

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4 // The rig will have six degrees of freedom to recreate the loads on a real airframe

International Follow-On Structural Test Project (IFOSTP) with Canada (see sidebar: *Award-winning testing*), which included the structural testing of an F/A-18A/B aft fuselage as well as it tail section at Fishermans Bend.

"Under the IFOSTP, DST was the first organization to simultaneously test real-time buffet and steady-state maneuver loads," says Molent. "Based on that experience, the US Navy considered that if DST could do that buffet testing – which could be at up to 64Hz – on the vertical tail of a Hornet, we could bring that experience to bear on a helicopter.

"The US Navy is a natural partner for the program and we know each other quite well. That's the genesis of the HAFT-TD project."

However, Molent points out that there are major differences between IFOSTP and HAFT-TD. "It's safe to say that the US Navy was very keen to engage and have us focus on the helicopter problem, but there are differences between the two programs. IFOSTP, for instance, was an open-loop control system, whereas HAFT-TD will be a closed loop system, and that's a challenge on its own.

"With the open loop control system it takes some time for the airframe to get up to speed. While it's doing that it is accruing damage that we're not accounting for. It's sweeping through its dynamic response until we reach the desired state.

"We do not want to do that with HAFT-TD. We want to switch it on and have it run at, say, 8Hz, so that it won't take much to get it up to its natural frequency. In a closed loop each channel is controlled individually, but with feedback, so they won't influence one another."

SIX DEGREES OF FREEDOM

Funding for HAFT-TD has been provided by the Australian Defence Capability Acquisition and Sustainment Group (CASG) and the USA's NAVAIR. The formal agreement to begin the test work was signed in November 2017, but DST began work on risk mitigation activities 18 months earlier.

Those risk mitigation activities are what led to the development of the 6DOF rig, which has been operating at Fishermans Bend for several months. The rig will help develop the complex control system required for the testing. Its cruciform shape is a crude representation of the helicopter structure.

"We're trying to load it with six degrees of freedom, because that's what we're going to need to do with the real airframe. To do that we need to control the actuators separately at very high rates and with very high levels of accuracy," Molent says.

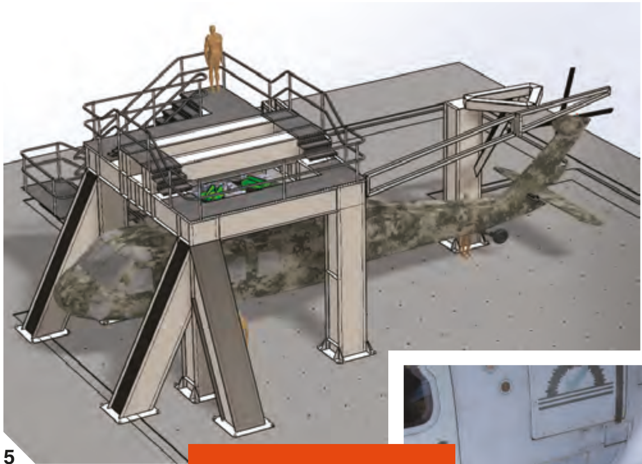
"It has to be successful if we want to transition from the cruciform to the real airframe. The helicopter fuselage will be subject to bending, twisting and yaw, so we want to be able to simulate those load actions into the real airframe."

To accomplish this next stage of the technology demonstration, the US Navy has supplied a retired MH-60R airframe – one of the prototypes that was modified from an earlier SH-60B Seahawk and dubbed 'Bromeo'. This helicopter arrived at Fishermans Bend in March 2018. The future schedule is to design the full-size test rig, with lock-in scheduled for the first quarter of 2020 and testing to begin early in 2021.

"After the five-year program we're hoping to provide the US Navy with confidence that it can write a requirement for a full-scale fatigue test of Romeo into the SLAP, which is something it is not able to do now," Molent concludes.

"We hope that whatever technology we develop will also transition to OEMs, so that in the future all helicopters can take advantage of the benefits derived from full-scale structural fatigue testing." \\

Nigel Pittaway is a freelance aviation and defense journalist based in Australia.



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5 // The HAFT-TD test rig could be used for full-scale fatigue testing of helicopters within five years

6 // The results of the study will be used for service life assessment

// PAUL E EDEN

Future Falco

1 // Dassault aims to deliver DLR's refurbished Falcon 2000LX in 2020

Already a Falcon 20 operator, the German Aerospace Centre will replace its A320 Advanced Technology Research Aircraft with a Falcon 2000 business jet by 2020. After extensive upgrades and subsequent modification with Dassault, the aircraft will enter service as the inflight Systems and Technology Airborne Research testbed

2 // The ATRA A320 during simultaneous engine noise and flow trials

3 // DLR and Dassault ink the F2000 iSTAR deal at ILA, in the presence of German Chancellor Angela Merkel

At the ILA Berlin Air Show earlier this year, the German Aerospace Centre (DLR) agreed to buy a Falcon 2000LX (F2000) development aircraft from Dassault. DLR, Europe's major flight test organization and one of the largest in the world, will use the Falcon to replace an existing Airbus A320 and bring additional capabilities to its portfolio.

Operated as the Advanced Technology Research Aircraft (ATRA), the A320 performs a variety of missions, generating data and helping researchers trial new methods of measurement and information gathering using a variety of modifications and trial installations. Transferring the A320's work to the much smaller Falcon seems a tall order, but Oliver Brieger, DLR's head of flight operations, believes the Dassault jet will be able to perform similar missions to the Airbus and at the same time usher in a suite of new capabilities.

"The F2000 offers higher agility and an expanded *g*-envelope – prerequisites for its inflight simulation capability. The nature of the test programs it will undertake, besides fundamental aerodynamic research and application of inflight measurement techniques, will be extended to include precise 4D navigation, surrogate UAV operations and the airborne demonstration of new aircraft design concepts," says Brieger.

636MPH
Maximum speed of the Falcon 2000LX DLR is acquiring from Dassault

47,000FT
Maximum service ceiling of the Falcon 2000LX

"The Falcon 2000LX greatly enhances our ability to conduct interdisciplinary research"

The Falcon will be known as the inflight Systems and Technology Airborne Research (iSTAR) aircraft in DLR service. As a former Dassault development airframe, it is already equipped with a flight test installation (FTI), which Dassault will modify to suit DLR requirements. Meanwhile, Dassault senior vice president of engineering and former flight test engineer Jean-Louis Montel says, "The aircraft is now under modification to comply with the definition of the type certificate, including the implementation of service bulletins, application of modifications and the completion of scheduled inspections."

There is a great deal of routine work to be done to bring the aircraft up to current Falcon 2000LX standards, even before the trials installation begins.

MODIFICATION SCHEDULE

Dassault is scheduled to deliver the refurbished aircraft to DLR during 2020, at which time, Montel says, "It will be equipped with a dedicated FTI, including workstations for flight test engineers and telemetry capability." Subsequently, around every two years until the mid-2020s, the aircraft will return to Dassault additional modification before the full iSTAR specification is fielded. Montel

A320 ADVANCED TECHNOLOGY RESEARCH AIRCRAFT (ATRA)

First flown in 1997, DLR's Airbus A320-232, registered D-ATRA, flew in airline service until 2006, before a modification program prepared it for trials work from late 2008. In cooperation with Airbus, DLR embarked upon an ambitious fuel cell installation that supplies auxiliary power to D-ATRA's systems.

The 20kW cell can generate auxiliary power for one hour. Extensive airframe modification was required to move the cell into the aircraft's cargo hold and then connect it into the existing electrical system. A mobile infrastructure for replenishing the cell's hydrogen and oxygen fuel was developed, as was a system for monitoring and gathering data in flight.

DLR says ATRA's extensive research capabilities include: aeroelastic measurement trials; inner space acoustics research; airframe noise measurement; turbulence (laminarization) assessment at the wing and tailplane; measurement technique trials, including particle image velocimetry; and wake vortex, atmospheric and engine data gathering.

Modifications to the standard A320 cockpit, including extra datalinks and a head-up display, enable further trials possibilities including, according to DLR: research into flight control commands as aircraft pass through wake vortices and for load alleviation, plus work exploring autonomous flight, airport surface traffic control, pilot assistance and display technology, research into flight deck workloads and exploration of navigation and communication technologies, plus low-noise approach and departure procedures.

For its wake vortex research work, D-ATRA has employed light direction and ranging (lidar) laser techniques to measure the velocity field of the vortex generated by a preceding aircraft. Subsequently, inflow sensors gather data for vortex modeling, the ultimate aim being to enable safe aircraft separation over reduced distances at busy airports.

Again, working with Airbus, DLR has also equipped D-ATRA for high-lift research aimed at improving aerodynamic efficiency in the take-off and landing phases, and reducing noise.

5

4 // The ATRA aircraft has enabled a variety of disparate trials

5 // An ATRA workstation

4

describes the additional work as installing an experimental digital flight control system (DFCS) in phase one and advanced control features around two years later. The latter will feature additional control surfaces, while the DFCS will include Dassault's Easy II interpretation of Honeywell's Primus Epic cockpit, complete with an enhanced flight vision system (EFVS), a Rockwell Collins head-up display (HUD) and a Dassault Falcon Sphere II electronic flight bag.

The experimental DFCS and additional control surfaces together will provide the jet with an inflight simulation – or emulation – capability. The A320's large aircraft flight and handling characteristics have been essential in some of its trials, and would seem particularly difficult for the Falcon 2000 to replace, but Brieger explains, "The inflight simulation capability will enable the aircraft to demonstrate large transport category aircraft configurations."

DASSAULT AND DLR

Close cooperation between Dassault and DLR is essential to iSTAR's success, and its importance should not be underestimated – the parties signed their contract in the presence of German Chancellor Angela Merkel. Speaking at the signing, Pascale Ehrenfreund, chair of the DLR Executive Board, said, "Dassault is granting DLR access to its in-house development expertise and extensive experience in aerodynamics. The Falcon 2000LX has the required flight and safety margins we need for a research aircraft and greatly enhances our ability to conduct interdisciplinary research throughout the aviation system."

"Close cooperation between Dassault and DLR is essential to iSTAR's success"

In fact, both parties can draw on considerable experience with Falcon testbeds. Between 1978 and 1982, Dassault modified a Falcon 20 for inflight simulation on behalf of the French Ministry of the Armed Forces. Montel notes that the experience proved very useful in the manufacturer's proposals for the iSTAR concept. "In addition," he says, "the extensive experience we have with digital flight control systems, gained in military aircraft and on the Falcon since 1978, has enabled Dassault to propose advanced solutions for the iSTAR's experimental DFCS."

Meanwhile, DLR has a long history with the Falcon, having operated a Falcon 20E atmospheric research aircraft since 1976. Equipped with underwing hardpoints and other structural modifications, the jet has been subject to continuous upgrade, maintaining its avionic suite at the latest standards and enabling global operations. Dassault's Mérignac plant in southwestern France, responsible for building in excess of 1,600 Falcons, is the focal point for the iSTAR engineering effort, but in service the aircraft will be based at DLR's Brunswick facility in north-central Germany. Reflecting its high level of modification, flight test history and upgrade to the latest Falcon standard, the aircraft deviates considerably from the type's regular check and service schedules, and Dassault will therefore continue to support it through an adapted maintenance plan.

DLR traditionally makes its test assets available to other national and European research institutions, and aircraft manufacturers and suppliers. The Falcon 2000 iSTAR will be no exception when it enters service around 2020 as a rugged, high-performance, FTI-equipped trials platform. Subsequent modification will equip it not only with simulation capabilities to fully replace the far larger A320 ATRA, but also for research into advanced navigation techniques and UAV operations. \\

42,000FT
Maximum altitude DLR's Falcon 20E has achieved

100FT
Closest that DLR's Falcon 20E has been flown to an airliner's jet engine

FALCON 20E

DLR employs Falcon 20E D-CMET as an atmospheric research platform. Extensively modified since entering service in 1976, the Falcon mounts instruments in its cabin, below the fuselage and on underwing hardpoints, while a long nose boom mounted above the aircraft's nose gathers data from the undisturbed air that is immediately forward.

Windows for lidar sensors are mounted in upper and lower fuselage positions, while one cabin window may be swapped out for radar or infrared antenna systems.

Constant avionics updates enable precision navigation and global deployment. International research teams use the jet worldwide, measuring for trace gases and aerosols in flight and for the collection of air samples for atmospheric research.

Gathering data from altitudes as high as 42,000ft, sufficient to reach the lower stratosphere at mid-latitudes, the Falcon has proven itself a rugged platform capable of flying close to thunderstorms and within 30m (100ft) of an airliner engine.

Although operated by DLR, D-CMET has become particularly important as an environmental and climate research machine with the European Facility for Airborne Research (EUFAR), investigating a number of parameters, but with an overarching international focus on global climate change and ozone depletion.


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6 // The Falcon 20 cabin, equipped for atmospheric research

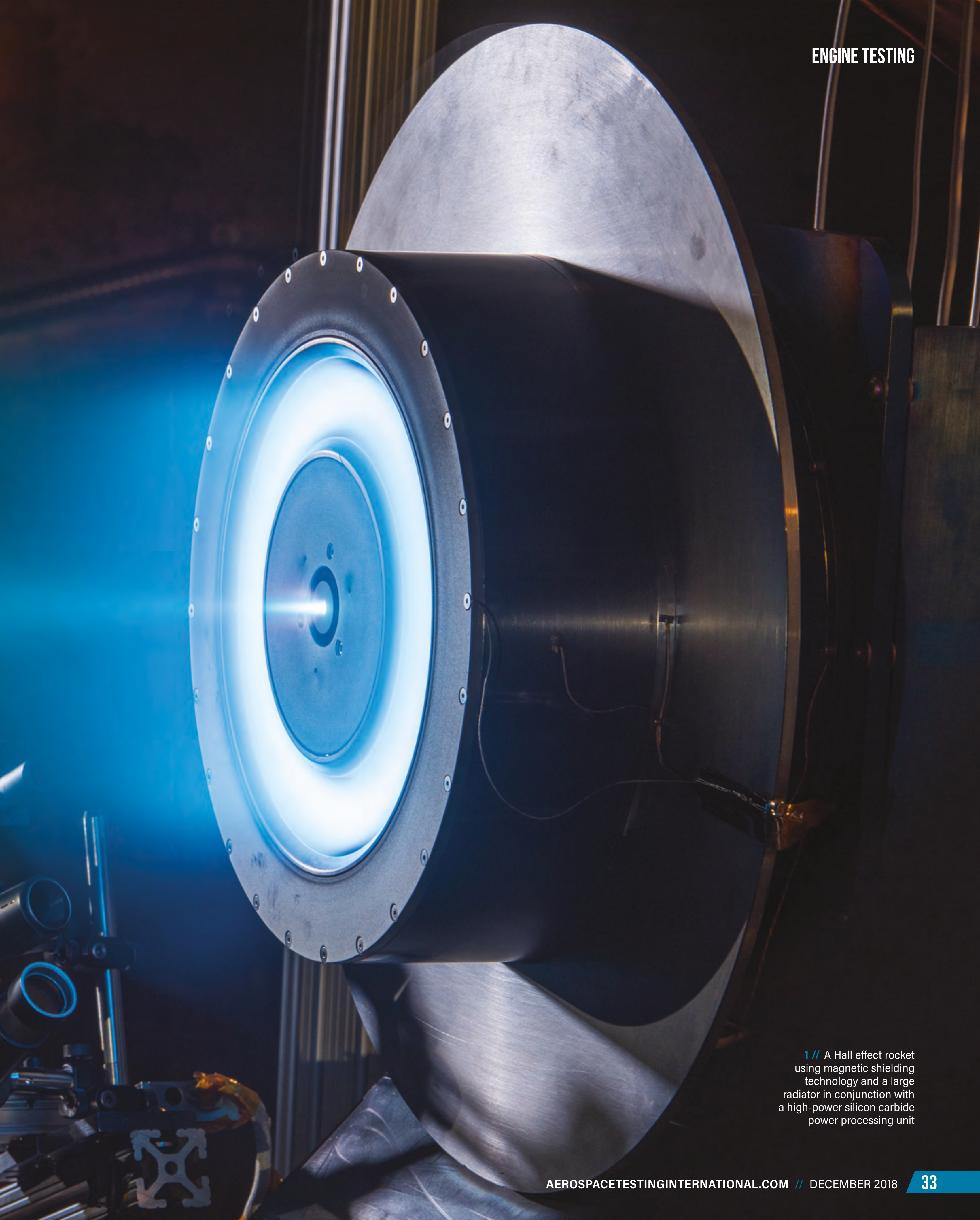
7 // Underwing hardpoints and a nose probe were added for the Falcon 20's research mission

(All photos: DLR)

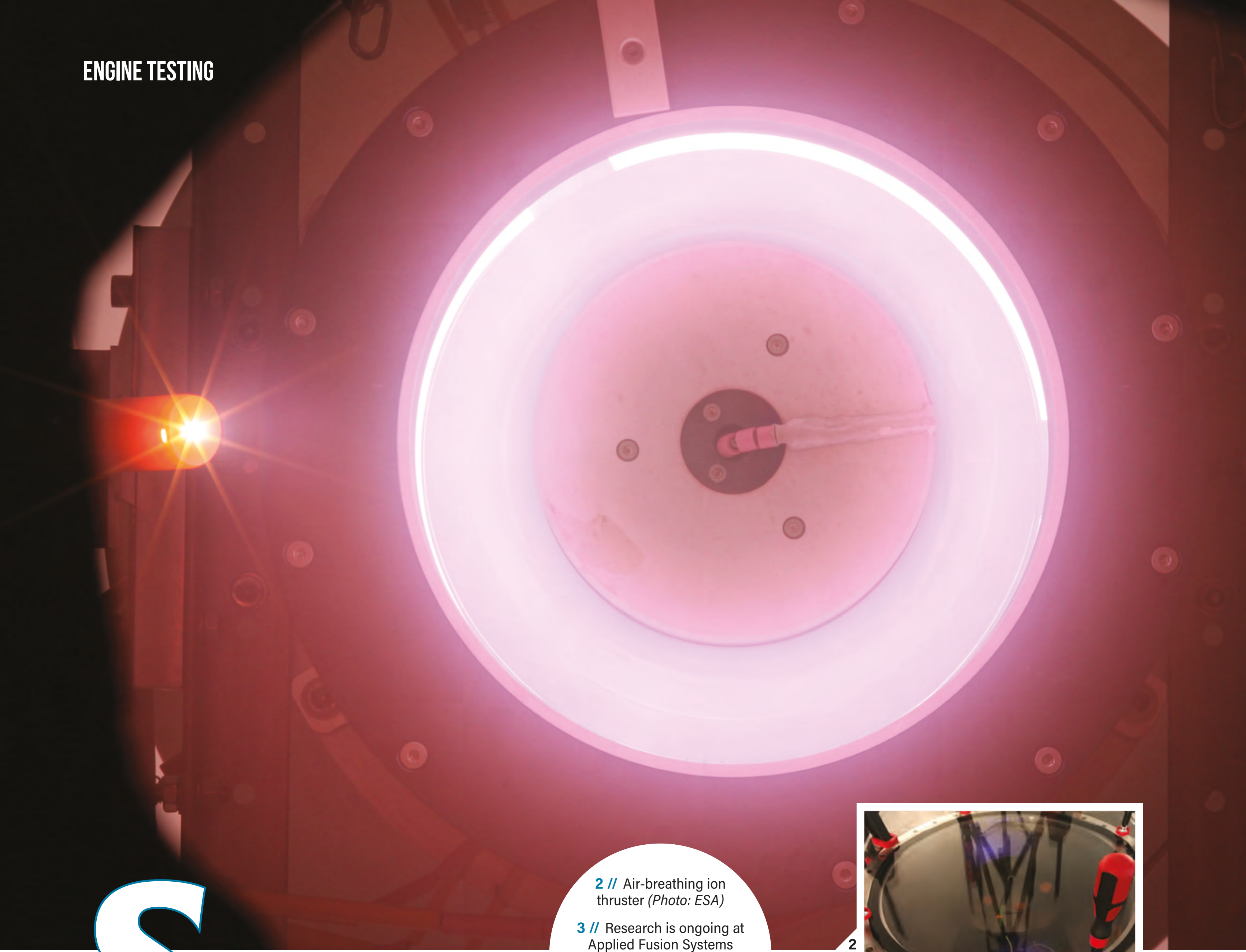
// PAUL WILLIS

Solving the plasma puzzle

Engineers developing ion thrusters and nuclear fusion reactors to propel mankind's push into deep space are facing some tough testing challenges here on Earth

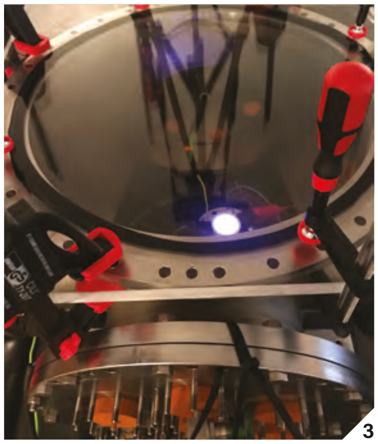


1 // A Hall effect rocket using magnetic shielding technology and a large radiator in conjunction with a high-power silicon carbide power processing unit



2 // Air-breathing ion thruster *(Photo: ESA)*

3 // Research is ongoing at Applied Fusion Systems



Somewhere in Princeton, New Jersey, a small team of physicists is hard at work making plasma in a lab.

Plasma, a superheated gas that is ionized or electrically conductive, is already around us in many forms. Lightning and neon signs are examples of partially ionized plasma. The center of the sun is fully ionized plasma. In the past two decades, plasma has entered the field of aerospace engineering through its use in ion thrusters. These small, plasma-powered engines are used on many modern satellites.

Plasma is made by subjecting a gas to a strong electromagnetic field. This causes electrons to begin breaking free of atoms, leading to the creation of positively charged particles known as ions. In an ion thruster, electric fields are used to push ions contained in a gas propellant out of the engine's nozzle at high speed to create thrust. "It's the same force that causes the hairs to stand up on your head if you were in an environment with a lot of static," says Dr Charles Swanson, a staff physicist at Princeton Satellite Systems, the NASA-funded startup involved in the Princeton lab tests.

One of the company's research projects is developing a Direct Fusion Drive, a 1-10MW rocket engine that could one day be used to propel a variety of space missions.

Plasma is a dangerous material to work with – not least because of the extremely high voltages necessary to create it. As a result, safety is paramount in the lab environment.

"Everything high voltage has to have ground-fault interrupters," Swanson says. "We wear safety goggles and big insulating gloves."

He and his team wear rubber-soled boots and only work with their right hands, keeping the left in their pocket at all times. This prevents the current from closing through the chest, keeping the heart safe in the event of an electric shock.

9 YEARS
to develop a prototype of Princeton Satellite Systems' ion thruster, which is fueled by a nuclear fusion reactor

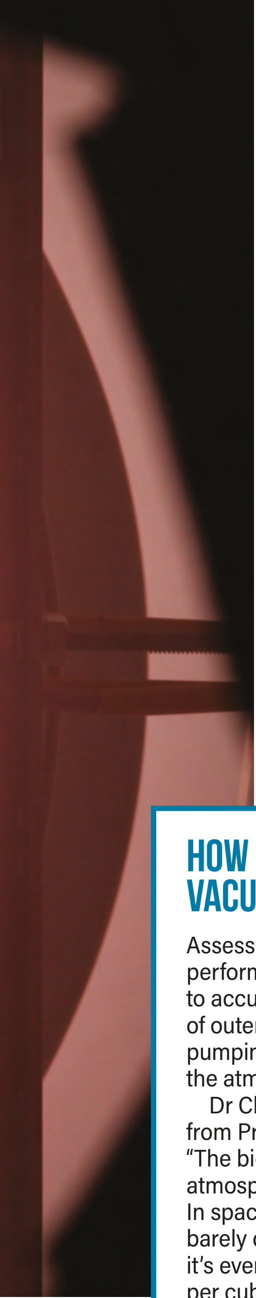
1-10MW
Target power of Princeton Satellite Systems' Direct Fusion Drive rocket engine

Swanson also wears a radiation dosimeter because at extreme heats plasma can actually generate x-rays. And the plasma does indeed get very hot.

"Our machine heats electrons up to hundreds of electron volts, which is the same energy they would have halfway to the core of the sun," he says.

NUCLEAR FUSION

To most, this level of heat is unfathomable. But for Swanson and his team it's only the beginning. They need to generate temperatures many orders of magnitude



4 // Ion and Hall effect thrusters are tested in vacuums at Applied Fusion Systems

5 // The team at Applied Fusion Systems believes nuclear fusion will be used for deep space exploration

years, the most conspicuous of which is the multinational International Thermonuclear Experimental Reactor (ITER) experiment, a massive donut-shaped fusion reactor currently under construction near Saint Paul-lez-Durance in southern France.

The reactor Swanson is developing for use in ion thrusters is much smaller – just 1.5m (5ft) across by 4-8m (13-26ft) long. But although building a small-scale fusion reactor to fit on spacecraft sounds daunting, it is not the hardest part of the work.

"Generating fusion power isn't the puzzle," Swanson says. "Significant amounts of fusion power were generated in the 1990s. The puzzle is converting the energy output from the reactor into thrust."

"Plasma is a dangerous material to work with... safety is paramount"

higher. Because Princeton Satellite Systems is not interested in making a conventional ion thruster. Its goal is to create a thruster powered by nuclear fusion.

To do this, the team must heat the ions in a plasma to temperatures so extreme that they actually fuse together. They aim to do this through a gradual approach, says Swanson.

"With this machine, after we perform some magnetic field upgrades, we expect to prove our mechanism for heating ions.

"From there, it will be a matter of scaling up. There'll be an intermediate machine, where we go from heating ions up to 1keV. Then with the next machine we expect to reach 5keV. The machine after that would be thermonuclear – dozens of kilo-electronvolts."

Creating this kind of heat is very difficult, but the pay-off in terms of energy output is huge. Fusion, after all, is what powers stars and its potential as an energy source of the future has led to a number of projects down the

Princeton Satellite Systems plans to solve the conundrum with an engine design composed of two layers of plasma – a super-heated core and a cooler outer layer. As hot ions from the core heat up the cooler plasma, an energy transfer will causes this outer layer to expand into a magnetic nozzle at the rear, resulting in thrust.

Swanson says, "It turns a hot, slow-moving plasma into a cold, fast-moving plasma. It's like the constriction in a conventional rocket nozzle – except it's all mediated by a magnetic field."

PROBING PLASMA

Princeton Satellite Systems isn't the only startup developing fusion-powered spacecraft. In a warehouse in Oxfordshire, England, engineers from Applied Fusion Systems are testing their own small nuclear fusion reactor to examine its properties as a thruster.

"If you can create the conditions for fusion, then the same device that is used to generate power would be capable of very fast exhaust speeds if reconfigured as a rocket," says Richard Dinan, CEO of Applied Fusion Systems. "I think we'll be deploying these devices in space before we're powering homes with them."

To fully understand how a fusion thruster will perform in space, Dinan's team must first recreate

HOW TO MIMIC THE VACUUM OF SPACE IN A LAB

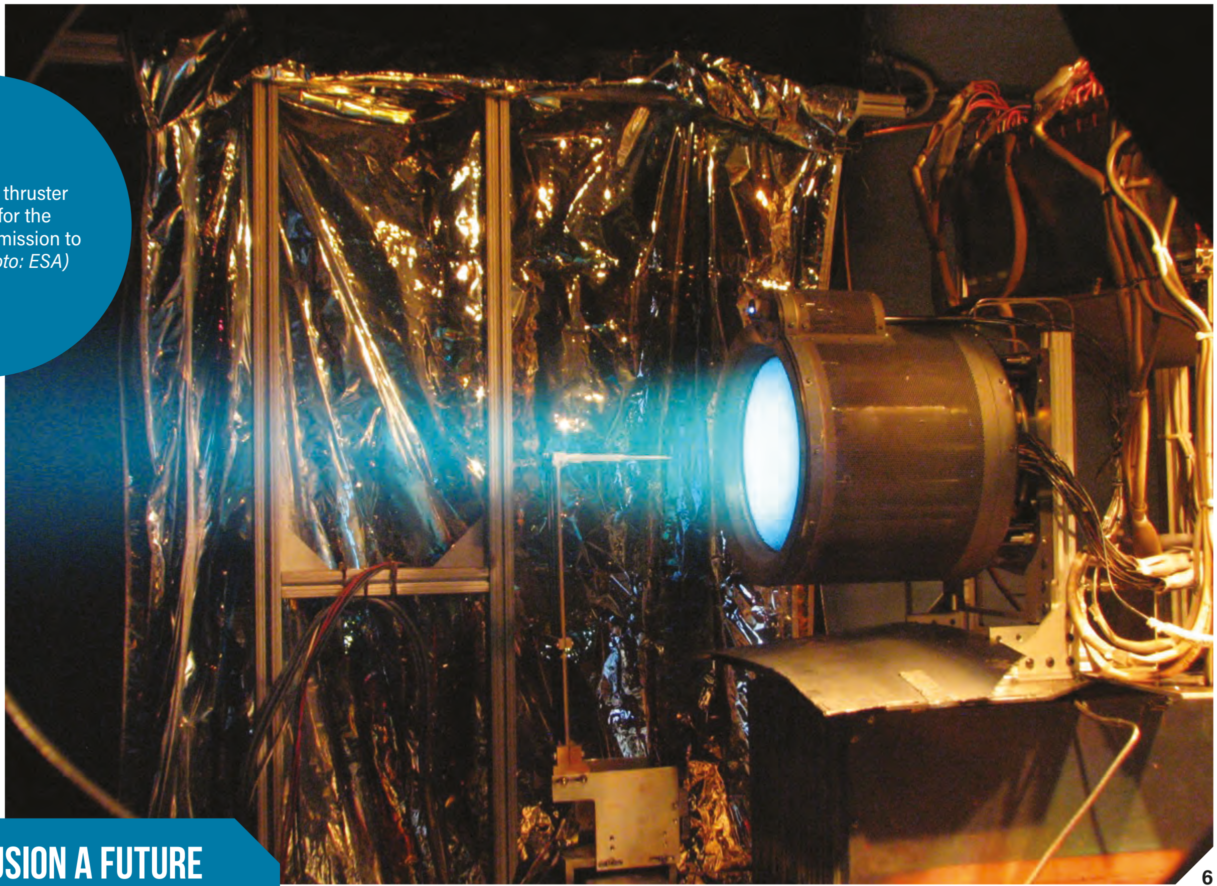
Assessing how plasma engines will perform in space requires test engineers to accurately recreate the conditions of outer space using a vacuum vessel, pumping out the gas inside to reduce the atmospheric pressure.

Dr Charles Swanson, a nuclear physicist from Princeton Satellite Systems, says, "The biggest difference between Earth's atmosphere and space is the gas density. In space, the atmospheric pressure is barely detectable, and in interstellar space it's even less, with only one or two particles per cubic meter. We use three types of vacuum pump in our lab."

The first is a mechanical pump, which gets the pressure down to a hundredth of an atmosphere. Below that pressure, the remaining gas stops acting like a fluid and begins acting like a collection of particles. "At that point, the piston pump doesn't really work any more," Swanson says.

The next pump is a turbo-molecular pump, which uses a turbine to force gas molecules out of the main chamber of the vacuum vessel into a smaller outer-chamber, where they can be pumped out by a more conventional pump.

"That can get you down to very low pressures – a hundredth of an atmosphere," he says. This is still not low enough to mimic the very high vacuums of interstellar space, however. For that, you need a cryopump, a metal plate that is cooled with liquid helium. "The plate gets so cold that gas molecules that hit it freeze and can be removed from the chamber," Swanson says.



6 // A T6 ion thruster under test for the BepiColombo mission to Mercury *(Photo: ESA)*

IS NUCLEAR FUSION A FUTURE FUEL FOR SPACE TRAVEL?

All space missions leaving Earth do so using a chemical propellant. However, once in orbit the large quantities of fuel necessary to travel into deep space would overload the spacecraft, dooming it to failure from the beginning. Dr Jason Cassibry from the University of Alabama says, "The rocket equation tells us that you need a small mass of reactor, relatively high exhaust velocity, and good-to-moderate thrust."

Ion thrusters are relatively lightweight and can generate a high velocity given sufficient time. But they're not powerful enough to power a manned space mission. Nuclear fission has also been touted as a possible method, but according to Applied Fusion Systems' CEO Richard Dinan, "It would be pretty inadvisable to be using something so unstable and reactive."

This is why many see nuclear fusion engines as the only viable alternative. A nuclear fusion reactor could generate adequate power, and be light and relatively safe.

"If you were to smash open a fusion reactor while it was switched on, there would be a puff of smoke and it would just break down," says Dinan.

the conditions of space on Earth. They accomplish this using a vacuum vessel. These are regularly used to test ion thrusters and their close variant, Hall-effect thrusters. Usually the thruster is mounted on cables hanging from the ceiling of the vacuum chamber – a configuration known as a thrust stand. The engine is powered up and the thrust generated causes the thruster to tilt. Measuring the angle of tilt enables engineers to calculate the thrust being generated.

For more in-depth analysis of an engine's performance, more complex measuring equipment is required, says Dr Jason Cassibry, a professor in aerospace engineering at the University of Alabama. "With fusion, depending on the type of fuel, you're most likely going to be looking at neutrons as the diagnostic to tell you how much energy is released," he says.

To measure neutrons, scientists use a scintillation probe, a device that works by generating photons in response to radiation and converts the light to an electrical signal using a photodetector and charge-coupled device. But in the case of superheated materials like plasma, use of the probes can become problematic, says Cassibry, "Any kind of probe that you stick in hot plasma is going to be so much colder than the plasma that it will affect the temperature of the material and you'll get a false reading. So you try to monitor it in a way that doesn't directly interfere with the plasma."

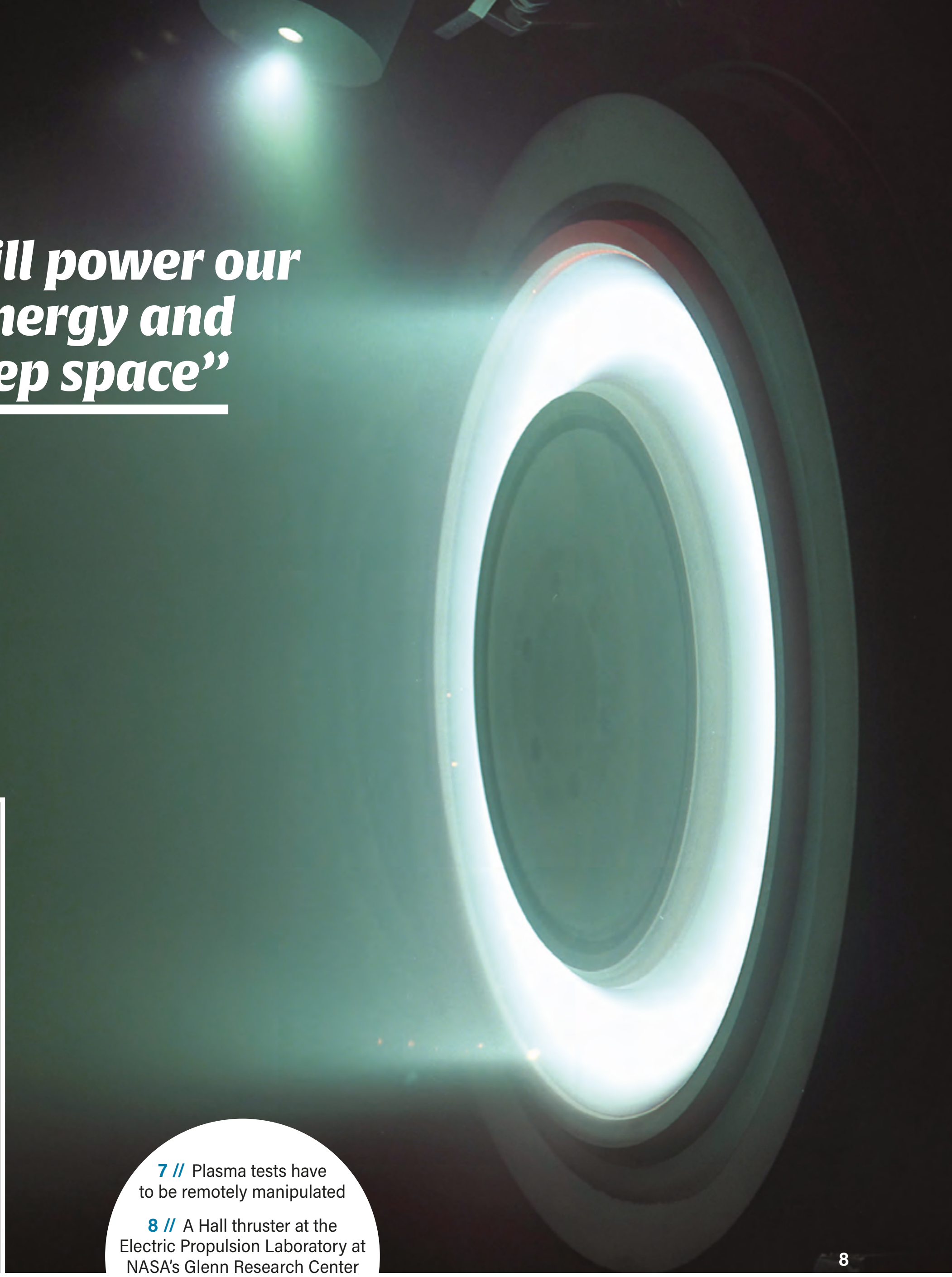
100MW
Planned electrical output of Applied Fusion Systems' first nuclear fusion reactor

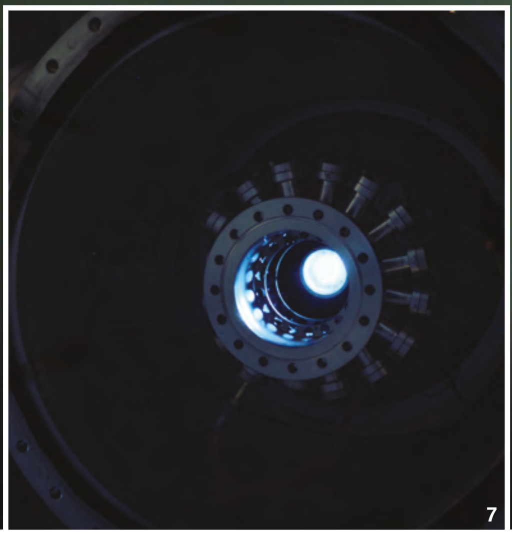
100,000,000
Temperature in °C required in plasma for nuclear fusion to occur (180,000,000°F)

Plasma is so hot that its electromagnetic spectrum is mostly in the x-ray region. Because of this, says Cassibry, x-ray diagnostics can be used by test engineers to look at the plasma and infer data about its structure, emissions and temperature without having to touch it.

Testing plasma engines throws up the added puzzle of how to manipulate and move things inside vacuum vessels. There are various solutions to this problem, says Swanson. He points to a robotic arm used in the Joint European Torus (JET), which

"Nuclear fusion will power our cities with clean energy and help us explore deep space"





7 // Plasma tests have to be remotely manipulated

8 // A Hall thruster at the Electric Propulsion Laboratory at NASA's Glenn Research Center

is the world's largest operational plasma physics experiment, located in the Culham Centre for Fusion Energy, UK. "It's the coolest robotic manipulator I've ever seen," he says. "But it's also very expensive."

A cheaper option is a Wilson seal. Swanson says, "It's a stainless-steel tube that fits inside another slightly larger tube with a rubber O-ring that you squeeze. It's the cheapest and most widespread way you can move things like probes in vacuum vessels."

RADIOACTIVE REACTIONS

The production of nuclear energy normally results in radioactive waste. But neither Swanson nor Dinan's research should produce more than negligible levels of radiation. In both cases the fuel combination they plan to use is deuterium and helium-3, neither of which is radioactive. "There's no radiation generated at all in the test phase," says Dinan. "Whereas with nuclear fission you'd needs guards, guns and government. That's not something a private corporation can do."

Despite all their hard work, Swanson and Dinan acknowledge that nuclear fusion space rockets are still in the very early stages of development. Swanson's team at Princeton Satellite Systems expects each of its test engine upgrades to take three years, meaning it will be at least 2028 before there is a working prototype. But those involved in the development of fusion power are used to long research projects. Construction of ITER in the South of France started in 2007 and the experiment isn't scheduled for completion until 2025. ITER aims to prove fusion power is technically feasible. Engineers believe it won't be until 2050 that a power plant capable of producing electricity from fusion will be built.

According to Dinan, the wait will be worth it. "As far as nuclear is concerned, so far we've only gone after the ugliest side of it," he says. "But the same technology that gave us some of the worst things mankind has ever done will give us some of the best things we will ever do. Nuclear fusion will power our cities with clean energy and help us explore deep space."

Cassibry also believes that fusion is the future of space travel. He says, "To go into deep space we'll need nuclear power of some sort. Deep space manned missions require a lot of energy and the smallest mass of reactor you can get.

"Solar won't work because when you get past Mars there's not enough sunlight – the power falls right off. Going to Saturn right now takes 10 years. If you want to get there in a year, you're going to need fusion." \\

Paul Willis is a freelance journalist based in the USA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// DAVID SMITH

1 // With its AS2, Aerion is one of several companies developing supersonic commercial aircraft designs

BO

Engineers are preparing to flight test supersonic aircraft designs that could see commercial supersonic aviation in our skies for the first time in decades

Beating the OM

> **“The hardest part is designing the tests to keep the shockwaves spaced equally at the back”**

Concorde’s sonic boom sounded like a mortar bomb going off and could rattle windows on flight paths. Although the loud bangs annoyed people, it wasn’t noise that ended Concorde’s life, after 27 years of operation, in 2003. Instead, it was the harsh commercial reality of operating a supersonic aircraft and the publicity from a terrible accident that ended aviation’s supersonic dream.

However, recent studies by aviation authorities and government bodies around the world show that the public are more intolerant of aviation noise than ever before. Most experts believe commercial supersonic aircraft will never return to the skies, unless a way is found to eliminate sonic booms. Fortunately, after decades of research and testing, NASA engineers are close to solving the problem.

COMMUNITY TESTING

NASA has been developing simulation models for its Low-Boom Flight Demonstration (LBFD) project, and tests on the ground, including in wind tunnels, suggest they can reduce the boom to a ‘sonic thump’ that would be acceptable to the public. The next stage in LBFD is to test the theories in flight. NASA recently awarded Lockheed Martin a US$247.5m contract to build the supersonic X-59 test airplane to demonstrate its Quiet Supersonic Technology (QueSST). The X-59 will cruise at 55,000ft at 940mph (15,000km/h) and should create a sound around 75PLdB (Perceived Level decibel) on the ground, about as loud as a car door closing.

After QueSST’s initial demonstration two years of testing from mid-2022 will involve flying over residential areas of cities in the USA to gauge public reaction. It’s a long process, but NASA hopes its test results will satisfy regulators at the Federal Aviation Administration (FAA) and the International Civil Aviation Organization (ICAO) and ideally lead to a standard for the design of low-boom supersonic air planes by 2025.

“Tests over cities are critical because we need to understand if people accept the sound of a low-boom supersonic aircraft. It could still be irritating to some and regulators need information with which to set acceptable noise levels,” says Peter Coen, NASA’s commercial supersonic technology project manager.

“People’s attitude to noise has changed. Most noise from aircraft is now localized around airports. But with supersonic aircraft everyone is potentially exposed.

“The ultimate goal of the LBFD project is to do the community tests with the experimental X-59. We’ll have sensors in communities and compare public responses to different noise levels.”

WIND TUNNEL RESULTS

NASA has been conducting wind tunnel tests with an X-59 model at the Langley Research Center in Hampton, Virginia. The tests are carried out in a 12ft (3.6m) tunnel to collect low-speed aerodynamic stability and control data, which is then used to develop simulation models and refine vehicle flight controls.

There are three phases – static stability and control tests, dynamic forced oscillation tests, and flow visualization tests using smoke and laser techniques. During the oscillation tests, NASA’s engineers measure the aerodynamic damping derivatives as the X-59 model is put though roll, pitch and yaw motions. The damping

2

THE SUPERSONIC TEST PILOT’S VIEW

In 2019, supersonic aircraft developer Boom’s chief test pilot Bill Shoemaker will fly the company’s XB-1 prototype – a two-seat, Mach 2.2 supersonic demonstrator aircraft – for the first time. The flight test program will let test pilots learn about flight dynamics, vital in refining flight controls.

Shoemaker’s role is not confined to flying the airplane. He is involved in testing XB-1’s engines and the results have already fed back into the design. He says, “We will extensively test all systems before the first flight. As the maturity of those systems advances, our testing will become more and more representative of flight conditions.

“Executing a safe and efficient flight test campaign on a prototype aircraft requires planning based on detailed knowledge of systems. I spend a good deal of my time developing my understanding of XB-1’s design and identifying potential vulnerabilities in our approach to testing it.”

There will be key differences between the XB-1 and the final aircraft. While both are primarily built from carbon fiber and will feature Boom’s variable-geometry engine intake design, the XB-1 demonstrator will use the latest engines and a hydro-mechanical flight control system, whereas the airliner will have engines that incorporate the latest advancements and fly-by-wire flight controls, which considerably improve its handling. “Without fly-by-wire controls, the XB-1’s handling qualities will present challenges to test pilots, but this difference is natural given the XB-1’s role as a demonstrator aircraft,” says Shoemaker.

"X-59 will fly at between Mach 1.6 and Mach 1.8, allowing for the use of an engine with a higher bypass ratio and a top-mounted engine inlet"

4

3

derivatives are able to model aircraft response to inflight turbulence. The smoke and lasers then illuminate the airflow, which provides insights into how the vortices created by the wings and canards behave.

"The wind tunnel tests are highly accurate simulations that give us detailed measurements of the pressure fields around the model X-59. The results make us pretty confident that our computational fluid dynamics [CFD] are working," says Coen. "The hardest part is designing the tests to keep the shockwaves spaced equally at the back, where lots of pieces interact, such as exhausts, tail and trailing edge of the wing. It has to be a sensitive design."

SOUND RESEARCH

Before the X-59's design is finalized, NASA has also conducted tests with its own LBFD aircraft this November. The flight series, called Quiet Supersonic Flights 2018 (QSF18), used a F/A-18 research aircraft to perform supersonic dives that produced a soft sonic thump over residential areas in Galveston, Texas.

The F/A-18 dived from 49,000ft and briefly went supersonic, before recovering to level flight at approximately 30,000ft. NASA engineers installed audio sensors on the ground to measure the acoustic levels. The main goal of the tests was to refine the techniques used for collecting community response data, but the flights also provided data to support new noise standards for supersonic flights over land.

"The Galveston tests were an important precursor to the X-59 project because we need to learn the best ways of engaging communities, conducting surveys and collecting acoustic data. We've done similar research flights before to prove that our flights are safe

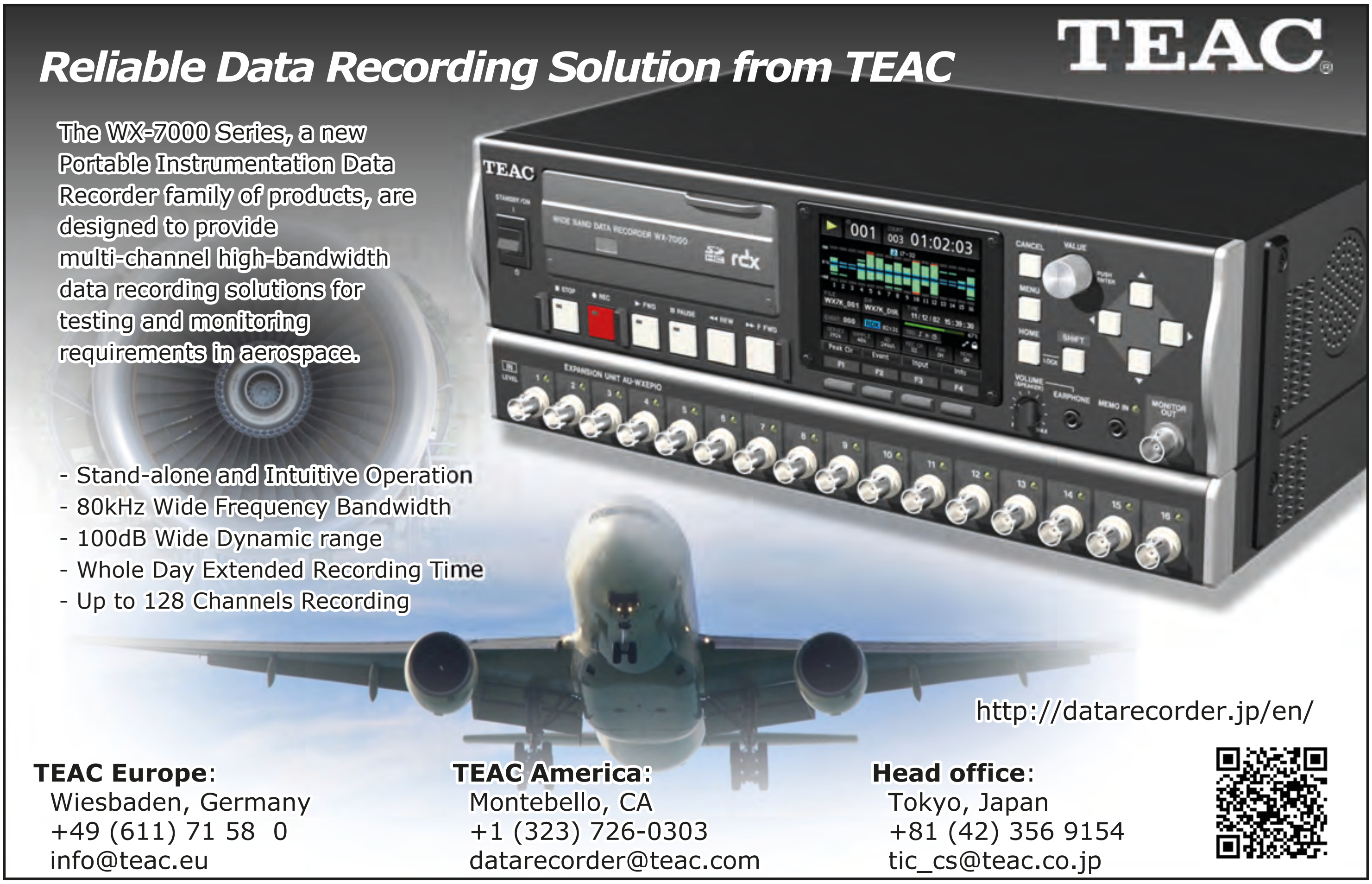
1,600MPH
Maximum speed of Boom's XB-1 test aircraft

6,200 MILES
Maximum range of the S-512 Quiet Supersonic Jet from Spike Aerospace

2 // A sub-scale X-59 model undergoes testing in the 12ft low-speed wind tunnel using smoke and lasers to gather data (*Photo: NASA/David C Bowman)*

3 // A NASA F/A-18 at the Kennedy Space Center, Florida, before it takes off to measure the effects of sonic booms

4 // Interior of a NASA F/A-18 during a supersonic test flight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5


6

"The most important aspect is the shape – the outer mold line and what's touching the air"

and that the sounds that we plan to create are not damaging," says Coen.

AERODYNAMIC SHAPING

The separate projects will lead to extensive testing of the X-59 itself in early 2022. A number of ideas are influencing the experimental aircraft's design, to quieten noise levels by around 30dB. For example, X-59 will fly at between Mach 1.6 and Mach 1.8, rather than Concorde's Mach 2, to allow the use of an engine with a slightly higher bypass ratio and a less complicated top-mounted engine inlet. In addition, NASA has designed exhaust nozzles that mix slower and higher speed flows more effectively to cut jet velocity. It slows down the blast from the back of the engine, reducing noise.

But the main noise-reduction technique is to redesign the aircraft to reshape the acoustic signature. A sonic boom consists of a double bang on the ground that is caused by two large pressure pulses. As the random shockwaves travel away from the aircraft at the speed of sound, they pile up and coalesce. The engineers aim to reshape the acoustic signature of the boom by preventing sonic waves piling up.

"You shape every aspect of the airplane to make the shockwaves as close to equal strength as you can. When they're as evenly distributed as possible along the length of the airplane, changes in temperature are small and the waves don't coalesce. When the signal reaches the ground, it's smeared out. Instead of two loud bangs, there's a pressure change and a soft thump," says Coen.

Once NASA accepts the aircraft from Lockheed Martin in late 2021, it will perform additional flight tests to prove the technology works and the aircraft is safe. It will then fly multiple times over arrays of microphones in the desert near the Armstrong Flight Research Center in California. Engineers will collect data showing NASA the ground signature, and how it varies in different atmospheric conditions. Then the acoustic validation phase will begin.

940MPH
Cruising speed of the X-59 QueSST experimental aircraft

2021
Year that engineers plan to fly the X-59 QueSST experimental aircraft for the first time

GROUND AND AIR MEASUREMENT

According to Coen, testing will first seek to improve the understanding of how the acoustic signature behaves near the aircraft as well as on the ground.

There are a couple of techniques available to engineers. One is air-to-air probing, where the X-59 is flown at a steady level while another aircraft with a measurement device mounted on a nose boom flies in formation. The second aircraft flies in and out of the X-59's acoustic signature, so it can collect details of the pressure on the near field.

NASA plans to use a similar technique to measure the acoustic signature before the aircraft passes through the turbulent atmospheric boundary layer. A motor glider equipped with a microphone sensor system will fly to 10,000ft and record the signal there, as well as in the clean, smooth air of Earth's boundary layer.

5 // Artist's impression of the X-59 research aircraft in flight (*Photo: NASA)*

6 // Peter Coen, NASA's commercial supersonic technology project manager

"We can take an image of an airplane in the air and get a detailed look at the shockwave pattern emanating from it"

7 // Researchers prepare a weather balloon as part of NASA's Sonic Booms in Atmospheric Turbulence research project

NASA has also invented a testing method called Background-oriented Schlieren (BOS) photography. This method adapts the Schlieren technique used in wind tunnels to visualize the patterns of shockwaves by altering the light paths that enter the camera. The shockwaves become visible when they cause differences in density.

"Our new technique is exciting," says Coen. "It takes advantage of advances in digital signal processing to make shockwaves visible in almost any environment, including an airborne situation.

"We can take an image of an airplane in the air and get a detailed look at the shockwave pattern emanating from it. Both the Schlieren and air-to-air probing will tell us what's going on with the flow around the airplane, so we can diagnose any problems with the acoustic signature."

COMMERCIAL RIVALS

NASA is not the only organization working to bring about supersonic flight. Startup Boom's XB-1 two-seater prototype will be flight tested for the first time in 2019 and should be capable of Mach 2.2. The regional aircraft Boom is developing has a similar design to Concorde, but Boom says that new materials and technology will enable it to fly faster and more quietly.

Boston, Massachusetts-based Spike Aerospace is also developing a low-boom signature supersonic business jet, the 18-passenger S-512 Quiet Supersonic Jet. Spike intends to have the S-512 aircraft flying by early 2021, with customer deliveries beginning in 2023. The S-512 will have a range of 6,200 miles (9,977km) and a cruise speed of Mach 1.6.

Meanwhile, Aerion has also partnered with Lockheed Martin to develop the AS2 aircraft that can fly at Mach 1.2 with no sonic boom. It will be a small supersonic business jet for around a dozen passengers, launching in 2025.

Jeff Miller from Aerion says the AS2 will meet Stage 5 take-off and landing noise standards that come into effect in 2020. It will be the first in a family of increasingly capable supersonic engines. Aerion is carrying out standard wind tunnel tests and vibration tests on various components at rig level. But, as in the NASA project, flight testing will be essential to assess reliability in a range of conditions and tests at supersonic speeds will mainly be conducted over water.

Aerion's noise-reduction strategy is different to NASA's. The AS2 will operate at speeds up to Mach 1.2 without a boom reaching the ground, Miller says. "This is technically known as Mach cut-off flight, but we call it boomless cruise. Rather than aerodynamic shaping, we will use onboard and remote sensors to evaluate atmospheric conditions and limit cruise speed to a setting at which a sonic boom would refract off warmer layers of the atmosphere or dissipate before reaching the ground," he says.

However, Aerion is monitoring NASA's low-boom tests with great interest and could incorporate it into future aircraft.

Although NASA sees the sonic boom as the main commercial barrier for supersonic flights, there are other important concerns, Coen says.

"We're focusing on the sonic boom problem for now, but we've not taken our eyes off two other important issues – take-off and landing noise and emissions. We've already made progress in those areas and when we finally break the sonic boom problem, we'll turn our full attention to the other issues," says Coen.

With a viable design, testing techniques, expertise and funding, all of the necessary pieces are in place for aircraft manufacturers to reintroduce commercial supersonic aircraft to our skies after 2025. All eyes will be on the QueSST and the LBFD program over the coming years to see if NASA's engineers can beat the boom once and for all. \\

THE QUEST FOR QUIETER SUPERSONIC BOOMS

Established by NASA, the X-59 Quiet Supersonic Technology (QueSST) began life in 2013 as a concept feasibility study to consider how to design an aircraft that would meet the noise requirements of 75PLdB (Perceived Level decibel).

By 2016, an airplane with a long, slender shape had been designed. Members of the NASA team worked in collaboration with Lockheed Martin, using wind tunnel testing and CFD (computational fluid dynamics) analysis to monitor if the design would meet the 75PLdB level. The design generates pressure signals that are representative of larger commercial transports, but the aircraft is smaller and only carries a single pilot.

The X-59's shape is the key to the low signature boom. Peter Iosifidis, Low Boom Flight Demonstrator program manager at the Lockheed Martin Skunk Works, says, "It's not about the material or the level of attention to screws, bolts or seams. The most important aspect is the shape – the outer mold line and what's touching the air.

"To achieve the low-boom signature, every inch of the airplane must meet the design criteria. The aircraft's long pointed nose, the sharply swept wings and the shape of the canards ensure the individual pressure waves, which are produced at speeds faster than Mach 1, never converge to cause a traditional sonic boom."

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Shake & bake

The Element laboratory in Warwick, UK, has to be able to conduct many types of tests while staying in front of technology and standards

1 // The bulk of the work done by the Element Warwick Laboratory is environmental testing for the aerospace sector

2

3

2 // The laboratory in Warwick conducts dozens of tests daily

3 // Test equipment and controls are constantly upgraded to keep pace with technology

The main laboratory floor at Element's Warwick facility is a long rectangular strip of environmental chambers, test cells and machines. There are a lot of machines: for heating things up, cooling things down, shaking things, driving sand at things and dropping things. There are instruments for measuring and recording, data acquisition systems and computers for analyzing data. Interspersed are the things being tested, sometimes sitting atop complex metal fixtures. Employees are busy, consulting test plans, making adjustments to tests or looking at graphs on screens.

The Warwick laboratory covers 42,000ft^2 and is the largest independent UKAS (United Kingdom Accreditation Service) accredited environmental test facility in the UK. It employs 45 full-time engineers and technicians. Around 75% of the testing performed at the laboratory is for the aerospace sector, for clients ranging from large OEMs such as Airbus, Rolls-Royce and UTC Aerospace, to Tier 3 component suppliers in the commercial and defense sectors.

The products being tested vary from large structural elements of aircraft down to small electronic components such as microchips and circuit boards. "It's mainly products for future deployment. Customers come to us before manufacturing for development and qualification testing," says Stuart Brown, general manager of the laboratory.

However, Element Warwick isn't just about physical testing. On the floor above the laboratory is a team of engineers designing in CAD and running FEA simulations. This Early Stage Qualification (ESQ) team helps clients with test procedures and designs the fixtures that hold objects under test while being subjected to shock and vibration. This is key, because a poorly designed fixture could adversely affect test results or cause damage. "We run the simulations to ensure we're not creating unwanted resonances," says Brown.

120
Runs conducted for ditch testing of the C919

3,000HZ
Maximum frequency of Element Warwick's new shaker

TESTING HOT AND COLD

At first the laboratory floor, with its bustle and various activities, seems chaotic – but slowly the organization reveals itself. Dominating the center are eight vibration test cells that house the largest and most valued pieces of test equipment.

Closest to the office area and ESQ team is a section for bespoke testing, where hydraulic, pneumatic and fatigue testing is conducted. A common sight here are items such as fuel pumps, which are fatigue tested using cyclical and differential pressure testing.

Next to the bespoke testing area on one side of the laboratory are 20 environmental chambers of various sizes and types. These can recreate temperatures as low as -73°C (-99°F) and as high as +500°C (932°F) and various humidity levels at altitudes of up to 90,000ft (27,000m). There is a corrosion testing chamber, where entire products can be tested for up to and beyond 10 weeks and a driving sand and dust chamber. Products are placed inside this chamber on a stand and blasted with dust and sand particles of a standardized size to check they do not cause clogging and to measure levels of abrasion.


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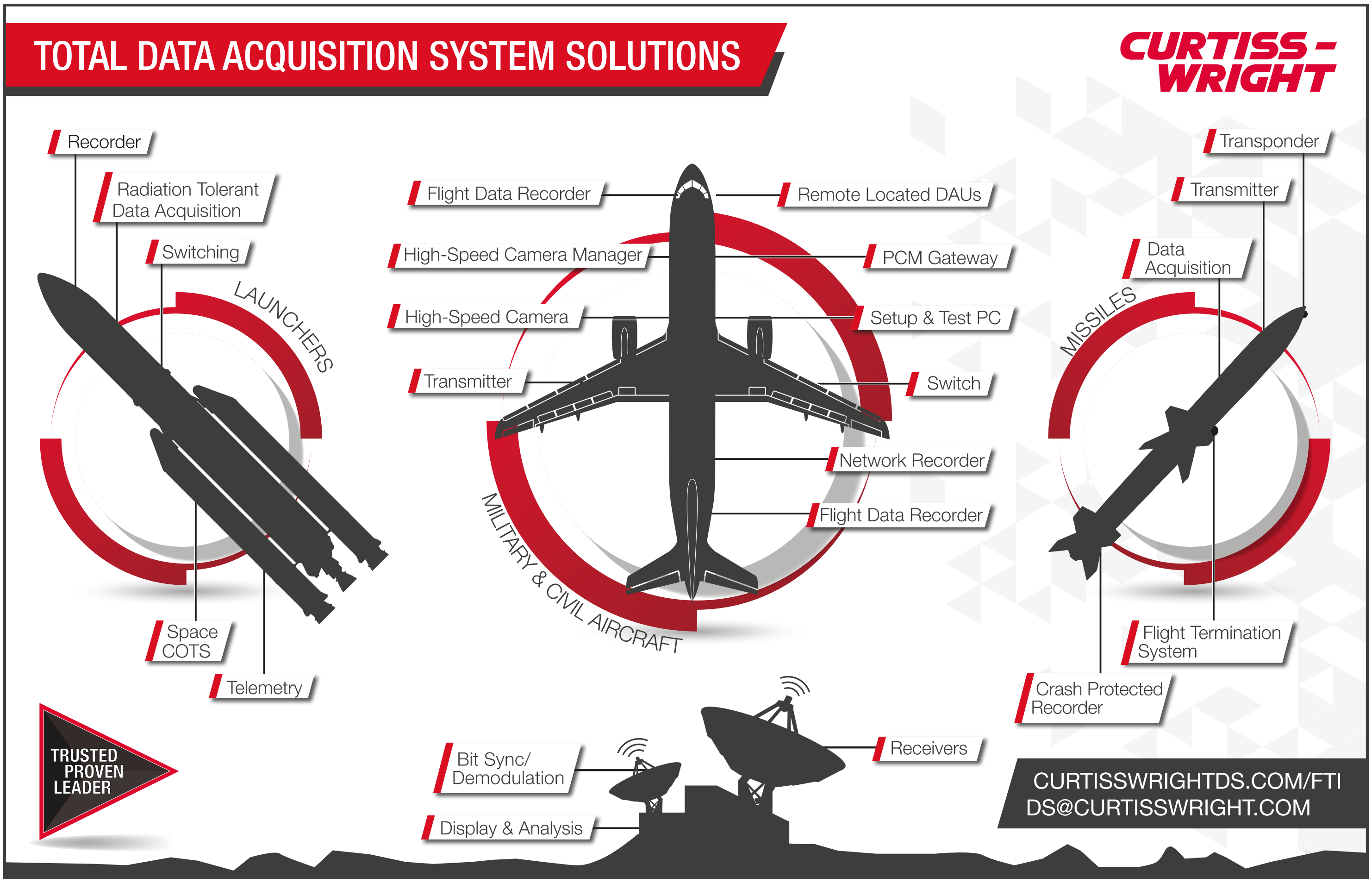
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PHYSICAL TEST VERSUS COMPUTER SIMULATION

Element's approach to testing is to create an environment for the test that is the best simulation of the real environment. Engineers will also integrate computer simulation and analysis with physical testing.

Stuart Brown, general manager of Element's Warwick Laboratory, says, "In aerospace, development analysis gets you to around 70% of the right answer. Testing gets you much closer, but not quite 100%.

"When you combine the two you get a really powerful tool. A lot of our bigger customers combine their in-house analysis with our results in order to validate and improve their modeling."

However, he believes there will never be a time when physical testing is not required. "Aerospace is littered with businesses that decided not to do testing and to just do analysis. They don't last long. And you won't optimize if you just do testing and don't do analysis. It needs a hand-in-glove approach."

"In-depth analysis of the fixture is required when testing at higher frequencies"

"Clients choose us because we can do all their testing in one place – temperature, humidity, dust, salt, fog, altitude, acceleration, shock, highly accelerated lifecycle tests [HALT], high cycle fatigue [HCF], bounce and vibration," says Brown.

SHAKING AND MOUNTING

The Warwick laboratory's eight vibration test cells each have a retractable roof to reduce noise and to enable test objects to be craned into position. Each cell houses a shaker able to deliver forces larger than 25kN. The laboratory's two largest shakers are 160kN LDS V984s. The impressive machines weigh 18 tons, are water cooled, can move test objects of up to two tons in three axes on a table up to 2.1m wide (7ft) and can be swapped between horizontal and vertical configurations. They are connected to a 32-channel M+P VibRunner control and monitoring system.

Vibration is the highest value testing conducted at the laboratory, so the process has been streamlined as much as possible to provide customers with their reports as fast as possible. Each cell has four analog lines and four Ethernet lines connected to a sleek control room with several controllers. This reduces complexity, noise and drop-outs. Software is standardized across all the machines and engineers use an automated documentation program to collate test results and output them into a single Microsoft Word file. "The documentation software has turned a part of the job that took up to three days into one that takes a few minutes," says Brown.

Away from the vibration test cells is a fabrication and storage area for the fixtures. A new fixture is made here every day in the workshop, which employs four technicians. On the opposite side of the laboratory to the test chambers are a number of smaller, self-contained test cells, where most HALT and HCF tests are conducted on many components and products, ranging from turbine blades from Rolls-Royce engines to cell phones. The equipment used in these test cells is smaller – air jets to create vibration and non-contact measurement tools such as laser vibrometers.

RESPONDING TO NEEDS

Environmental testing is slow to change compared with, for example, EMC testing. Nevertheless a current major trend in environmental testing is the continual drive for improved fuel efficiency in commercial aviation. This is affecting aircraft engines and the areas around them in particular. As a consequence, testing in and around the engine is becoming more difficult, with engineers having to recreate higher temperatures, speeds and pressures.

The Warwick laboratory will soon install a shaker capable of testing at high levels of up to 3kHz to help meet this need. Brown says, "The new system will give customers in Europe something they've never had access to before.

"Engine manufacturers want to test at these levels – engines are running hotter and at higher pressures, which transfers to higher frequencies and greater *g*-levels.

"Vibration is the most complex testing we do. The bigger the product the more complicated it becomes. Testing at higher frequencies is also harder. You have to do in-depth analyses of the fixture you are connecting the product to."

Mark Heaven, director of global aerospace product qualification

6 // Lifecycle and fatigue testing for smaller products and components are conducted in dedicated test cells

testing, says, "It's not just about vibration. It's about being able to control the product during the vibration cycle so that you drive the energy into the right parts. Otherwise you can waste a lot of time and money by not testing properly and damaging the test equipment."

Another complex area the laboratory handles tests for is parts for helicopters and turboprop aircraft. The vibrations in lower frequency areas give lower blade passing frequencies, so 'sine on random', or 'random on random' with swept tone testing is necessary.

"Those tests can be really complicated to program and to control, but we have the experience and expertise to do it," says Brown.

ELECTRIC PARTNERSHIPS

Heaven anticipates that the emergence of electric and hybrid aircraft is another trend that will cause a change in environmental testing. Electric generators on new aircraft are becoming more common and the first smaller, all-electric aircraft will start to operate in the early 2020s. "An electric propulsion system is different from what we deal with now, so different stresses and issues will have to be dealt with," says Heaven. "But it's still similar. We will deploy a testing service that meets customer need. Standards tend to lag behind technology, so we have to keep ahead of technology."

42,000FT²
Size of Element Warwick's laboratory

18 TONS
Weight of the laboratory's LDS V984 shaker

The best testing programs therefore usually start with a discussion with clients and continue with consultation throughout. Heaven says, "We are a facility that can be used when needed in a comfortable, connected way. It's no longer a gated process for testing to standards. Our level of involvement with clients is much higher."

Brown agrees that this close partnership approach is the best way to run tests. "We can do something very prescribed or we can invent something highly bespoke. It depends where the problem is.

"It's difficult for aircraft manufacturers and suppliers. The specification will be for things that haven't been made yet and will be in service for 25 to 30 years." \\

C919 DITCHING TESTING

One of the most unusual and technically accomplished tests recently performed by Element's Warwick laboratory was a scale model ditching test for Chinese aircraft manufacturer COMAC's C919. The laboratory has performed controlled ditching tests, which are a requirement for certification, for two other aircraft, including the Mitsubishi Regional Jet (MRJ). "It's the ultimate environmental test of the aircraft and its airframe in very difficult conditions," says Mark Heaven, director of global aerospace product qualification testing.

Element was contracted by COMAC in November 2016 to perform the tests. Engineers from the Warwick laboratory first built an accurate 1:14 scale model of the C919 from the original CAD models. It was constructed from balsa wood and can be split into separate parts and configured with different scale strength attachments to the engines, flaps, and front and rear spars. The model is designed and built so that it behaves in exactly the same way as the full-scale aircraft. "It's remarkably difficult

to build. You have to get the drawings and the model right and the placement of the instruments right," says Heaven.

Once the model was made, a 3D laser scan was performed and compared with the full-sized aircraft, to ensure conformity within a very tight tolerance. The model was loaded with sensors and instrumentation, including accelerometers positioned at the front, middle and back and a 360° gyroscope in its center. It was then taken to the Hydrodynamic Research Agency in Wallingford, Oxfordshire. Here Element's engineers repeatedly catapulted the model into a large wave tank at different velocities, weights, moments of inertia and approach conditions such as pit, roll and yaw. A total of 120 runs – 90 in calm water and 30 in scaled waves – were conducted. During the tests, the model was landed on different parts of the wave in a number of different altitudes. Tests with head seas were performed last because they are the most damaging to the model.

Measurements recorded during the ditch tests included the pressure across the model, particularly the bottom. The results give COMAC information about the flight parameters, such as which angle of entry gives the best chance of survivability when the aircraft lands into water. The information is used in the pilot's manual.

General manager of the Warwick laboratory Stuart Brown says, "The moment of inertia is important to get right and one of the hardest aspects. We have to ensure we have stable flight, so we built a small spoiler into the model to trim the approach conditions as we do not have a scaled pilot.

"The model ditched really well and yielded a large amount of quality data for the customer."


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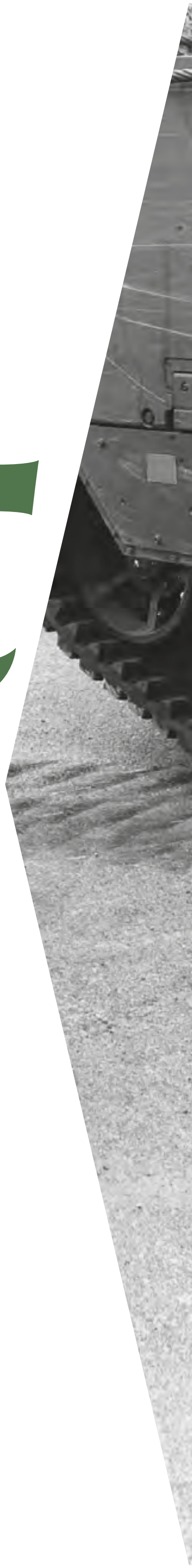
Rocket man

In a remote part of Norway, a group of engineers are using the latest equipment to test ammunition and rockets



1 // Trond Aasmundstad has managed Nammo's Raufoss Test Centre for 20 years

"The most important thing is people's attitude towards safety"

> **“The last round hit the side of the barn and ended up in the pigsty; when the test finished, the police came”**

Norwegian aerospace and defense company Nammo not only has some of the most advanced test facilities and equipment in the world at its Raufoss facility, it also has decades of experience.

The Raufoss Test Center’s manager, Trond Aasmundstad, has managed activities there for the past 20 years. In this interview, he tells *Aerospace Testing International* about running the busy facility, handling multimillion-dollar test programs, and pigsties.

WHY DID YOU CHOOSE AN AEROSPACE CAREER AND WHAT WAS YOUR FIRST JOB?

My background is in the military. I went to the Naval Academy, trained as an engineer and served on many submarines, before I became a chief engineer on one. When I started my civilian career, I wanted to use my military background. I ended up in Nammo, which at the time was known as Raufoss Ammunition.

Since then, I’ve had a few different positions in the company – quality assurance, international sales, and for the past 20 years, testing.

Military and civilian are two different worlds, but knowing military systems helps a lot when you are working with ordnance products. Producing ordnance is a very different experience from using it.

WHAT IS YOUR CURRENT POSITION AND WHAT DOES IT INVOLVE?

I manage Nammo’s Raufoss Test Center. I am responsible for all the activities there. We test all of Nammo’s products and products for commercial customers. It’s mainly ammunition, rockets and rocket motors for civilian and military applications. We do a lot of the testing for the Norwegian defense force, including all of its maintenance testing for ordnance.

We have a big civilian customer base, within space, automotive, and oil and gas. We do a lot of environmental testing for them – climatic, vibration and shock – a lot of safety tests at extremes. We simulate climatic conditions using a variety of chambers.

Raufoss is the largest testing laboratory in Norway. It is a certified NATO National Test Center and Nammo’s only fully equipped test facility.

WHAT IS A TYPICAL DAY FOR YOU AT WORK?

We do about 20 different tests on a normal day, which means we start very early, around 6:30am, with a cup of coffee, and finish late, around 11:00pm. It takes a lot of planning to conduct so many tests.

2 // Ground testing of Nammo’s hybrid rocket, called the Nucleus

HYBRID ROCKET MAKES MILESTONE LAUNCH

Nammo achieved a key milestone in its history with the launch of the first Nucleus rocket in October. Nucleus, which is powered by a hybrid rocket motor, has been in testing for 10 years.

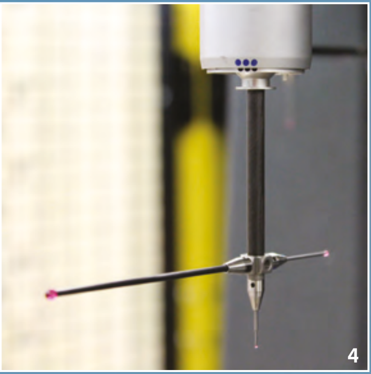
The rocket was launched from the Andøya Space Center in northern Norway on September 27 and reached an altitude of 107.4km (67 miles). This made it the first rocket powered by a Norwegian motor design to cross the Kármán line and the first European hybrid rocket motor to do so in more than 50 years.

The Nucleus is 9m (30ft) long with a total weight of around 800kg (1,700 lb) and is able to provide 30kN of thrust. The planned final version of the engine will provide up to 100kN of thrust. Ground testing of the rocket was completed in July.

The hybrid engine uses both liquid and solid fuel and emits only water and carbon dioxide. According to the company, the oxidizer – hydrogen peroxide – is safer than other liquid fuels because it is non-poisonous. The engine can also be throttled, turned off and restarted.

The Nucleus rocket is designed to lift scientific instruments into the upper layers of the atmosphere, and during this first flight, carried three different experiments. Engineers at Nammo hope to scale-up the hybrid rocket motor, propelling it to lift a range of payloads, including small satellites weighing up to 150kg (330 lb), into low Earth orbit.

The Nucleus is Norway’s bid to join the list of countries with the capacity to build launch vehicles for satellites and send them into space from home bases. This includes Russia, India, China, USA, France and Japan. Nammo is hoping that the new propulsion technology demonstrated with Nucleus will be able to power future launch vehicles for small satellites.



3 // Testing of Nammo's extended range 155mm ammunition in 2017

4 & 5 // The precision machining for munitions carried out at Nammo's factories is tested at the Raufoss Center

In the summer, if we test tracer ammunition in the evening, we can get complaints about keeping people awake at night, but not very often. People in Raufoss are used to it.

20
firing ranges at the Nammo Test Centre

2,000M
maximum firing distance for ordnance

WHAT EQUIPMENT AND FACILITIES DOES NAMMO HAVE?

We have a lot! The site at Bradalsmyra has existed for 100 years this year – it covers 400 hectares [990 acres] and is 100% owned by Nammo.

There are 20 firing ranges with a maximum firing distance of 2,000m [6,560ft] and 80 buildings, so we can test all types of conventional ammunition, from 4.6mm to 155mm howitzer. We maintain around 70 different weapons, including test guns that have been custom-built for internal ballistic measurements, and operational guns that are identical to those used by soldiers or installed on platforms such as vehicles, aircraft and ships. We can test ammunition ranging from 4.6-155mm and with muzzle velocities exceeding 2,500m/s.

We test rockets, shoulder-launched systems, and rocket motors, for military use and space rocket motors. We test armored vehicles and a lot of other things. There is a lot of variety.

There are 35 people working full-time on the site. Several of them have worked here for more than 40 years and have exceptional knowledge and experience.

WHAT TEST EQUIPMENT IS THE CENTER'S MOST IMPORTANT?

We have four electromagnetic systems to conduct vibration and shock tests, including the LDS V994 machine, which is the world's largest electromagnetic vibration machine and one of very few worldwide that is certified to test energetic products. We're very proud that we have the world's largest vibration machine out here in the woods in a remote part of Norway.

WHAT TECHNOLOGY HAS CHANGED THE WAY YOU CONDUCT TESTS THE MOST?

Live test firing is still the most precise method to verify that military equipment meets strict requirements. But the systems we test are far more advanced than they used to be and the technology for test equipment has changed dramatically.

Many of the products that we test I consider to be flying computers. So, what's changed the most is data acquisition. Data acquisition is our core business. For example, high-speed cameras have moved from 40,000fps to 2,200,000fps during my time. That's real technological progress. We invest a lot of money so we can have the most advanced test equipment.

IS THERE A TEST THAT STICKS IN YOUR MIND?

We go elsewhere for longer-range missile tests. There was a secondary range on Lake Mjoesa, Norway's largest lake. One


6

7

6 // Up to 20 different tests can be performed on a typical day at the test center

7 // Raufoss has 20 firing ranges for different types of weapons testing

October day in 1962, it was very foggy. The test manager was under a lot of pressure, there was a big delivery for a naval customer, so despite the fog he decided to go ahead with the tests.

They started the test – 60 rounds – and couldn't see where the projectiles landed. A rifled gun will always move to the right. If you don't secure it, it moves. In the last 30 rounds they ended up landing on a farm – each a little further inside it. The farmer was out plowing a field and believed he was under attack. The last round hit the side of the barn and ended up in the pigsty. Then the test finished and the police came.

HOW IMPORTANT ARE YOUR TESTS?

Every test is important, especially to the customer. Our tests can mean millions of dollars lost if they fail. Among the most spectacular test we have done recently was the Nucleus rocket, which is being developed to launch science experiments and small satellites. Before we launched the rocket, we had been testing the rocket motor for 10 years. The ones that take the longest stick in the mind. We were testing the F-35 fighter's ammunition for 15 years before it went on board the aircraft.

2,000,000 frames per second can be captured by the high-speed cameras at the Nammo Test Centre

2,500M/S maximum muzzle velocity of ammunition that can be tested

> **"Every test is important. It can mean millions of dollars lost if they fail"**

That's a lot of tests and a lot of money. When you see a project that takes so many years through to completion, it is fantastic.

HOW IS THE COMPANY CHANGING?

The company has also changed dramatically during the time I have worked for it. Nammo was initially a national Norwegian company – now we are very international. The job is very different. When we acquire another company from outside of Norway, it means the test center gets a new internal customer, because we are the only instrumented test center in Nammo.

WHAT SKILLS AND KNOWLEDGE DOES WEAPONS TESTING NEED COMPARED WITH OTHER TYPES?

The skills for testing weapons and ammunition aren't that different from other types of aeronautical testing. What you are testing is not important – the most important thing is people's attitude toward safety and that they want to do a good job. Safety is always the number-one priority and the safety requirement is the same whether you are testing a 1g detonator or a 1-ton rocket motor. In the past 100 years at Bradalsmyra there has been only one major accident – back in the 1970s.

WHAT IS THE MOST IMPORTANT LESSON YOU HAVE LEARNED?

I tell myself every day that when you are working with such potentially dangerous items, never be stressed. It's when mistakes are made. It's simple – but when you're in a hurry, walk slowly.

WHAT ARE YOU MOST PROUD OF IN YOUR CAREER?

I've had the privilege to lead this extremely professional team for the past 20 years. No one has done that before, so I am very proud of that.

WHAT DOES THE FUTURE HOLD FOR THE RAUFOSS TEST CENTER?

There is a new challenge every day, every hour, for us. At the moment we are building a large facility for testing space products. We've just finished a large building for testing F-35 ammunition.

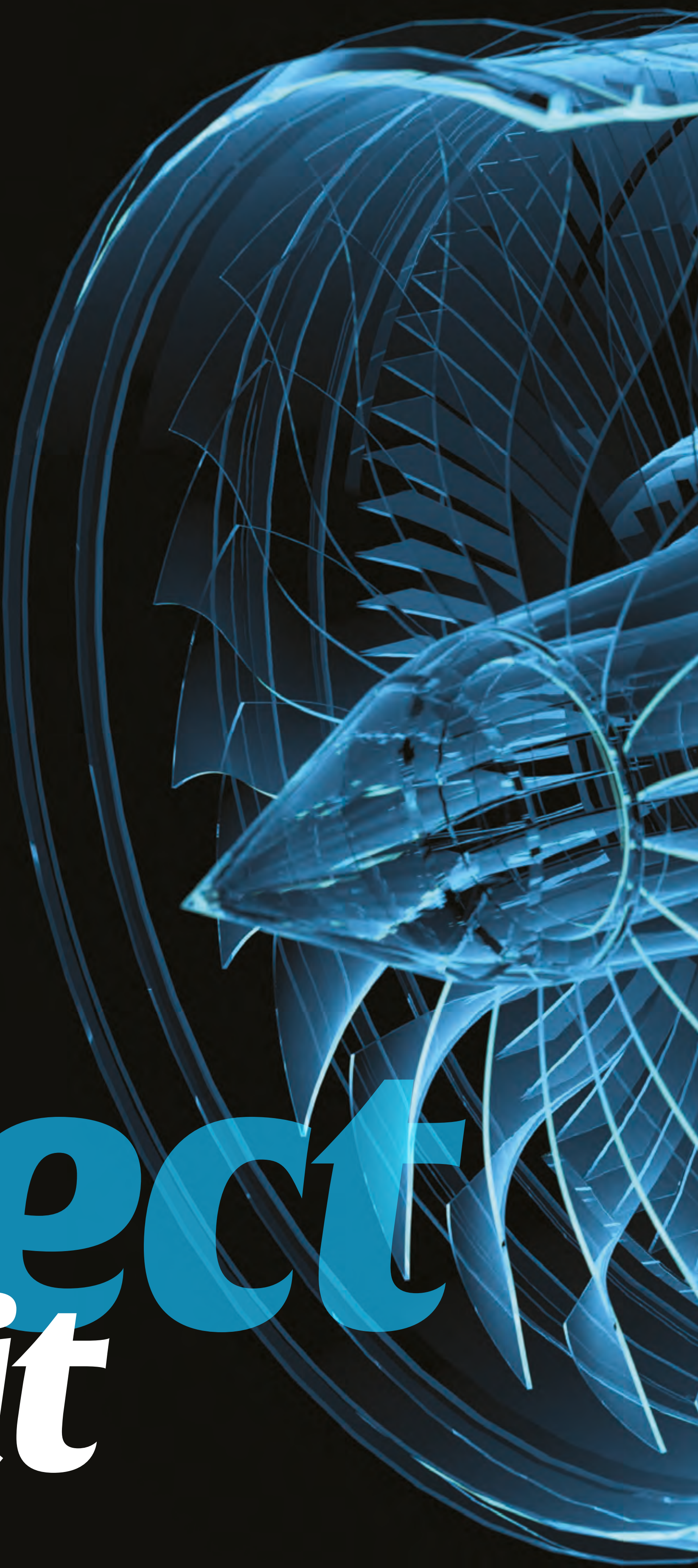
ANY ADVICE FOR PEOPLE THINKING ABOUT A CAREER IN AEROSPACE?

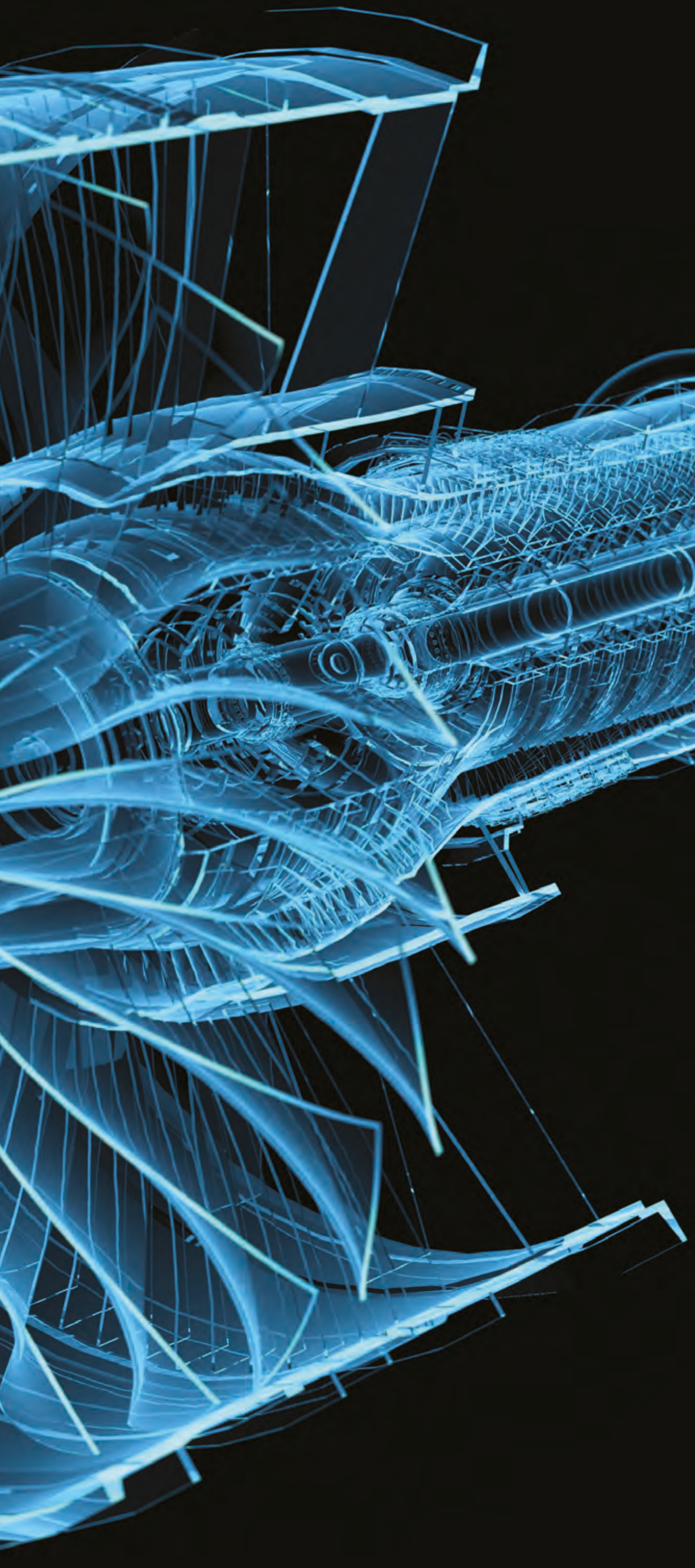
It's a lot of hard work but it's never a dull job. Go for it and you will never have a boring day. \\

// BEN SAMPSON

Changes in aircraft design and wider technological trends are increasing the complexity of tools and techniques for production metrology

The perfect fit





1 // Dimensional metrology data can be combined with digital twins to enable benefits during manufacturing

Dimensional metrology is how we quantify the size and shape of things by measuring their length, angles and other geometric properties, such as flatness and straightness. Among its most important uses is the inspection of components and products, to ensure they assemble and work correctly.

Dimensional metrology is used for this type of inspection throughout the aerospace lifecycle – in R&D, design, production and maintenance. And metrology's importance in aerospace is increasing, thanks to the ongoing drive to improve aircraft performance, the introduction of more stringent environmental standards and the application of new technologies and materials such as electric propulsion systems and composites. Furthermore, technological trends such as IoT (Internet of Things) and cloud computing are changing dimensional metrology itself.

GET IN LINE

According to the latest research from consultancy Frost & Sullivan, the use of dimensional metrology in aerospace manufacturing is growing, with the market for supplying metrology machines, tools and services to the

2 // Digital measurement and controls are a crucial part of current efforts to improve manufacturing

2

sector expected to be worth around US$840m this year. Prem Shanmugam is senior consultant for measurement and instrumentation at Frost & Sullivan, and provides information and advice to aerospace metrology suppliers. He says, "Aerospace is one of the major sectors for production metrology. Engineers spend a long time considering which will be the right technique to use for their production metrology solution."

Modern production metrology uses many different tools, including coordinate measurement machines (CMMs), laser scanning, vibration sensors and accelerometers. According to Shanmugam, one of the areas where the use of production metrology is growing the most in aerospace is in in-line.

In-line metrology integrates the measurement system within the production line or machinery itself. The technology is used in aerospace both at the component level and during airframe assembly to check things like fasteners and the fit of panels and other structural elements. Laser scanners and white light devices are generally used for such tasks, while CMMs are more suited for use during production.

"Normal practice is for engineers to sample using statistical methods and perform 100% quality inspections," says Shanmugam.

"But the use of in-line metrology is growing fast in aerospace. The high value and stringent regulations mean there is a drive to carry out 100% inspections of everything, and in-line metrology enables that."

25%
of blisks have to be reworked because of defects

US$30M
of savings have been made possible by using network adaptive production in the manufacturing of blisks

Another driver of in-line metrology's use in aerospace is IoT. This trend goes by various names around the world and is most commonly known as smart factories in the USA and Industry 4.0 in Europe. Shanmugam says, "There is a digital transformation happening in industry. Connected instruments mean manufacturers can send data back to the cloud for analysis. The information that is obtained can then be used to improve products and production processes.

"Digital technologies such as augmented reality are being employed by aerospace companies like Testia. It is using tablets with cameras to find defects in aerospace components and structures."

> **"Connected instruments mean manufacturers can send data to the cloud"**

NETWORK ADAPTIVE PRODUCTION

The Fraunhofer Institute for Production Technology (IPT) in Aachen, Germany, is developing advanced production metrology solutions for aerospace. Much of the research at the Fraunhofer IPT focuses on the use of optical metrology and sensors, and how to integrate metrology, machine networks and production equipment to improve production processes. Aerospace, with its high-value components, complex production processes and high safety standards and regulations, is seen by the Fraunhofer IPT as a potential early adopter of several of the concepts being developed.

One of these advanced concepts is network adaptive production, which makes use of 5G networks. The idea is to use metrology, 5G connectivity and cloud-based data storage and analysis tools to develop novel manufacturing techniques and processes that save manufacturers time and costs.

Niels König is head of production metrology at the Fraunhofer IPT. He says, "5G enables new applications where existing wireless technologies are inadequate for

> **"If we see a deviation, we can adjust the measurement program on the spot"**

the application. Wi-fi can be unreliable and has too much latency. We want to be able to react to changes in the manufacturing environment and product during production as quickly as possible."

However, Shanmugam from Frost & Sullivan believes that 5G communication networks should not be seen as a requirement for advanced production metrology solutions and notes that 4G networks are yet to be used in many industrial spaces.

"Current wireless technologies can often perform adequately," he says. "Manufacturers can also be confident of security and confidentiality with existing wireless solutions, which is paramount in aerospace."

BLISK MACHINING

Several ongoing projects at the Fraunhofer IPT involve German aerospace companies, including MTU Aero Engines. One of the highest profile projects has developed a real-time monitoring solution capable of measuring blade-integrated disks – blisks – while they are precision machined.

A blisk, which is part of a jet engine's compressor, is a complex and expensive component that is machined as a single part. When milling parts like blisks at high speeds, excessive vibration can occur. This vibration causes surface defects that subsequently require rework. Sometimes, and this is the case with blisks, the workpiece cannot be inspected until the lengthy milling process is over. Fraunhofer IPT researchers estimate that defects make rework necessary in up to 25% of the blisks made using current production methods.

The manufacturing solution developed to solve this problem combines vibration sensors, a 5G network supplied by Ericsson, a secure cloud-based platform and a Mikron MILL P 500 U from GF Machining Solutions. The Mikron machine features dynamic direct torque motors and a gantry with up to 1.7*g* acceleration and an accuracy of ±2µm in the plane.

The blisk has vibration sensors and a 5G transceiver attached to it. As the milling process progresses, data from the vibration sensors is transmitted over the 5G network, analyzed in the cloud and instructions sent back to the Mikron machine. The data is communicated from the sensors and production data returned to the machinery in less than a millisecond. The predictable, real-time, monitoring of vibration in the part and the fast and powerful production control of the Mikron milling machine enable adjustment of the cutting parameters.

Researchers at the Fraunhofer IPT believe a single factory could save up to US$30m a year using the blisk process monitoring system. Also, production and sensor data can be stored for each product to create digital twins. These twins could be used to improve designs, produce more accurate documentation and for analytics. If defects arise, the manufacturer will be able to pinpoint where the fault originated and the production process can be changed accordingly.

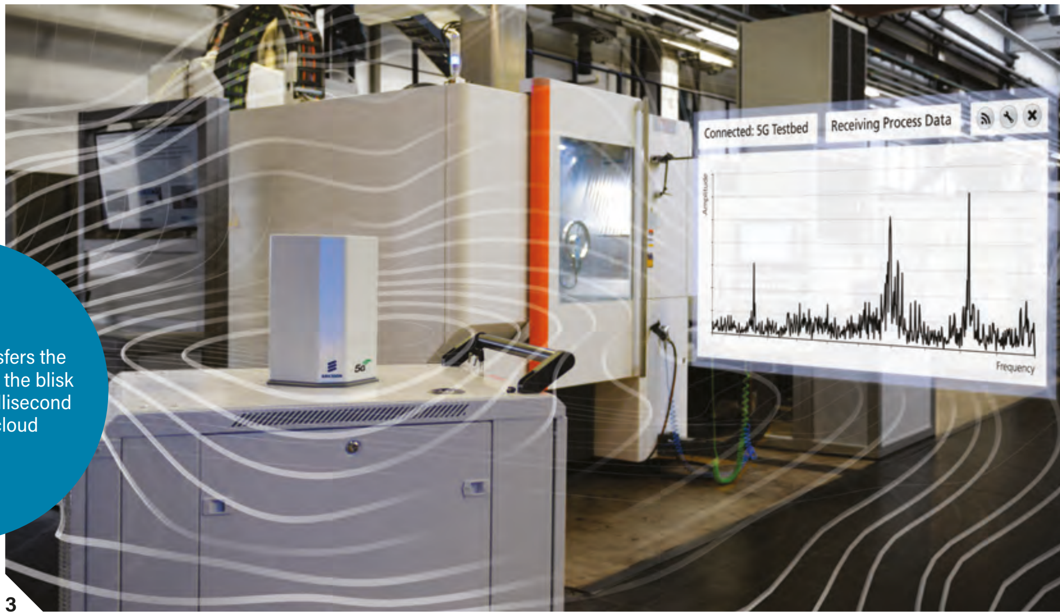
"With this technology we will be able to do quality assurance and monitoring during machining – and change our measurement strategy. If we see there is a critical deviation coming from a machine, we can adjust the CMM's measurement program on the spot," says König from the Fraunhofer IPT.

Researchers at the institute are now refining the wireless sensor connections and the real-time data analysis process to further reduce reaction times and improve the adaptive control process.

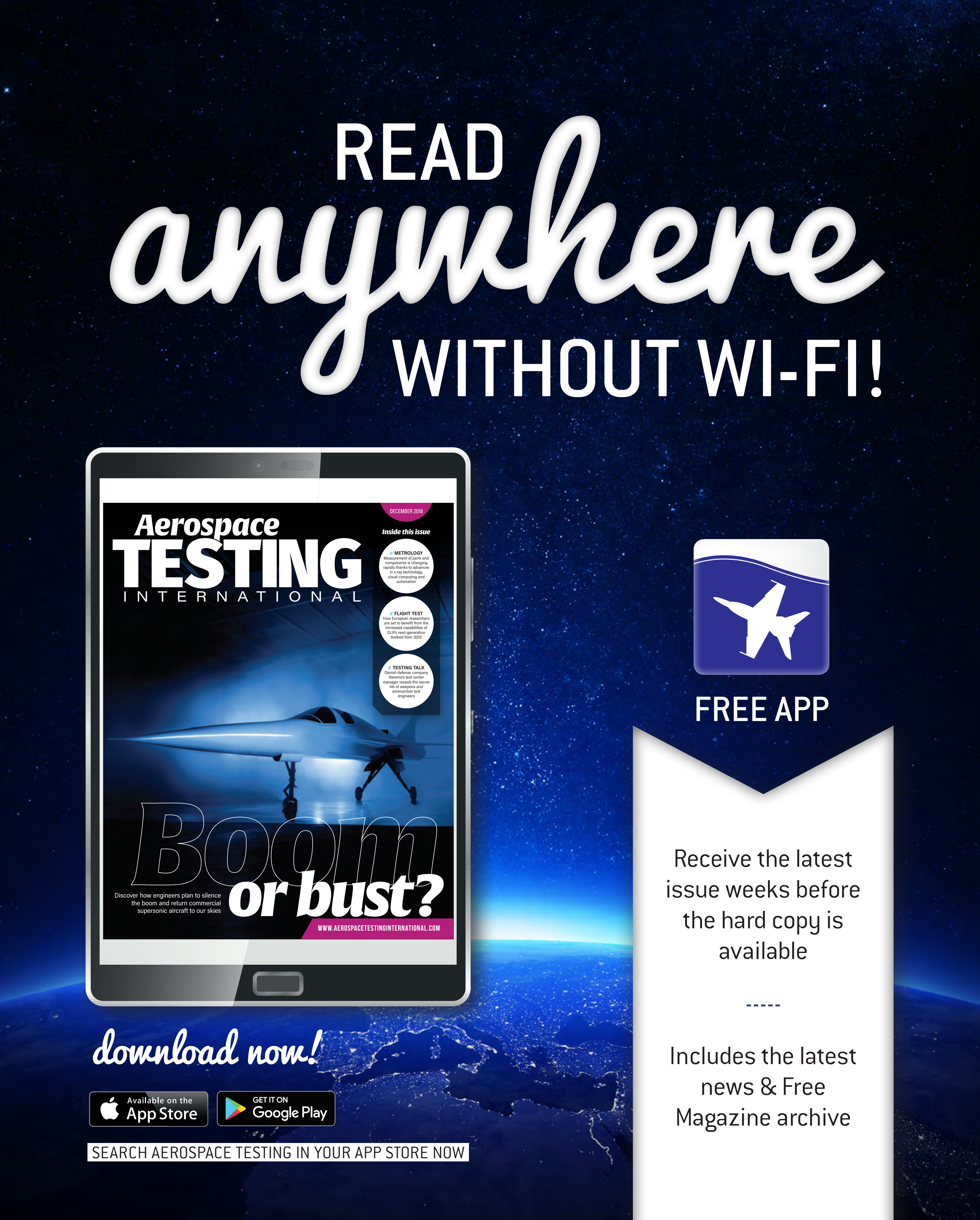
"The technique could be used for any product that is difficult to machine, with very complicated geometries,"

1 MILLISECOND
Time it takes for measurement data to be collected and processed, and adjustments sent to the machine during blisk manufacturing

US$840M
Value of the aerospace dimensional metrology market



3 // A sensor transfers the vibration spectra of the blisk via 5G with sub-millisecond latency to the cloud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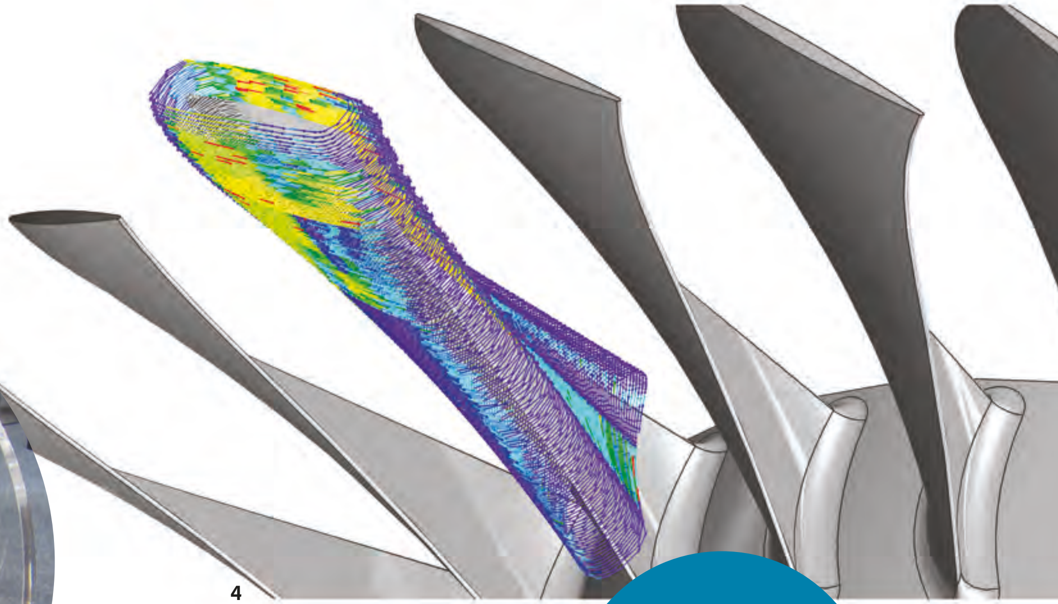

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4 // A CNC-milled, single piece axial compressor blisk

5 // Rapid data transfer enables a digital twin, to show vibration in a component while it is being machined

König says. "We aim to integrate quality assurance further into production machinery. Not the touch probes you have within certain machines now, they don't deliver the certainty you are used to from CMM.

"But, for example, you can integrate a laser scanner and an optical light sensor within a milling machine and scan the part so you can see the deviation in real time, determine the material that you have to cut away and reduce offcuts."

CT SCANNERS

Another technique that is being used more in aerospace production metrology is computed tomography (CT) scanning. Most CT scanners are based around a cabinet, inside which the test piece is placed, although larger systems do exist that take up entire rooms.

CT works by building up a moveable graphical representation of a cross-section of a test object by taking x-rays of it from different positions. It is used at different stages of production and for quality assurance.

Valentina Aloisi, metrology product innovation manager with North Star Imaging, which supplies CT scanners, says, "Where CT can be used depends on the volume and the type of the product. The larger the size of the component and the denser it is, the more difficult it is to scan."

CT is used primarily to perform measurements in smaller, complex, high-value components such as turbine blades or castings. "There are advantages and disadvantages with every method of measurement.

For example, CMMs have been widely used for many years. They provide accurate measurements and internationally accepted standards exist, but they do not allow for inspection of internal non-accessible features," says Aloisi.

"CT is being used more for metrology in smaller aerospace components because you can acquire a lot of information from one scan and in a shorter time.

"For example, you can make dimensional measurements such as wall thickness analysis and measure the freeform surfaces of a [turbine] blade. With x-ray CT it is also possible to get information, in a non-destructive way, on the internal defects of the part, such as voids and cracks."

ROBOTICS

Shanmugam from Frost & Sullivan agrees that the use of CT is increasing. "The use of all non-contact measurement systems is growing," he says. "They are often faster and offer more flexibility.

"Composites, titanium and aluminum alloys are also being more widely used in aircraft bodies. These materials, as well as more complex designs, are increasing the importance of CT in metrology."

He notes that another key trend in manufacturing is the integration of production metrology solutions into robotic systems. "It's part of the move in manufacturing to use more automation. It enables increased accuracy, precision and tracking," he says.

Production metrology is no longer the preserve of tools such as CMMs, calipers and micrometers. There has been an explosion in the number of metrology products and services that are available to engineers producing aerospace components and aircraft, from network-connected 3D scanners for in-line metrology to portable/handheld instruments and automated metrology carried out by robots. This growth in options and complexity inevitably leads to tougher decisions when selecting a metrology solution, but has the potential to significantly save costs and time when the right decision is made. \\

"More complex designs are increasing the importance of CT in metrology"


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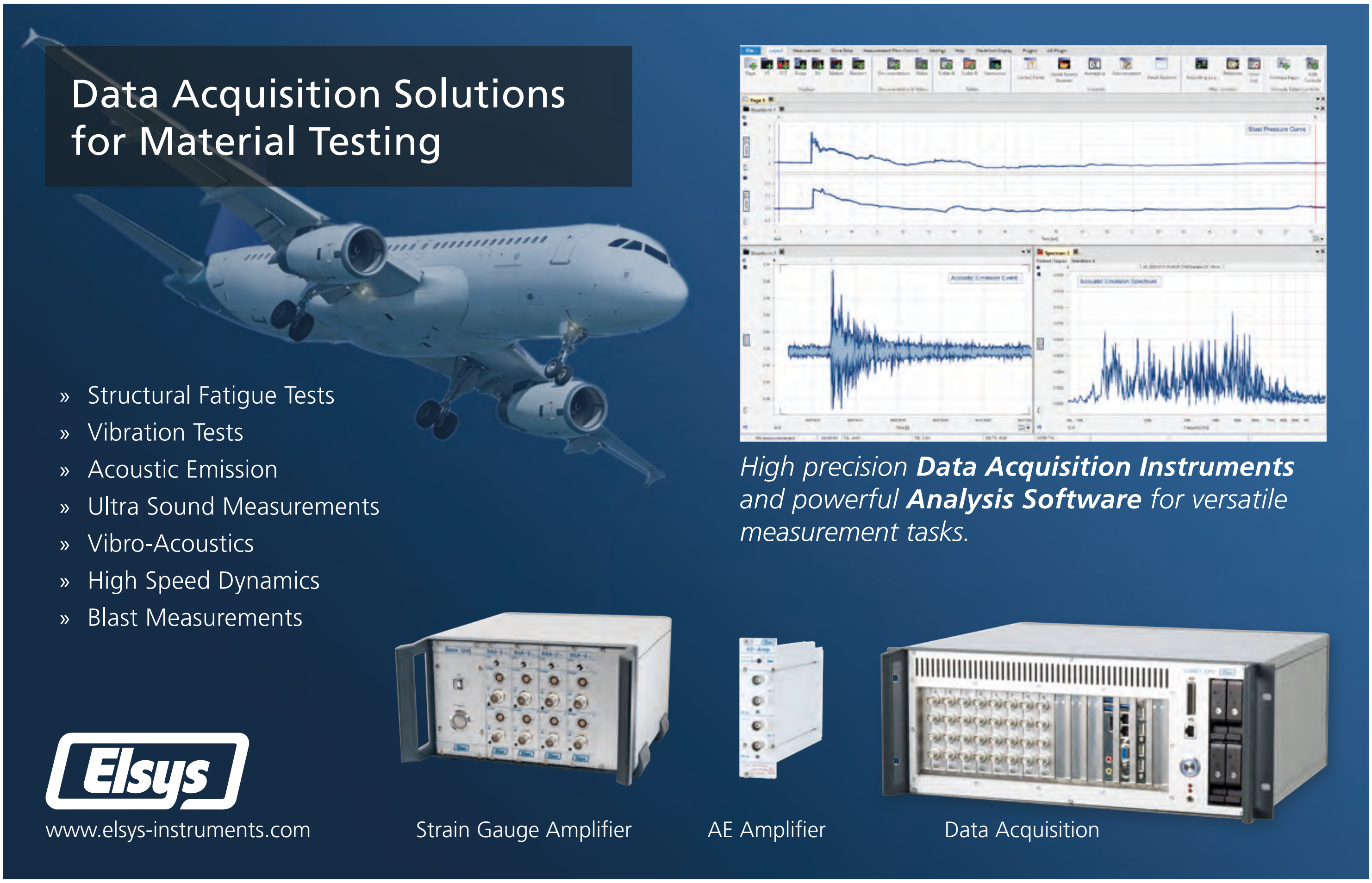
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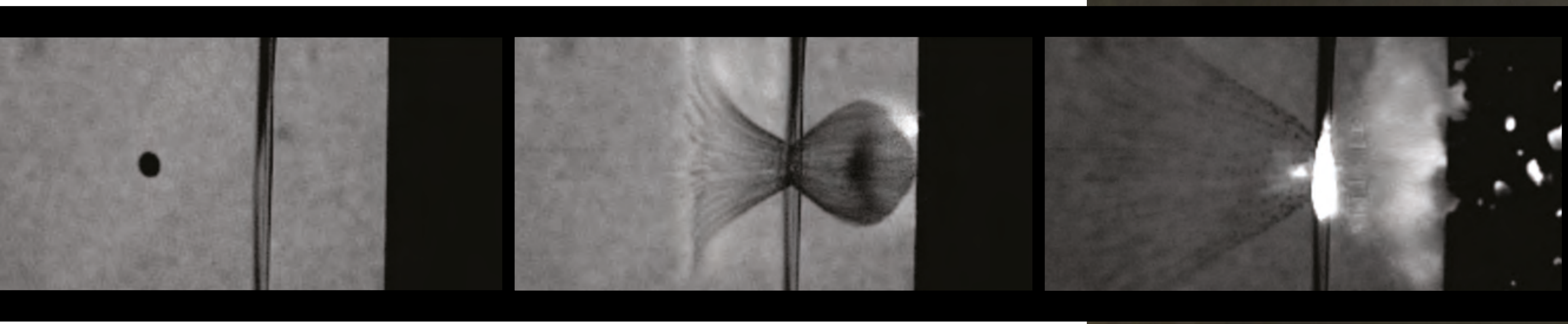
// ANDREW WILLIAMS

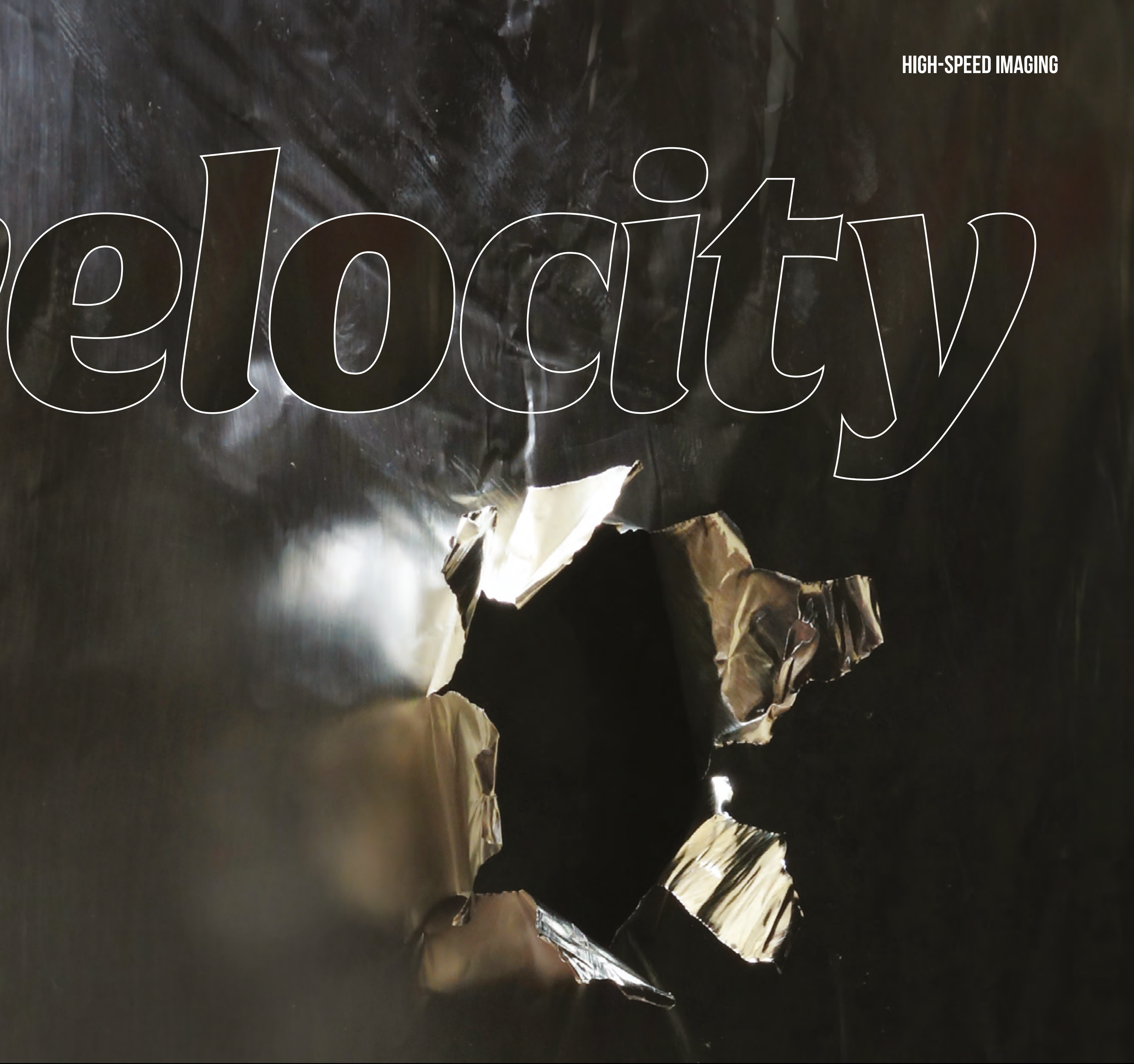
Hyperv impact

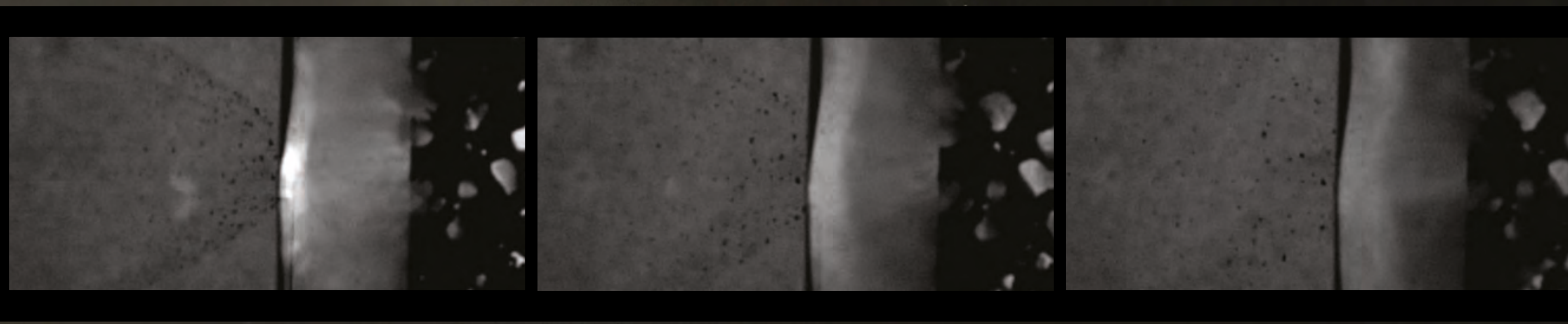
High-speed imaging technology and techniques are being pushed to their limits to capture the effects of hypervelocity impacts



1 // High-speed images of an aluminum ball hitting a target at a speed of 6.7km/s (15,000mph)

elocity





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2 // The materials used in spacecraft require testing for hypervelocity impacts

3 // A satellite vessel after a hypervelocity impact

Hypervelocity impacts occur when an object strikes another object at more than around 3,000m/s (6,700mph) and the inertial forces are so great they cause the material to behave like a fluid.

Hypervelocity impacts include weapons fire on fighter jets or space debris hitting satellites. Capturing these events to investigate them is one of the toughest tasks for high-speed camera systems.

SPACECRAFT PROTECTION

Better understanding of hypersonic and hypervelocity-impact physics plays a key role in protecting spacecraft from accidental debris and may in the future also help protect them from intentional attack. It is also essential for the development of military armor systems.

The Remote Hypervelocity Test Laboratory (RHTL) at the NASA White Sands Test Facility (WSTF) in Texas recreates the effects of micrometeoroids and orbital debris impacts on spacecraft shielding, components and materials using a variety of test configurations. The first steps in such tests are the specification of the target or test article and of the projectile size and speed that will be used. Engineers then develop the configuration of the test and how they will analyze and provide the results to the customer.

The RHTL team uses ultra-high-resolution framing cameras and high-speed video to capture images of the projectile in flight prior to impact and to calculate projectile velocity, as well capturing impact events and assessing test article performance.

Karen Rodriguez, project manager at RHTL, says, "High-speed data acquisition at 100MS/s and imaging systems – at up to 200Mfps – capture projectile, environment and target data for results analysis. "As more spacecraft use a Low Earth Orbit, the number of particles that could damage spacecraft will increase. The need to test better shielding and analyze potential impacts will continue to be very important to all space programs," she adds.

23,500MPH
Projectile speed achieved by Thiot Ingenierie's two-stage gas gun

17,000
Pieces of space debris bigger than 10cm (3.9in) in diameter recorded in orbit in 2016

METEOROID IMPACTS

The Southwest Research Institute (SwRI) in Texas conducts an array of hypervelocity impact testing, alongside associated computer simulations, model development and material characterization. Its work spans a variety of applications: supporting the development of hypersonic technology; examining hypervelocity space debris impact and shielding scenarios; exploring planetary and meteoroid impact events; investigating defense-related armor systems; and performing fundamental impact physics experiments.

The primary tools the SwRI team uses during tests are its two-stage light gas guns (see *Gas Guns* on next page) and a NASA-funded explosive fragment launcher – previously used to characterize the shielding on the

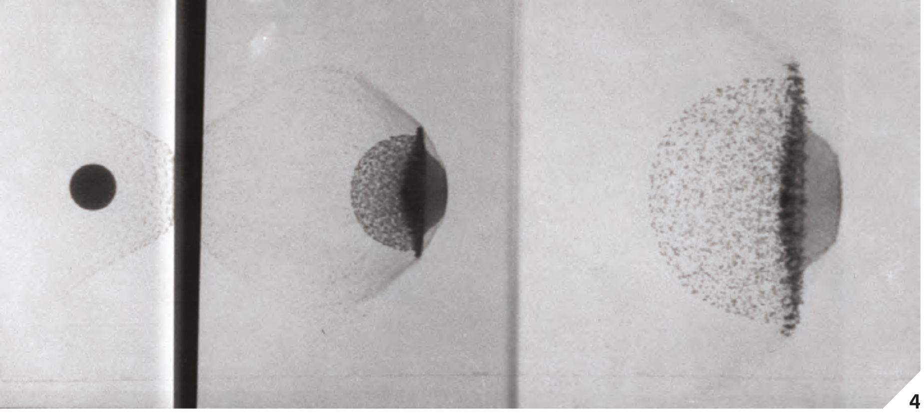
IMAGING CHALLENGES

In the past, imaging systems were limited by the number of frames that could be captured over the period of interest, typically several microseconds, for a single impact experiment. However, the emergence and improvement of gate-intensified framing cameras to deliver multiple images at microsecond intervals with nanosecond-scale exposure times has greatly improved the ability of scientists and engineers to investigate hypervelocity impact phenomena fully.

"As with any optical system though, the spatial resolution of the system must be characterized. Additionally, the presence of spatial distortions must also be checked and potentially corrected, " says Jonathan Mihaly, a researcher from the Small Particle Hypervelocity Impact Range (SPHIR) facility at the California Institute of Technology.

A challenge for intensified cameras, which is often present for older cameras or when the gain is operated near maximum, is that the background brightness or default pixel grayscale value may vary with time. This means that, prior to the actual impact experiment, the background variation must be characterized and quantified to understand the possible effect on measurements and to inform what Mihaly describes as "uncertainty estimation".

"For high-speed cameras, another challenge can be the size of the resulting video files. The useful frames in a series are often limited to only several or tens within hundreds or thousands. Therefore, it is often useful to develop postprocessing functions that automate the elimination of unused frames and isolate only useful data from an otherwise cumbersome series of images," adds Mihaly.



4

International Space Station – capable of launching 1g of aluminum fragments at up to 11.2km/s (25,000mph) in an evacuated chamber. Two high-speed camera systems (primarily Phantoms) and digital flash x-ray imaging are used for imaging.

The SwRI team sometimes also uses an Imacon high-speed framing camera capable of recording images at millions of frames per second, but this has a limited recording capacity. The fastest the team has run this system is 5Mfps at 200µs between frames, with a 5ns exposure time and laser illumination to obtain the required brightness.

Dr Nicholas Mueschke, senior research engineer in the engineering dynamics department at SwRI, says, "Camera technology has advanced a great deal over the past few decades. Thirty years ago, we used primarily flash x-rays with some high-speed celluloid film. Today we primarily run high-speed digital cameras with some use of flash x-rays.

"More recently the advances have included faster sampling of the CCD and higher resolution, both of which improve our data collecting capability."

To better understand experimental observations, the team uses a range of computer simulation codes – typically relying on EPIC (Energetic Plasma Instrument Calibration), an SwRI-developed explicit finite element analysis code designed specifically for simulating complex impact events, and CTH, a Eulerian hydrocode developed by the US Department of Energy.

BALLISTIC LIMITS

Also in the USA, a team at the University of Dayton Research Institute (UDRI) performs hypervelocity testing, mainly to evaluate the impact response of spacecraft structures, shields and thermal protection systems to potential micrometeoroid and orbital debris threats.

Kevin Poormon, research engineer and leader of the Impact Physics group at UDRI, says, "We measure projectile velocity using laser-photodetector stations along the projectile flight path and high-speed data acquisition systems record data from sensors employed during tests.

"Flash radiography is a common way for people to capture images of the projectile in flight and the break

5

4 // Flash radiography is used to photograph what happens after an impact

5 // Thiot Ingeniere's R&D team has achieved world record breaking speeds with its gas guns

250,000MPH
Maximum speed at which SwRI's gas gun can fire projectiles

5,000,000FPS
Top speed of the SwRI's high-speed framing camera system

GAS GUNS

One of the most important pieces of equipment in a hypervelocity test lab is the gas gun, a device used to fire materials or objects at extremely high speeds. SwRI in Texas uses two-stage light gas guns (LGG) that operate by launching a large piston down a barrel using conventional powder as the energy source. This piston then compresses the light gas, in this case hydrogen. Once compressed, a rupture disc releases the high-pressure hydrogen into the barrel with the projectile to be launched.

The SwRI recently built a new lab to host its large LGG, which is capable of launching projectiles at speeds up to 7km/s (15,650mph) depending upon the mass of launch package. "We launch projectiles into an evacuated flight range where we can perform a number of inflight and terminal impact experiments," says Nicholas Mueschke from the SwRI.

French company Thiot Ingenierie designs and uses compressed gas guns capable of achieving both low- and high-velocity ranges. Its single gas guns cover the range of velocity up to 1.4km/s (3,100mph), with double-stage LGGs covering the range between 1.4km/s and 10.5km/s (23,500mph). It also carries out hypervelocity impact testing in the aerospace, space and defense sectors.

Dr Pierre-Louis Hereil, R&D manager at Thiot Ingenierie, says "In our Shock Physics Lab in Puybrun, France, we use two single-stage gas guns and two double-stage guns. One is equipped with a firing-range chamber and one with a detonation chamber," he says.

"Our equipment enables us to respond to a wide range of requests and guarantee operator safety. We have a large panel of metrology instruments used for impact tests to detect details invisible to the naked eye due to their speed, including high-speed cameras, radars, lasers and interferometry equipment."

"We achieved a world record for hypervelocity ballistics by launching an aluminum ball at a speed of 10.5km/s [23,500mph].

"In the defense sector, our activity concerns the behavior of complex armor and specific projectiles. For all these domains concerned by dynamic phenomena, testing with high speed cameras is essential because calculations are not reliable enough to predict the behavior of the target."

6 // A cement sphere being impacted at 5km/s (11,000mph) at the University of Kent, UK

up of the projectile after impact – the debris cloud. We use computed radiography screens in place of the radiograph film, which has better resolution.

"The data from experiments is recorded by high-speed data acquisition systems, usually at sampling rates above 1MHz, and is used as a benchmark for simulations," he says.

Mark Burchell, professor of space science at the UK's University of Kent, also conducts hypervelocity impact tests. In addition to high-speed cameras, he and his team use spectrometers to measure temperature and identify molecular species in the debris from impacts.

"We also image the target afterwards with cameras, optical microscopes and scanning electron microscopes to look at the damage. We use hydrocodes such as Autodyn to reproduce the impacts in computer simulations for validation, so the code can then run other speeds and sizes."

> *"Exposure times in the order of nanoseconds may be required to capture phenomena"*

GATE-INTENSIFIED CAMERAS

Research at the Small Particle Hypervelocity Impact Range (SPHIR) facility at the California Institute of Technology has traditionally focused on providing empirical data for the development of advanced uncertainty quantification (UQ) methods and computational mechanics models.

Jonathan Mihaly, a researcher at SPHIR, says, "The development of such tools can support a number of space and defense applications. For example, the development and evaluation of micrometeoroid and orbital debris impact shielding for spacecraft.

"The camera systems used for a given impact experiment depend greatly on the intended measurement. The greatest demands on a camera system for this application are the frame rate, exposure time and field-of-view."

Mihaly also points out that exposure times in the order of nanoseconds may be required to capture phenomena. This means that a single impact event may require frame rates approaching 1Mfps.

"A limitation of high-speed cameras typically is that the available spatial resolution decreases as frame rate increases, providing constrained fields of view at maximum frame rates, typically topping out at several hundred thousand frames per second," he says.

"Therefore, for applications that require large spatial resolution with a challenging frame rate, gate-intensified camera systems can be used to provide a limited series of images.

"These cameras can provide impressive frame rates with full available spatial resolution. However, the series of images is limited to a relatively small number, depending on the number of CCDs in the camera, and nowhere near the number of images available from a typical high-speed camera," he adds.

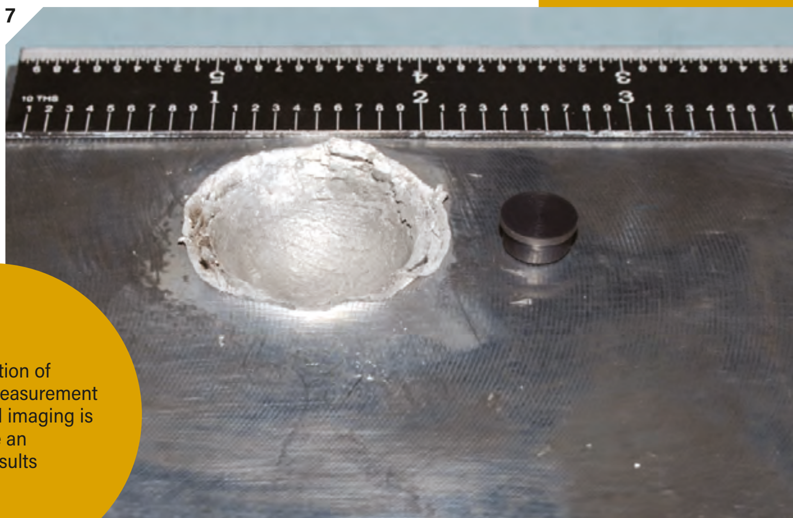
ILLUMINATING

Imaging hypervelocity impact experiments optimally also requires bright illumination sources, particularly for "challenging image exposure lengths", says Mihaly. "Flashlamps are a common source used in experiments. Part of my research at the SPHIR facility was developing an imaging technique that used collimated laser light as an illumination source," he says.

According to Mihaly, the measurement of impactor velocity is the most important aspect of an impact to capture because results depend on the correct speed. High-speed imaging can be used to measure the impactor speed.

"Light barriers are another common technique used in impact experiments, where the impactor interrupts several light barriers en route to the target, and the timing of the interruptions is used to measure impact speed.

"Producing a trigger signal for instrumentation often comes down to a pulse generator activated by an input signal. The interruption of a single light barrier or detection of an impact flash using a photodiode that could be employed to provide an activation signal for triggering," he says. \\



7 // A combination of conventional measurement and high-speed imaging is used to analyze an experiment's results

CLOSED LOOP ACOUSTIC CONTROL

Accurate and consistent control is required when testing satellites and their subsystems in acoustic reverberant rooms

The launch of a satellite into space is a traumatic event for the components it is made of. Before a spacecraft reaches its orbit, it is subjected to very extreme environmental conditions in Earth's atmosphere. The many kinds of dynamic load it experiences during this time may affect its components and subsystems and can eventually cause damage or failure affecting its functionality.

During the first seconds of launch, a satellite is encapsulated in the spacecraft vehicle's fairing. This payload fairing is used to protect the spacecraft against the severe impact of dynamic pressure and aerodynamic heating that is encountered during its journey through the atmosphere.

Additionally, the sound pressure levels that the payload is exposed to can easily exceed the overall values of 130-140dB. This is enough to produce considerable vibrations, which may compromise the functionality of lightweight solar panels and the reflector shells of antennas – the subsystems that are most vulnerable to acoustic excitation.

To prevent damage to the components, space hardware must therefore undertake dynamic environmental tests prior to launch. Such testing encompasses a number of essential tests for the qualification of space hardware. Acoustic testing is one of the most crucial steps in this process and subjects an item to intense noise levels while measuring its vibration response.

Satellite acoustic testing is traditionally performed in acoustic reverberant rooms, where representative sound pressure levels are reproduced in controlled environments. In most testing cases these large facilities are built to be up to 1,000m^3 (35,300ft^3) in size so that they can accommodate large spacecraft. They are usually driven with nitrogen gas, which additionally provides a lower sound absorption coefficient than air.

The noise is generated by modulators connected to horns in the chamber: the result is a noise level that can exceed 150dB. Using this equipment in the chambers, engineers simulate the noise field that excites the satellite in the launcher's fairing.

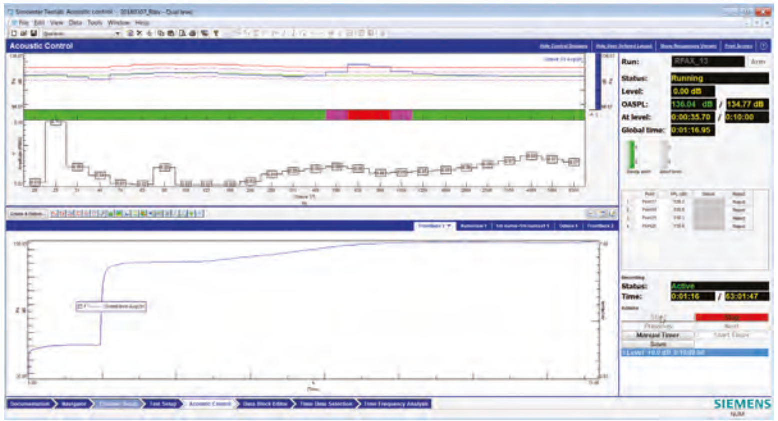
Satellite subsystems such as antennas and reflectors are also tested using this method, albeit often in smaller, medium-sized reverberant rooms. Regardless the geometry of the reverberant room, in all the cases the noise generated must replicate the operational environment. As well as its extensive offering for multichannel data acquisition, Simcenter offers a comprehensive solution to control acoustic signals in the reverberant room. Simcenter Testlab Closed-loop Acoustic Control is designed to control the acoustic level and shape in reverberant rooms.

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

With Simcenter Testlab Closed-loop Acoustic Control, Siemens offers a complete suite for mechanical space hardware qualification. The control algorithm used for reverberant rooms has more than proved its worth in several acoustic facilities around the world. It can be connected to a data acquisition system for the online processing of the hundreds of channels that record or monitor vibration data.

Simcenter Testlab Closed-loop Acoustic Control enables the user to easily set up a reference profile in 1/1 or 1/3 octave. It automatically controls the drive that feeds the amplifiers, modulators and horns so that the average sound pressure level measured by the control microphones matches the test requirements. It also responds to the most stringent safety and tolerance requirements used in the space industry.

The Simcenter Testlab Closed-loop Acoustic Control solution complements the complete Simcenter portfolio of solutions for space labs, which has been meeting the needs of the industry for many years. \\



2

CONTROL SYSTEM ENABLES HELICOPTER ENGINE QUICK START

A quick-start system for helicopter turboshaft engines reduces start times by 90%

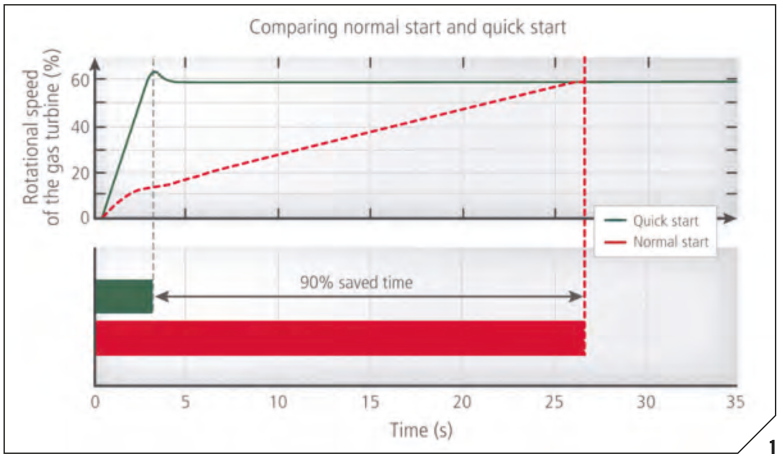
For safety reasons, modern helicopters generally have two turboshaft engines. This redundancy ensures that if one engine fails, the other provides the power to maintain flight. Therefore multi-engine helicopters generally have excess engine power because the combined performance of both engines is usually required only during vertical flight, while flying at high speeds and during ascent. At all other times the simultaneously running engines operate only in a partial-load range and fuel consumption is high. An optimized strategy for operating the engines will lower fuel consumption.

One plan is to switch off one engine in a controlled manner – intended single-engine operation (ISEO). This requires a higher power output from the remaining engine, which improves the specific fuel consumption. As a result, fuel burn and exhaust gas emissions decrease. The latest research shows that fuel savings of up to 21% can be achieved using this method.

Since only one engine is used when flying in ISEO mode, this also entails a reduction in flight safety. If the running engine faces any problems, the second, previously deactivated engine cannot take over immediately because starting the engine can take up to 26 seconds with a common starter. Smaller helicopter gas turbines are usually started with a battery-operated electric motor. Because this type of starter system is optimized for weight, it can only provide a limited acceleration torque for the shaft of the core engine, the gas generator. The transmission between the electric motor and the core engine shaft is not designed for higher torques. Thus, to shorten the start phase of the engine, other methods are needed.

The Department of Turbomachinery and Flight Propulsion at the Technical University of Munich has developed a quick-start system for helicopter turboshaft engines that reduces engine start time by 90%. The system uses compressed air directed at the trailing edges of the engine's radial compressor blades to rotate the shaft.

For the development of the system, the researchers conducted tests on a test bench using an Allison 250-C20B turboshaft engine. Handling the high air pressures and optimizing the reaction time of the engine control unit poses exceptional challenges.

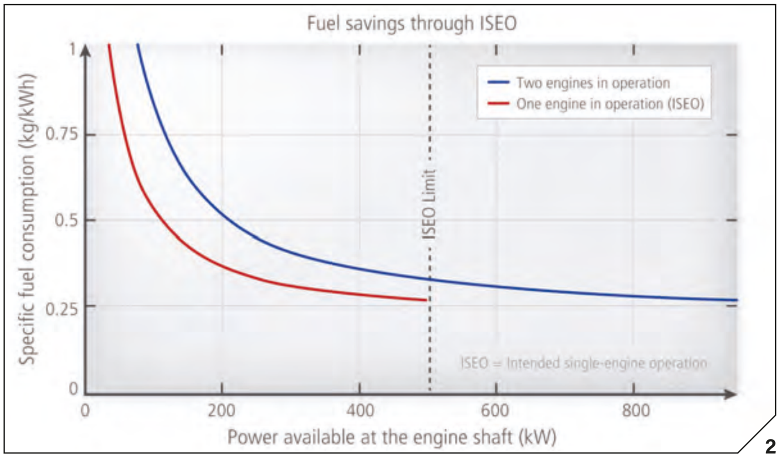


1 // Comparison of a normal start (red) and a quick start (green) of the gas turbine

2 // Instead of two engines working at an unfavorable partial load, only one engine works at a higher load when using ISEO, so it operates at a more fuel-efficient range

The quick-start time of the engine is only 2.6 seconds, during which time it accelerates from standstill to 30,000 revolutions per minute. This corresponds to 60% of the designed rotational speed of the core engine. During this interval the controller must perform various control and monitoring tasks. These tasks include controlling the fuel release valve when a certain rotational speed is reached and the sending of a signal to close the compressed air valve. Safety-critical values, such as the gas temperature at the rear of the combustion chamber, must also be monitored.

A dSPACE real-time system was used for engine control during development of the quick-start system and the numerous parameters were monitored and set using the dSPACE ControlDesk experimental software. Since the test operation requires setting various quick-start parameters, this graphical user interface was very beneficial because it offers a multitude of options to configure instruments, displays and input masks. \\



BONNETS AND THE CONTINUING SEARCH FOR CABLE UNOBTAINIUM

Centuries-old cable insulation technologies are being improved with the latest materials and designs

Michael Faraday, a famous British scientist of the 19th century, had a problem. It was 1831 and he was conducting electrical experiments that would revolutionize thinking about electricity. He needed to find a way to efficiently insulate the bare copper wire he was using for his study of electromagnetism. The solution was staring him right in the face. At that time, women were wearing bonnets (Figure 1) whose wide brims were supported by wrapping cotton around steel wire.

Faraday realized that he could use this same millinery technique to insulate wire conductors. The machines used to make bonnets were subsequently modified by William Henley to create insulated cable. In later years, William Henley went on to develop and lay over 14,000 miles (22,500km) of submarine cable.

In the 21st century, aerospace scientists and engineers are still searching for ways to insulate wiring and are focused on developing materials to improve performance in extreme environments. It has became common to use the term 'unobtainium' to describe the range of materials needed. This term is now in popular use and referenced in movies and newspapers. It is often heard among engineers, especially with regard to high temperature cable.

The jackets and insulators of softline cable typically offered in the sensor industry today for piezoelectric accelerometers range significantly below 1,000°F (538°C). Table 1 provides examples of common insulating materials and estimates for their upper temperature operating limits.

To reach higher temperatures than those found in Table 1, manufacturers commonly resort to hardline cables. These cables are challenging to install and unforgiving should a bend be made incorrectly, because many only support a 'bend once' capability. Furthermore, they are subject to pinhole leaks and microcracking. Lastly, when directly attached to accelerometers, they are prone to pin detachment.

Meggitt has recently solved a particularly difficult unobtainium cable problem for extreme temperature piezoelectric accelerometers. The company's engineers developed a cable (Figure 2) that has the temperature capability 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.

Known as Endevco 3076, this cable is available in standard and custom lengths and is 100% tested prior to shipment. The outer jacket of the 3076 cable is constructed of 304L braided stainless steel and has diameter of 0.095in (2.4mm) with a bend radius of 0.25in (6.35mm). This cable is insulated between the connector backshell and the stainless outer sheath to prevent inadvertent grounding. It features rugged 10-32 hex connectors on both ends.

Thin glass fibers insulate the center stainless-steel conductor from the metal outer jacket. To ensure the highest accuracy, the 3076 cable has been designed to minimize the triboelectric effect that typically plagues PE (piezoelectric) accelerometer cable assemblies.

1 // 19th century bonnets inspired Michael Faraday's approach to insulating electrical wires

2 // The Endevco 3076 extreme temperature, flexible cable assembly

3 // Table 1: Nominal upper temperature limits of insulators and jackets for softline cable

The 3076 is removable and has lock wire holes for secondary retention when mated to the accelerometer. Connector and pin assemblies are manufactured in California, ensuring the highest-quality product available is used. Furthermore, the connector employs a fused-glass dielectric for maximum reliability and moisture protection. The stainless-steel connector pin is welded to the cable's center conductor for maximum pull-strength and minimum noise.

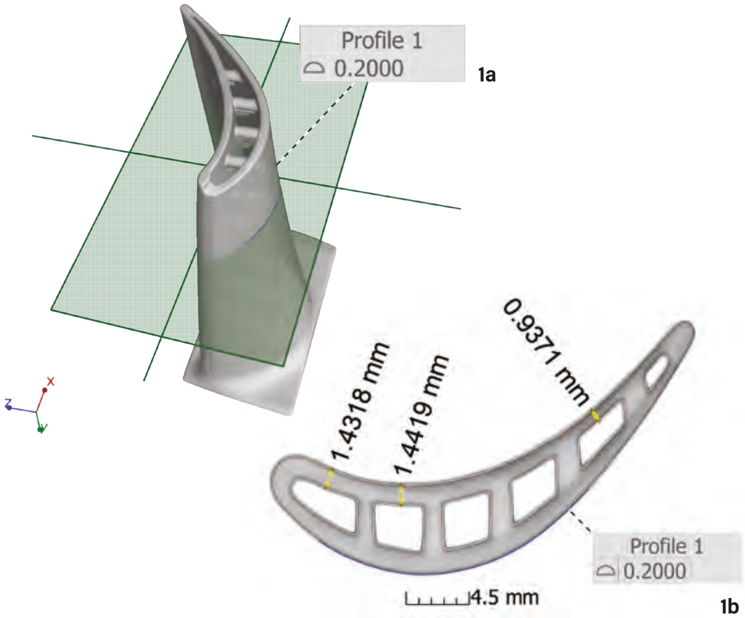
As for the most common wrapping for millinery steel wire today – it is not cotton but rayon. Invented in 1846, rayon did not become popular until the 1920s. \\

3

Abbreviation	Name	Temp. (°F)	Temp. (°C)
PVC	Polyvinyl chloride	221	105
FEP	Fluorinated ethylene	392	200
PFA	Perfluoroalkoxy	392	200
TFE	Tetrafluoroethylene	500	260

X-RAY COMPUTED TOMOGRAPHY FOR DIMENSIONAL METROLOGY

The testing and inspection of high value and complex components can be achieved faster and more cost-effectively with x-ray CT scanning



1a

1b

X-ray computed tomography (CT) has successfully entered the field of coordinate metrology as an innovative and flexible non-contact measurement technology for performing dimensional measurements on industrial parts. It provides advantages not available with conventional tactile and optical coordinate measuring machines (CMMs), giving the ability to perform non-destructive measurement tasks that are often not possible with any other measurement technology. These include, for example, the inspection, without any need to cut or destroy the components, of complex, high-value additive manufacturing products featuring a high density of information.

In the aerospace market, CT can be used to inspect smaller to medium-sized components such as turbine blades, aluminum castings and tube welds. With CT, quantitative analyses can be performed at several stages of the product cycles, enabling the optimization of products and manufacturing processes and the evaluation of conformity to product specifications.

The three main components of an x-ray CT system are the x-ray source, rotary table and detector. Different CT system configurations exist: for example, flat panel detectors (also known as digital detector arrays [DDA]) or linear diode array detectors (LDA) can be used. With LDAs, the phenomenon of x-ray scattering, relevant while scanning high-density materials such as in aerospace applications, does not impact the scan.

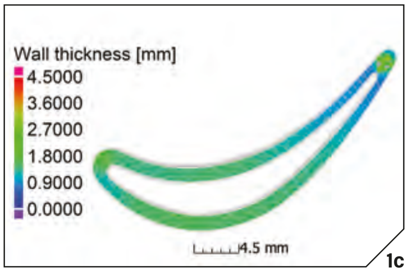
Longer scanning times are required, however. The x-ray source to detector distance and x-ray source to object distance define the geometrical magnification of the CT scan and the voxel size of the 3D CT model of the part. The use of variable x-ray source to detector distances, as offered in the NSI system portfolio, is also fundamental for aerospace applications to achieve the best signal possible. Indeed, being the CT technology based on x-ray attenuation principles, the size and the thickness of the part and the material density play fundamental roles. The bigger the component and the denser the material, the more power is required for the x-rays to penetrate.

The output of a CT scan is the 3D model of the part. This model is used to perform accurate measurements of the entire workpiece without any form of contact or need to cut or destroy the part. CT also enables material inspection and identification of internal defects such as voids and cracks and can be used to identify delaminations when inspecting composite materials.

In Figure 2 the color bar represents the different pore sizes, which are also visible on the 3D CT model. CT is capable of locating the porosities in the 3D model of the part and of providing information on the different porosities' volumes. The size of the porosities or defects that can be detected depends on the scan resolution, which is also a function of the part size, geometry and material. Advanced scanning techniques such as NSI Subpix can achieve an improved resolution and therefore a larger field-of-view for a given resolution.

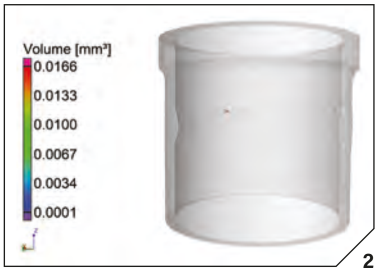
Other CT applications include nominal/actual comparisons in which the volumetric model of the actual part is registered and compared to its nominal model and fiber analysis for composite materials.

CT offers a wide range of advantages over conventional measurement technologies, including the ability to perform holistic measurements of the component on complex and/or non-accessible features in a non-contact and non-destructive way, with high density of information. In aerospace this is fundamental because the often high cost of parts does not encourage destructive testing. CT also enables engineers to quickly evaluate the conformance of the parts before high-cost machining processes. When measuring, for example, the freeform surfaces of turbine blades, CT can provide a high density of points in a much shorter time than conventional tactile CMMs, and being a non-contact technique, there is no need for probe tip compensation when inspecting freeform surfaces. \\



1c

1 // Example of dimensional analysis on a turbine blade. a) 3D view of the blade with clipping plane; b) measurement of dimensional features and airfoil profile; c) wall thickness analysis



2 // Example of porosity analysis on a tube weld

THE HIGH-FREQUENCY HEAD AND TORSO SIMULATOR

Clear communication is essential and requires realistic, accurate and repeatable acoustic measurements applicable to real people and real environments

Clear communication in the cockpit is necessary, and in combat environments, its importance and hindrances increase exponentially. Decisions must be made and acted on quickly, and are often based on rapidly changing situations in extremely noisy environments. Evaluating helmet noise-reduction properties and the speech intelligibility of communication products is crucial to minimizing delays and reducing the need for command repetition.

Audio products worn on or in the ear, as well as those pressed up against the ear pinna, cannot be adequately assessed using microphone measurements – their frequency response characteristics change significantly with acoustic loading against a human ear. To solve that problem, manufacturers have long used head and torso simulators (HATS) to more accurately simulate the sound that is actually picked up by the human ear in an operational environment.

However, the traditional type 711 coupler, while providing accurate acoustic loading, doesn't provide the geometry of a human ear, which is crucial for the accurate evaluation of in-ear devices. Additionally, its frequency range is limited to a maximum of 8kHz, which is insufficient for many wideband devices available on the market today.

Brüel & Kjær has spent more than 10 years perfecting the next-generation high-frequency HATS (HF HATS) Type 5128. HF HATS introduces a number of innovations that improve the ease of testing, such as improved accessibility to internal components, but for end users of the final communications devices, it is the improved accuracy and real-world relevance of the acquired data that is most important.

The entire goal of this project was to create a system that would acquire the same data that is processed by the human being sitting in a cockpit. Therefore the artificial ears were modeled after the measured ear geometries of over 40 people. The specificity of the pinna alone enables realistic deformation levels for measuring in open, semi-sealed and sealed conditions. Its accurate human shape and stiffness provides the ability to accurately evaluate communication devices for electrostatic characteristics, communication quality and pilot noise exposure up to 20kHz. But the correct geometry was not the only thing needed for accurate data.

While the geometry of the ear is a crucial part of obtaining correct data, if the materials used aren't also accurate representations of human anatomy, the data won't be truly accurate. Therefore the composition of materials comprising the walls of the ear canal had to be optimized for the correct and variable damping characteristics of the ear as it transitions from soft pinna to hard, bony structures toward the eardrum.

The correct composition of properties resulted in an accurate ear response measurement that extends to the full range of human hearing – up to 20kHz. The result of this meticulous design effort is a new evaluation tool that uses accurate human ear canal geometry and damping to provide the most reliable and realistic results possible and, as a result, enables the closest thing to evaluations of real-world communications as received by the human sitting in the cockpit. \\


2


1

1 // HF HATS covers the full audible frequency range

2 // The materials used in the simulator's ear mimic the composition of materials in a human ear

HOW TO PICK THE RIGHT HIGH-SPEED CAMERA

A range of important factors must be taken into consideration when selecting a high-speed camera for challenging aerospace tests

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.

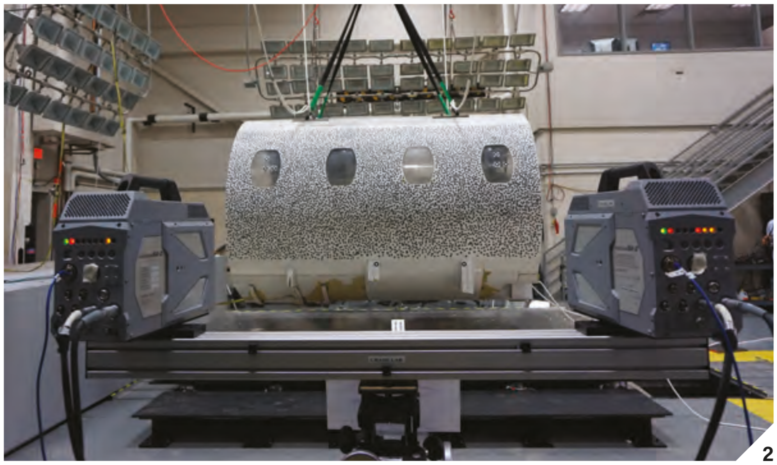
There are many factors to consider when purchasing a high-speed camera. The first consideration is frame rate. How many frames per second are required to capture sufficient image detail to analyze a high-speed event?

In certain applications, light sensitivity may be the most critical consideration. Light sensitivity impacts the quality of high-speed images. Without it the images will be dark and difficult to analyze. Light sensitivity is typically presented as an ISO value. The higher the ISO value, the more sensitive a camera should be. There are standards – such as ISO 12232 – that define how to measure light sensitivity, but many high-speed camera vendors do not adhere to the standards when they measure the ISO values of their cameras. Some vendors publish ISO values, but do not specify which ISO standard the values conform to. Without such information, the ISO values are meaningless.

Some very fast high-speed events require extremely short exposure times – sometimes even less than a microsecond – to stop the motion of those events. A camera's ability to achieve a sub-microsecond exposure is dependent on two things. First, the camera's sensor must be capable of performing such a short exposure. Second, the camera's sensor must be sensitive enough so that during a sub-microsecond exposure, it can capture enough photons of light to generate video that is of sufficient quality for analysis.

After the high-speed event has been captured, the video data must be transferred from the internal memory on the camera to a more permanent location for storage and analysis. Most camera suppliers have chosen to implement some form of Ethernet to enable the transfer of the data from the camera. Because the recorded data can be tens of gigabits or larger in volume, the data transfer over Ethernet can create a bottleneck in getting the data out of the camera.

As an alternative to Ethernet, some cameras can download images at very high data rates to a removable non-volatile memory source such as a high-capacity removable SSD. Recorded data can then be directly accessed from the SSD while it is coupled to the camera, or the drive may be removed from the camera and inserted into a docking station for image transfer to a PC.



1 // The FastCam range from Photron offers megapixel resolution and performance to 21,000fps

2 // Drop test of fuselage at Wichita State University

3 // Drop tests provide impact energy data about components

Certain testing environments contain large quantities of airborne dust and other corrosive particles. Some camera suppliers have implemented a sealed body design that prevents such contaminants from being ingested within the internal camera body where they can damage electronics.

Aerospace testing environments can be challenging for high-speed cameras. Frame rate and light sensitivity are typically the most important factors to consider when purchasing high-speed cameras, but there are other things one should think about, such as minimum exposure time, data offload speeds, and a camera body design that protects electronics from contamination by airborne particles. Photron's new FastCam Nova provides impressive performance in each of these areas. \\

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HIGH-DETAIL AND HIGH-SPEED IMAGING

The Phantom v2640 ultra-high-speed camera is the next major evolution in high-speed imaging.

Pushing the limits of 4MP imaging further than before, the v2640 is capable of 12,500fps in full 2K resolution (1920x1080). It provides very high image quality with very high dynamic range and low noise, for the most crisp and detailed images.

Along with exceptional detail at faster speeds, a variety of flexible modes make the v2640 an innovative imaging tool in aerospace testing. Binning enables researchers to switch between standard and high-speed modes, which adjusts the fps and resolution possibilities and increases the situations in which the camera is useful. The v2640 also brings a new mode called 'Brightfield mode' to Phantom cameras and aerospace testing. This mode can be critical in situations where there is intense bright light in most of the field-of-view. In aerospace testing, a bright blue sky can cause visual concerns when trying to see fine details during a high-speed event.

Brightfield mode works to eliminate the noise that can be found in very bright backgrounds to identify the finest details in an event. By using this mode to increase the signal-to-noise ratio, extremely clear images are possible – thus enhancing measurements and data. \\

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VISION RESEARCH

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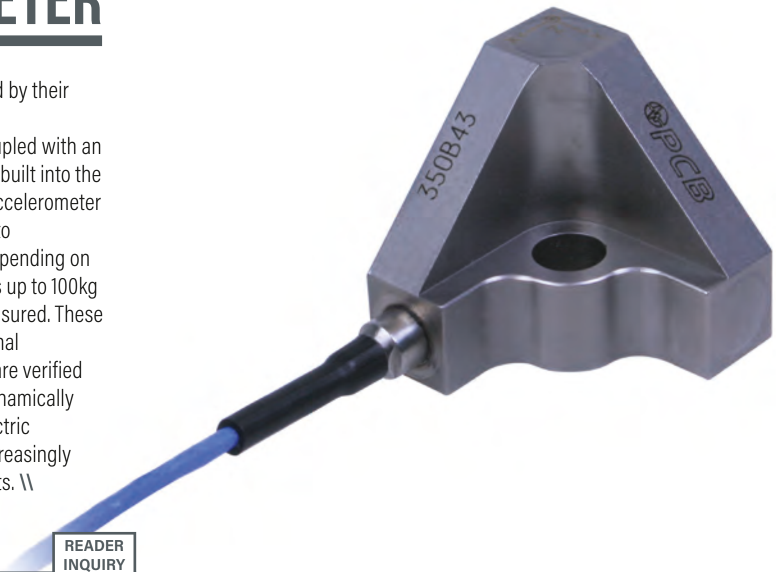
TRIAXIAL SHOCK ACCELEROMETER



The latest series of piezoelectric, case isolated ICP (integrated circuit piezoelectric) triaxial shock accelerometers are mechanically isolated, electrically filtered, and hermetically sealed for use in harsh environments such as pyroshock.

Compared with the traditional three independent shock accelerometers mounted on a triaxial block, the new accelerometers bring the coordinate system closer to the mounting location. This makes for muh improved data quality and survivability for out-of-plane measurements.

Piezoelectric ICP accelerometers afford a very high signal output (+/-5V full scale) and the ease of two-wire electrical connectivity. Their inherent ruggedness enables them to be severely over-ranged without damage. The addition of internal mechanical isolation minimizes the high-frequency stress that would otherwise be encountered by their ceramic sensing elements.

This mechanical isolation, coupled with an internal two-pole electrical filter built into the ICP circuitry, tailors the overall accelerometer response to assure data quality to frequencies as high as 10kHz. Depending on the specific model, accelerations up to 100kg (220 lb) can be successfully measured. These modern designs, with their internal elastomeric isolation materials, are verified through calibration to remain dynamically linear and are enabling piezoelectric accelerometers to operate in increasingly severe acceleration environments. \\

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PCB PIEZOTRONICS

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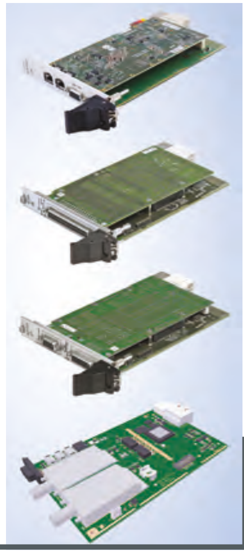
ACE IN THE HAND FOR STANAG3910

The latest ACE family of test and simulation cards from AIM offers PXIe users and platform providers with support for MIL-STD-1553, ARINC429, AFDX/ARINC664P7 and now STANAG3910/EFEX databus communications. Model ACE3910-3U-1 is the latest member of AIM's family of PXIe cards supporting STANAG3910/EFAbus Express (EFEX) communications.

It concurrently operates as the bus controller, multiple remote terminals, and the chronological/mailbox bus monitor with one fully independent dual-redundant STANAG3910 high-speed and low-speed interface. Protocol testing and simulation of STANAG3910 LS/HS functions can operate at full bus loads. The ACE3910-3U-1 incorporates full protocol error injection and detection; it also allows for reconstruction and replay of previously recorded electrical/optical STANAG3910 bus traffic to the LS/HS databus with high timing accuracy.

The ACE family of avionics databus communication cards use AIM's field-proven, common-core hardware design and use a powerful system-on-chip approach, including programmable logic and a multicore processor architecture. Two real-time processor cores act as the bus interface units and a further core as the application support processor running an onboard Linux operating system.

ACE cards incorporate support for the PXI instrumentation bus with triggering and system clock capabilities. An onboard IRIG-B time decoder and generator enables



synchronization of multiple ACE cards, with the IRIG-B source being an external IRIG-B time source, or the onboard time code generator of one ACE card as the reference.

A complete documentation package and driver software for Windows, LabVIEW VI, LabVIEW RT and Linux is included to accomplish an out-of-the-box, smooth integration with any PXIe platform.

The industry standard PBA.pro test and analysis software for Windows and Linux is also available as an option with the ACE family of test and simulation cards. \\

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AIM

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HIGH-SPEED CAMERAS FOR MILITARY TESTS

The high-speed cameras of AOS are widely known for their reliable functionality under the most severe environmental conditions, as experienced in real-world military tests. These specifications make the cameras the ideal choice for mounting in, or attaching to aircraft.

The cameras can record multiple sequences, store data in the camera's built-in, non-volatile memory, and download data instantly to the optional flash cards. The data collected provides an excellent basis for subsequent quantitative and qualitative motion analysis in the lab.

AOS cameras are designed according to MIL 810 standard and built to meet the challenges of inflight image data recording.

All cameras are available with different types of MIL-specified connectors for ease of integration into existing aircraft wiring. The cameras comply with GigE Vision standards and can record in standard speed ranges, as well as in high-speed camera mode. If the application requires it, AOS can provide a special enclosure for the camera, specific software functions, and last but not least, the extension of functionality that is vital for the test setup. Lastly, AOS can support these solutions over the full lifespan. \\

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AOS

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PRECISION ANTI-ALIASING FILTERS FOR COMPACT DAQ AND RIO

When analog signals are sampled by A/D converters, the sampled data record could have come from other signals outside of the bandwidth of interest – aliases. The Sampling Theorem states that an analog signal must be sampled at least twice the highest frequency contained in the signal to prevent aliasing. In other words, no information higher than half the sampling frequency can exist in the signal, otherwise aliasing will occur.

Signals above Fs/2 do exist in the signal and require a filter to attenuate them to an acceptable level. If you do not properly filter the input signal, the digitized output will contain aliasing errors that look like real data and since the aliasing signals are unknown, the errors are unknown and cannot be corrected by post-processing.

The CompactDAQ and CompactRIO platforms, introduced by National Instruments, provide a convenient form factor for data acquisition systems; however, many A/D modules do not have front-end filters requiring the user to provide an external filter to provide protection against aliasing.

Precision Filters offers a pair of low-pass filter modules for the CompactDAQ and CompactRIO platforms that enable users to easily add high-performance, anti-aliasing filters to their system. The 9602 provides six-pole filters with cut-offs programmable from 10Hz to 127kHz and includes an integrated amplifier to gain up low-level signals. The PFI-9608 has four-pole programmable filters with cut-offs available from 10Hz to 30kHz. Both modules feature Precision's FLAT/PULSE filter characteristics. \\

Index to advertisers

The tin donkey

World War I saw more than 50 new aircraft designs developed, including the world's first usable all-metal aircraft

Last month marked 100 years since the end of World War I, and there is an important aeronautic legacy to The Great War that should be remembered.

World War I catalyzed the development of more than 50 different aircraft between 1914 and 1918. Reconnaissance balloons, the Zeppelin, fighter aircraft, bombers, even the beginnings of air traffic control in the form of two-way radio, were all invented during the war. Aerial combat of the time evokes images of Fokker Eindeckers and Sopwith Camels, and of flying aces wearing goggles and scarves. But it's a little-known experimental aircraft, developed early in the war, that is considered by many historians to have had the greatest impact on modern aviation.

The German Junkers J1 was the world's first practical all-metal aircraft, although the Romanian A Vlaicu III is credited as being the very first all-metal aircraft. The experimental J1 monoplane, which never saw active service in the war, pioneered several features of modern aircraft. It had cantilever wings, metal structural elements including reinforcement around load-bearing areas, and a metal stressed-skin construction. It also had a single vertical tail formed of sheet steel. The aircraft was powered by a six-cylinder liquid-cooled Mercedes DII 120hp engine with a radiator placed in a ventral position underneath the forward fuselage.

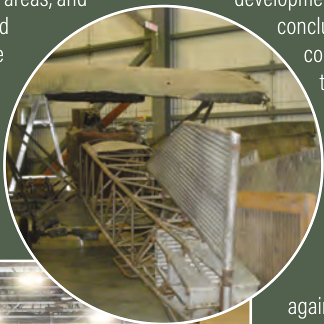
The J1's test program started with static loading trails carried out on the aircraft's structure using sandbags. A series of static thrust tests of the engine and propeller combination were also undertaken. The flight test program began in December 1915, when the aircraft made its maiden flight, reaching an altitude of almost 9.8ft.

During a landing in December, the J1's port wingtip scraped the ground, resulting in repairs that delayed testing for more than a month. Once flight testing resumed in January, the aircraft reached a maximum height of 3,000ft and a top speed of 170 km/h (106mph). Test pilots determined the inflight handling of the J1 to be stable.

However, the aircraft did not win plaudits. It was slower and more sluggish in the air than many existing wood and fabric aircraft, despite having a more powerful engine. The welded construction of the aircraft also proved problematic for technicians on the ground to work with. These problems earned it the nickname *Blechesel* – the 'Tin Donkey'.

Despite this, military chiefs supported the J1's development, and when flight testing concluded in January, the Junkers company won a contract to develop the all-metal concept into the J2 single-seat fighter. The J2 shared a similar structure, but was more refined aerodynamically and slightly smaller. Like the J1, the J2 also failed to see front-line service.

The Junkers J1 was not flown again after the flight test program and was placed on static display in 1926 at the Deutsches Museum in Munich. The aircraft was destroyed at the museum in an Allied bombing raid in December 1944, during World War II. \\



// An example of the Junkers JI, the mass-produced derivative of the J1, in the Canadian War Museum

DEC 12,1916
First flight

J1
Model number

42FT
Span

28FT
Length

2,381 LB
Gross weight

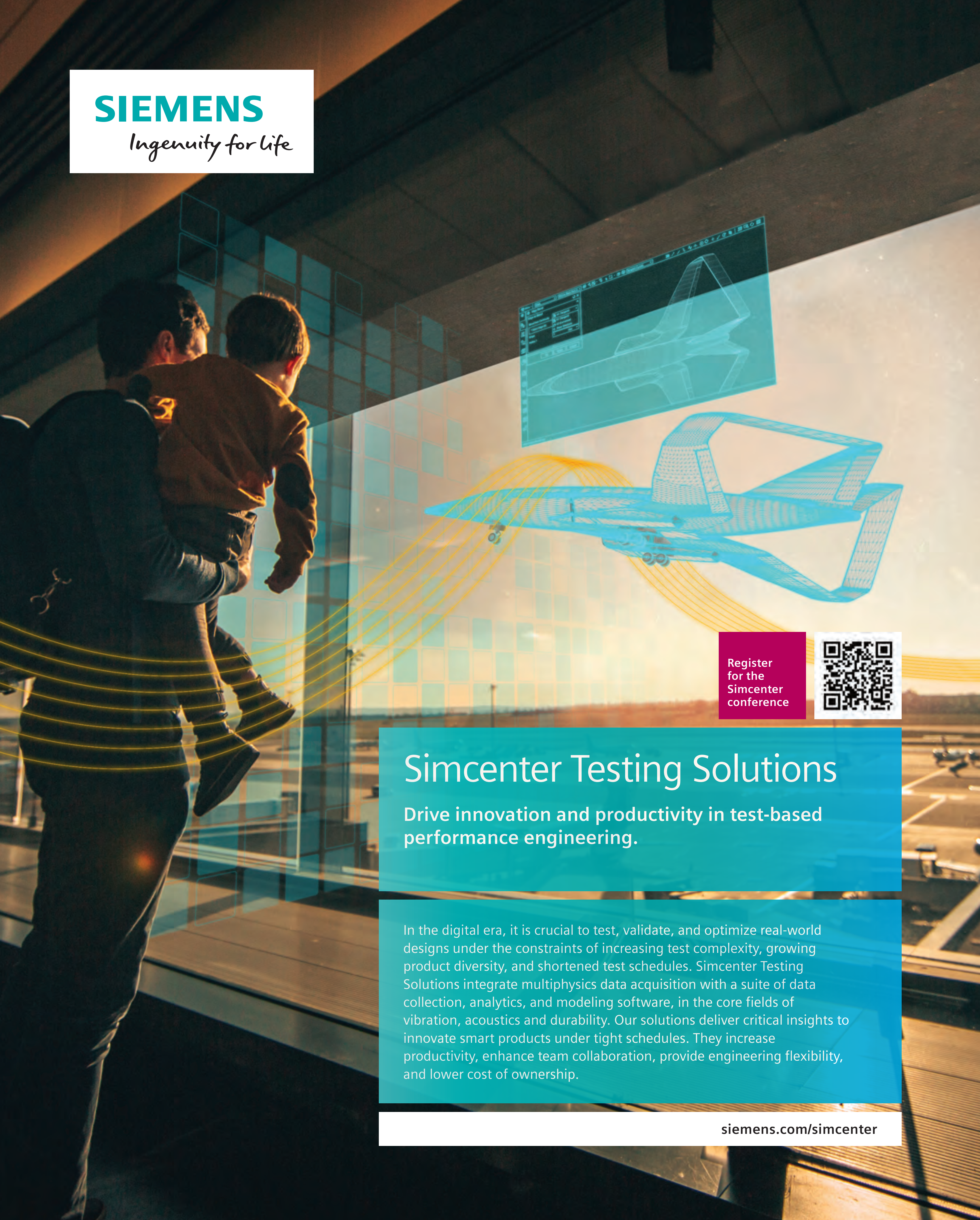
106 MPH
Top speed

193 MILES
Range at full load

13,123 FT
Ceiling

120HP
Output of Mercedes DII engine

1
crew – a test pilot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