SEPTEMBER 2016

Aerospace TESTING INTERNATIONAL

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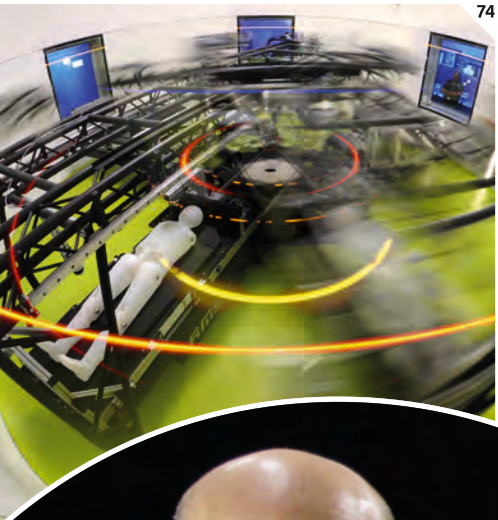

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Global briefing

Inside this issue

// Worth the wait

Journalists are in general an impatient breed, always wanting to be the first with the news and driven by a desire to discover fresh facts that help their audience arrive at a more enlightened understanding. However, when in search of a great story, one sometimes has to be very patient indeed. This was certainly true for Paul Eden, when attempting to arrange an interview with the RAF's 41 (Reserve) Test & Evaluation Squadron, based at RAF Coningsby, Lincoln, UK. It took over a year to pin down, but we hope you agree it was worth it – turn to page 28 to read the fruits of Eden's labors.

"Arriving at its main gate, it's immediately obvious that Coningsby is a busy station," remarks Eden, when asked about his recent visit. "Its frontline and OCU Typhoon requirements keep the flight line and circuits noisy, while frequent visiting aircraft and the Battle of Britain Memorial Flight ensure there are always plenty of enthusiasts at the fence. Amid all this activity sits 41(R) TES, a lodger unit at Coningsby, as it is controlled by the Air Warfare Centre rather than 1 Group, going about its exacting business quietly and professionally, while few at the station or even in the wider MoD fully appreciate what its role entails."

As Eden discovered, visiting 41(R) is an art in being available and accepting that cancellation at the very last minute is always a possibility. "The squadron's regular trials workload is immense, but it is always ready to take on priority issues emerging from the frontline, often triggered immediately by a phone call or email," he says. "Sit in the crew room and the unit's interesting mix of RAF, civil service and contractor personnel is quickly evident. It's also striking that this collection of talented individuals work together on the basis of mutual respect and understanding, from newly posted flight lieutenant engineer, through squadron boss to senior civil servant."

Thomas Newdick, who penned this issue's cover story on Saab's Gripen E, was equally impressed by the teamwork and dedication he discovered when interviewing those responsible for the next-generation fighter's ongoing testing: "Developing a new fighter aircraft in the 21st century – and the Gripen E really is a new fighter, despite appearances – is a huge challenge, beyond all but the biggest military-industrial powers," opines Newdick. "The exception is Sweden, where Saab has adopted a smart approach to planning, developing and testing its new-look Gripen."

The fact that the Gripen E has already won firm orders from Brazil and Sweden would seem to back up Newdick's point of view. "The only way to bring a new fighter onto the market in this day and age is to make use of smart practice from the (virtual) drawing board to the flight line," he continues. "Saab's approach to preflight test of the Gripen E shows how you can make the most of limited resources, and provide a genuine challenge to the big players."

Talking of 'big players', they don't come any bigger than NASA and the European Space Agency, both featured in two articles written by Rob Coppinger. On page 66, he takes a look at space food trials: "A nine month voyage to Mars is one of the longest trips anyone could imagine, but you'll never get tired of the huge variety of food and drink that NASA will provide its astronauts for the journey," he says.

Meanwhile, on page 74, we examine ongoing artificial gravity trials: "The classic sci-fi movie *2001: A Space Odyssey* had astronauts living in a huge rotating chamber to create the centrifugal force needed for artificial gravity," he says. "The likely reality for the astronauts that will go to Mars will be cycling on a spinner on a spinning platform to deliver the same anti-bone loss health effects."

So there you have it – another fact-packed issue that we hope you will agree was worth the wait!

***Anthony James**, editor-in-chief*

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COVER IMAGE: Saab's Gripen E/F put through its paces in the flight simulator (Photo: Saab)

WORLD test update

// B-52 RELEASES JASSM FROM INTERNAL BAY

A B-52 Stratofortress flying from Edwards Air Force Base, California, has successfully dropped three Joint Attack Surface Standoff Missiles (JASSMs) from a revolving weapons launcher mounted in the internal weapons bay.

The aircraft has long been capable of carrying JASSMs on its wing pylons, but this is the first time they have been successfully released from a conventional rotary launcher (CRL) in the internal bay.

The bomber has long been capable of carrying up to 12 JASSMs on its wing pylons. Integration of CRL in the internal weapons bay adds the capability of carrying eight more missiles in the aircraft, increasing the B-52's JASSM payload by more than 60%.

The previous launcher used in the B-52's internal bay was the common strategic rotary launcher, which was only capable of carrying unguided munitions or 'dumb bombs'.

Edwards AFB, California, USA

READ MORE ON OUR WEBSITE

// H160 FLIGHT TESTS VALIDATE AEROMECHANICAL CONFIGURATION

Airbus Helicopters announced on July 28 the validation of the H160's aeromechanical configuration – a crucial milestone that allows the program teams to confirm some key aspects of the twin-engine helicopter's design and performance.

More than 200 hours of flight testing have confirmed several key design assumptions according to an Airbus Helicopter statement.

During the flight test campaign, carried out with two prototypes at the company's main site in Marignane, France, the H160 demonstrated "exceptionally low vibration levels along with remarkable aircraft stability levels, setting new benchmarks in the field," according to the company.

The next steps in the flight campaign will focus on hot weather trials, to take place over the summer, followed by continued performance testing of the Arrano engines, which are now installed in both prototypes. Cold weather tests will follow later in the year.

Marignane, France

// VIRGIN GALACTIC SPACE CRAFT TAXI TESTING BEFORE FIRST FLIGHT

The US FAA's Office of Commercial Space Transportation (FAA-AST) has awarded Virgin Galactic an operator license for SpaceShipTwo. The license award, which will ultimately permit commercial operations of the vehicle, was the culmination of several years of in-depth interaction with the FAA.

The license review process consists of an in-depth review of the vehicle's system design, safety analysis and flight trajectory analysis, culminating in FAA-AST approval.

On August 1, 2016, the Virgin Galactic team began conducting a taxi test with SpaceShipTwo (named VSS Unity) and a tow vehicle. Taxi testing is an important step toward the flight test program. It was used to check out the navigation systems and braking.

Mojave Air & Space Port, California

SEE OUR SPACE FOOD STORY ON PAGE 66

// AW609 RETURNS TO FLIGHT TESTING

Leonardo-Finmeccanica announced that the first flying AW609 prototype has arrived in Philadelphia following the recent resumption of flight testing.

With pre-production activity underway, Leonardo-Finmeccanica has expanded the AW609 tiltrotor program to include the company's Philadelphia facility, which represents the anticipated progression toward assembly and certification in the USA with the FAA.

This prototype now in Philadelphia will soon be relocated to Italy. An Italian-assembled and ground-tested AW609 will be shipped for flight testing in Philadelphia. A Philadelphia-assembled AW609 will join the fleet in 2017. Certification of the first commercial tiltrotor is expected in 2018, with deliveries to customers to follow.

Philadelphia, USA

// HYBRID AIRSHIP TAKES FIRST FLIGHT IN BRITAIN

The hybrid airship Airlander 10 took off for a short first flight on the evening of August 17 from its base in Cardington in the UK. The 302 x 143ft (92 x 43.5m) helium-filled craft is part lighter-than-air blimp and part airplane and designed to use less fuel as its shape should give it additional lift (40%) in addition to that provided by the gas (60%) contained in its fuselage.

Top speed should be 90mph (145km/h) and the aircraft could potentially stay aloft for two weeks – unmanned. Payloads up to 10 metric tons are planned for the aircraft, which can also land anywhere, potentially opening up new point-to-point routes.

The original concept was designed for the US Air Force, , but the project was dropped during 2014 budget cuts. The building cost for the prototype was approximately US$100m. HAV purchased the prototype for US$300,000 and took it to the UK, after which the company made over 100 design changes, making it essentially a new aircraft design.

Cardington, UK

// RECORD LIGHTWEIGHT ELECTRIC MOTOR MAKES PUBLIC FLIGHT

Siemens researchers have developed a new type of electric motor that, with a weight of just 50kg, delivers a continuous output of about 260kW – five times more than comparable drive systems. This propulsion system successfully completed its first public flight on July 4 at Schwarze Heide Airport near Dinslaken, Germany, where it powered an Extra 330LE aerobatic airplane. The new drive system had already made its maiden flight on June 24, 2016. This advance means that hybrid-electric aircraft with four or more seats are now possible.

Frank Anton, head of eAircraft at Siemens's central research unit, corporate technology, said, "This is the first time that an electric aircraft in the quarter-megawatt performance class has flown." The Extra 330LE, which weighs nearly 1,000kg, serves as a flying test bed for the new propulsion system.

Dinslaken, Germany

READ MORE ON E-FLIGHT ON PAGE 36

// SOLAR IMPULSE 2 SUCCEEDS IN ROUND-THE-WORLD FLIGHT

Solar Impulse 2 (Si2) successfully completed the first ever circumnavigation of the world by a solar-powered electric aircraft using only the energy of the sun on July 26, 2016. Bertrand Piccard and André Borschberg took turns flying in 17 legs in the single-seater cockpit over 43,041km in a circumnavigation that began on March 9, 2015, when Si2 set off from Abu Dhabi, the United Arab Emirates capital.

A total of 19 world records were set or are still pending with the World Air Sports Federation (FAI).

"This is not only a first in the history of aviation, it's above all a first in the history of energy. I'm sure that within 10 years we'll see electric airplanes transporting 50 passengers on short- to medium-haul flights," Piccard said.

Abu Dhabi, UAE

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// NASA Aeronautics researchers will use the X-57 to demonstrate that electric propulsion can make airplanes quieter, more efficient and more environmentally friendly

NASA TALKS MORE ON E-FLIGHT ON PAGE 85

Electric plane gets the 'X' factor

NASA continues to test new propulsion technology using an experimental airplane that was recently designated the X-57 and nicknamed 'Maxwell'. The X-57 designation was assigned in June by the US Air Force, following a request from NASA, while it is named in honor of James Clerk Maxwell, the 19th century Scottish physicist and electromagnetism pioneer. (The first X-plane was the X-1, which in 1947 became the first airplane to fly faster than the speed of sound.)

The general-aviation-sized X-57 features 14 electric motors integrated into a uniquely designed wing and is part of the agency's 10-year-long New Aviation Horizons initiative. Five larger transport-scale X-planes are planned, firmly underscoring NASA's belief in hybrid and electric flight.

Part of a four-year flight demonstrator plan, NASA's Scalable Convergent Electric Propulsion Technology Operations Research project will build the X-57 by modifying a recently procured, Italian-designed Tecnam P2006T twin-engine light aircraft. Its original wing and two gas-fueled piston engines will be replaced with a long, skinny wing embedded with 14 electric motors – 12 on the leading edge for take-offs and landings, and one larger motor on each wing tip for use while at cruise altitude.

NASA hopes to validate the idea that distributing electric power across a number of motors integrated in this way will result in a five-fold reduction in the energy required for a private airplane to cruise at 175mph (relative to the performance of the original aircraft in the same flight conditions), as well as slashing noise levels. \\

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// The B-1B sits on the turntable inside the Benefield Anechoic Facility

B-1B goes back to the BAF

The Benefield Anechoic Facility (BAF), originally constructed to test the electronic warfare countermeasures on the B-1B Lancer supersonic bomber, has recently welcomed back a B-1B bomber for retesting to ensure the system remains fit for purpose. The US Air Force plans for the B-1B to continue to serve into the 2030s, with the Long Range Strike Bomber (the B-21) replacing it from 2030.

The visit of the B-1B, which began on July 27 and finished on August 12, was used to examine the effectiveness of the ALQ-161 threat protection system 27 years on with the goal of improving it to enhance the bomber's survivability.

Rodney Brooks, 579th Software Maintenance Squadron, out of Robins Air Force Base, Georgia, USA, explained, "The ALQ-161 receives all the radio frequency energy when the aircraft is flying and will process it and determine if it's a threat to the aircraft, and then it can set up automatic jamming to jam that RF energy from a missile, aircraft or ground missile."

"The 161 system has been on the B-1B since it was built and we've done a lot of improvements in the last 10 years. We're looking to make some more improvements in the future and we need to collect data from the antennas here in the BAF so that we can move forward."

Data is being collected from tests for directional signals, antenna patterns and system channel testing. The team is observing how the ALQ-161 responds to signals and what the system is looking at when it sees signals out in the field. The data will be analyzed to see if the hardware, software or both need to be upgraded to extend the B-1B's service life. \\

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Flight simulators: passé or the future?

Flight simulation is undoubtedly a valuable part of the aerospace testing process, but has technological development in the field stagnated?

Pilot-in-the-loop simulation was once the centerpiece of forward-looking technology in the aerospace industry. In an industry where product lifecycles span decades, it became possible to progress from initial concept to 'flight' test in a matter of days. However, the underlying concepts have remained fundamentally unchanged since the initial inception and use of flight simulation.

Flight simulation 'progress' has been mostly in graphics for the visual environment. More impressive graphical output does not necessarily improve the overall fidelity of the simulation. Once a basic acceptable level is reached, additional detail does not affect the way pilots use visuals to control their aircraft. This assumes the maneuver in question requires substantial use of external visual references – often not the case. Surely there must be a more effective use of computing power than producing superficial visual improvements?

While graphics are undoubtedly improving, the fundamental idea of simulating visuals has not changed for more than 40 years.

Emergent technologies such as virtual and augmented reality are so far confined to the realms of niche video gaming, but have the potential to deliver more immersive and easily reconfigurable simulations.

Perhaps testing should be finding new and interesting ways to make use of these technologies, rather than just throwing money at making better versions of the same graphics. Rapid prototyping of changes to cockpit controls and displays in a high-fidelity simulator could offer huge efficiency savings and result in a better end product. However, such is the complexity of modern simulators that the embodiment of modifications is often just as onerous as in a real aircraft cockpit.

Pilot-in-the-loop simulators are no longer novel and innovative, but are 'part of the furniture' for aircraft development. While they fulfill an important function, development has succumbed to the lack of inertia associated with large aerospace projects. The challenge for the next generation of engineers is to identify technologies and techniques that can offer the same potential step change in capability that originally brought simulation into the mainstream test community. If such potential is genuine, it is impossible to argue against. \\

Garnet Ridgway
has a PhD from the UK's University of Liverpool. He has designed cockpit instruments for Airbus and currently works for a leading UK-based aircraft test and evaluation organization

Sophie Robinson
works at the front line of aerospace testing as a rotary-wing performance and flying qualities engineer for a leading UK-based aircraft test organization. She also holds a PhD in aerospace engineering from the University of Liverpool

Flight simulation has evolved to become a key part of aerospace testing. Many of the airborne activities once dominated by flight test are now undertaken in simulators, and the simulation industry is still a rapidly developing one.

The use of simulation in testing and training began in the late 1920s with the development of the Link Trainer – a synthetic trainer used to provide pilots with instrument flying experience. Over time, the complexity and fidelity of simulation systems has increased, enabling increasing reliance on testing without flight. While my co-author argues that there is little to be gained from superficial increases in the graphical qualities of the visual environment (which is very true) and that the step change seen in other areas of aerospace technology has been long overdue in the simulation industry, advances are still being made.

Hardware technology may have somewhat stagnated, yet our understanding of how simulation delivers transfer of training, and how it can be used to reduce flight hours in testing, has continued to improve. Engineers have become more able to carry out hardware-in-the-loop testing, enabling earlier evaluation of novel systems. Issues are identified early, and it avoids repetition of the usual fly-fix-fly cycle, which is inefficient and costly.

Engineers are also exploiting more off-the-shelf technology. An understanding about the required levels of simulation fidelity increases, new routes to achieving the desired outcomes of simulation-based testing are developed, further reducing the time required and consequently the cost of testing.

As a consequence of these developments, simulation is now able to support the entire life of the product, not just the testing phase.

Looking to the future, this reliance on simulation will only increase. Couple this with the increasing capabilities of aerospace systems, and the fact that the limitations of our current simulation technology are frequently revealed by flight testing, and engineers are faced with a real challenge: how can we continue to advance our simulation capabilities to meet the demands of novel aircraft, while continuing to reduce the costs and time spent in flight testing? \\

// THOMAS NEWDICK

1 // Saab's 'smart' approach to Gripen E/F development has made extensive use of synthetic flight test aids, including both static rigs and simulators (All photos: Saab)

Model b

Smart testing for a smart fighter: the Gripen E is being developed and tested to ensure maximum value and efficiency

ehavior

2 // The first Gripen E prototype, aircraft 39-8, was rolled out to an audience of air force officials and global media at Saab's Linköping facility on May 18, 2016

On May 18, 2016, Saab unveiled its latest Gripen E fighter prototype at its Linköping facility in Sweden. Described as a 'smart fighter' by the manufacturer, the Gripen E is the result of an equally smart development program, which is already yielding a considerable reduction in costs and time.

According to Lars Ydreskog, Saab's head of aerospace operations, "We have reduced development and production costs by 40%." Rather than using traditional design drawings, the Gripen E's three-year full-scale development effort has been based around what the Swedish manufacturer calls model-based systems engineering (MBSE).

Test data has been gathered in advance of the Gripen E's first flight using experience from previous, in-service Gripen variants (JAS 39A to D), and a dedicated test airframe, the Gripen Demo, colloquially known as the 'Dash 7'. (The Gripen Demo is aircraft 39-7, while the first full prototype Gripen E is aircraft 39-8).

Thanks to MBSE, costs relating to modeling, evaluating and building the Gripen E have been trimmed. And once the Gripen E takes flight later this

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3 // Gripen test pilot Marcus Wandt (left) and Ulf Nilsson, Saab's head of aeronautics (Photo: Thomas Newdick)

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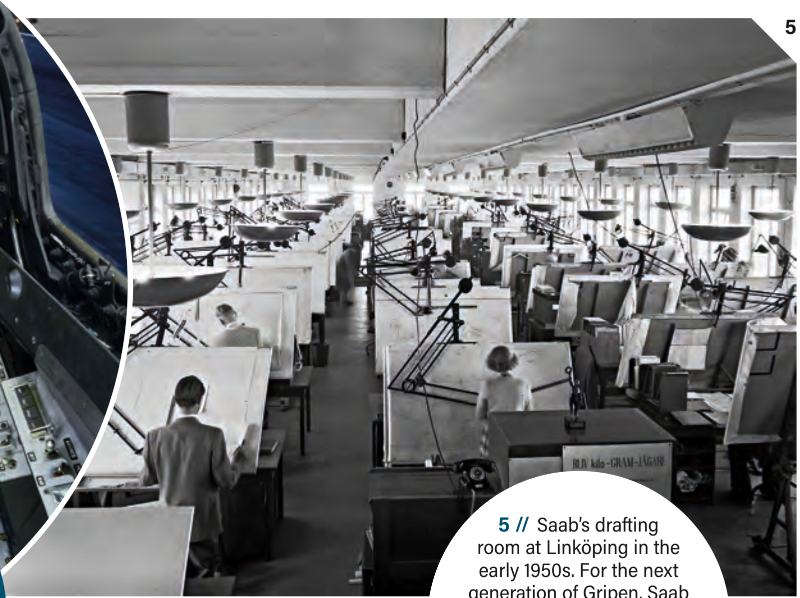


4 // The cockpit of the Gripen E. This has been tested extensively using the rear cockpit of the two-seat Gripen Demo. The Demo's front cockpit remains broadly unchanged from the Gripen C/D

5 // Saab's drafting room at Linköping in the early 1950s. For the next generation of Gripen, Saab chose to completely abandon two-dimensional drawings in favor of 3D-based documentation

2

6
nations have ordered the Gripen. New-build aircraft have gone to Sweden, South Africa and Thailand, and will be delivered to Brazil. Refurbished aircraft have been supplied to the Czech Republic and Hungary. In the UK, the Gripen is flown by the Empire Test Pilots' School

209
Gripen A to D variants built for the Swedish Air Force, including five prototypes and three production lots

650
sorties flown by Swedish Air Force Gripen C/Ds over Libya during the type's combat debut in 2011. More than 150,000 reconnaissance images were taken, and nearly 2,000 flight hours recorded

year, Saab aims to continue its lean approach via a considerably reduced flight test campaign.

ADDED CAPABILITIES

Compared with the Gripen C/D, the Gripen E carries 40% more fuel, offers greater thrust, has more weapons stations and increased overall weight. Sweden's Defence Ministry plans to buy 60 new-build Gripen E fighters, and is considering buying another 10 on top of that, while Brazil has ordered a total of 36 aircraft under a US$4.5bn contract. Ultimately, there is the potential for a future Brazilian Air Force fleet exceeding 100 aircraft while the Brazilian Navy could buy 24 examples of a navalized Sea Gripen, or Gripen M.

"First flight was traditionally important," Ydreskog explains. "The first flight for us of Gripen E is of course important, but it is not that important for us to verify that all the functions work." As such, the abbreviated flight test campaign will focus on areas that are difficult to model using computer software alone.

The Gripen E program involves an entirely new-build airframe allied with a new engine and new, but proven, technology.

SOFTWARE STEP CHANGE

In order to reduce the quantity of certification test work required for the Gripen E, the amount of computer software code relating to flight-critical elements has been cut to just 10%. The remaining 90% of code is dedicated to tactical functionality. This has the additional benefit of enabling Saab engineers to make rapid tactical upgrades without having to modify flight-critical avionics. Saab likens this approach to adding apps to an existing smartphone.

The first Gripen E prototype will be used to complete the verification of the flight control software. In the meantime, the software is being proven on the ground, using a simulator and test rigs. Gripen test pilot Marcus Wandt says that tests of the software in the simulator show that it is already "very stable".

Certain key features are intended to separate flight management software from tactical management software, explains Wandt. "You don't want code from tactical management to affect flight management. We need to be able to change tactics really quickly and also be able to change hardware without touching the applications."

Speaking to *Aerospace Testing International*, Ulf Nilsson, Saab's head of aeronautics, confirmed that the company's new approach to testing reduces the number of test flights required by 30 to 40% compared with the traditional model – as was used for development of the previous-generation Gripen C/D. "We see potential for even more reductions," says Nilsson, "now that we are using the philosophy of working with the simulators and the model-based design and everything that is bringing with it."

The wealth of data that will be obtained prior to the first flight of the Gripen E also means that the first test aircraft will be much more similar to the production fighter that follows than was the case in previous programs. "The model-based design is a really important point," observes test pilot Wandt. "The first test aircraft will be surprisingly similar to the production aircraft. Normally you have to test the prototype and then you have to go and test the production aircraft, with a lot of overlapping testing. We avoid this overlap by being able to provide a lot of the answers to test points right now."

6 // Prior to the roll-out of the Gripen E, critical test work has been carried out using the Gripen Demo testbed, aircraft 39-7. Here, it carries IRIS-T and Meteor air-to-air missiles and GBU-16 guided bombs

6

TEST PILOT TALK

Aerospace Testing International met with Gripen test pilot Marcus Wandt for an exclusive interview during the course of July's Farnborough International Airshow. Marcus provided details of the latest test work in the run-up to the Gripen E's first flight. "We have flown around 350 hours on the Dash 7. We are doing a lot of testing in simulators and rigs, where we are looking at the avionics systems, and how they interact. We also have rigs, which are using the Gripen E sensors: AESA radar, IRST and electronic warfare systems. These are on the roof of one of the buildings and you can fly against them as well.

"The avionics in the back seat of the Dash 7 are Gripen E avionics, with displays to control the AESA radar and other sensors. In the front cockpit, the Dash 7 is still a Gripen D, albeit a test version. We do fly it a lot and then we can do real testing. Since it's not flight critical, the back seat part of it, we can do really quick upgrades and new fixes. That's what we are doing right now. Doing all this in parallel will put us in a really good place compared with what's traditional, and then we can actually start flying the first test aircraft."

DEMO PAVES THE WAY

The Gripen Demo is a key element in the program's risk-reduction effort. This aircraft, originally a two-seat JAS 39D, was extensively rebuilt as a surrogate two-seat 'Next Gen' variant, and was first flown as such in 2008, just seven months after the Swedish government approved plans to develop some of the features proposed for the future Gripen E/F.

Items of new technology destined for the Gripen E have been progressively added to the Demo airframe and then tested. At the time of the roll-out, Saab had flown a total of "several hundred" sorties.

As first flown in May 2008, the Gripen Demo included an increased-area wing, new landing gear, additional hardpoints under the wing, and the new General Electric F414 engine. After a total of 79 sorties – including demonstration of super-cruise capability at Mach 1.2 – the Gripen Demo was returned to the manufacturer to receive a host of further modifications. It returned to flight in October 2009, now with active electronically scanned array (Selex ES-05 Raven) radar, elements of the self-defense system, as well as activation of its increased internal fuel capacity.

"We've been flying the AESA radar for a long time," confirms Ydreskog. Furthermore, the Gripen Demo has also flown with the Selex Skyward-G infrared search and track (IRST) sensor and other avionics elements.

It is certainly a step change from the beginning of the Gripen program, when a modified Saab Viggen was required to serve as an avionics 'surrogate' for the maturing fighter, completing almost 250 flights until it was retired from the program in 1991.

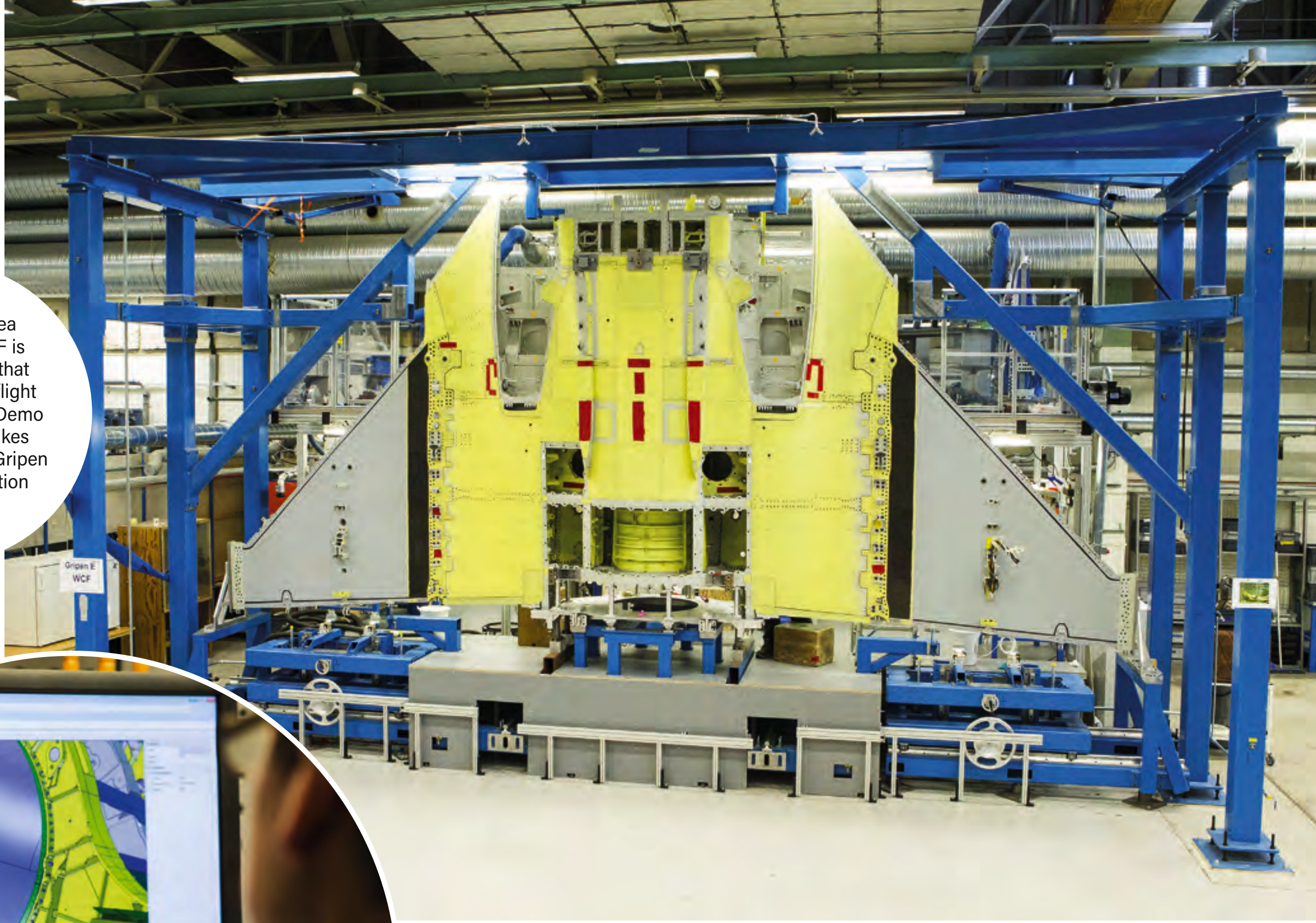
2,000
flight hours recorded

1,900 LB (862KG)
additional internal fuel found in the Gripen E demo than in the Gripen C/D

Another break in the flight test program saw the Gripen Demo fitted with its current open-architecture avionics (with separation of flight-critical and mission critical functionality), new tactical mission computers, Ethernet capability and new cockpit displays. The aircraft returned to flight in May 2011.

In March 2014, the Gripen Demo was first flown with the production-standard IRST. Also previously test flown in the Demo jet is the new missile approach warning system (MAWS), satellite communications (SATCOM), new displays and avionics architecture (installed in the Demo's rear cockpit), and the new digital head-up display (HUD). In terms of structural test, the Demo has flown trials of the increased internal fuel, new landing gear, and the two new stores stations.

Marcus Wandt talked about his experience of the Gripen Demo as regards fulfilling the test program criteria: "As long as we can answer the questions, we can move on with the test program. Some of the tests include



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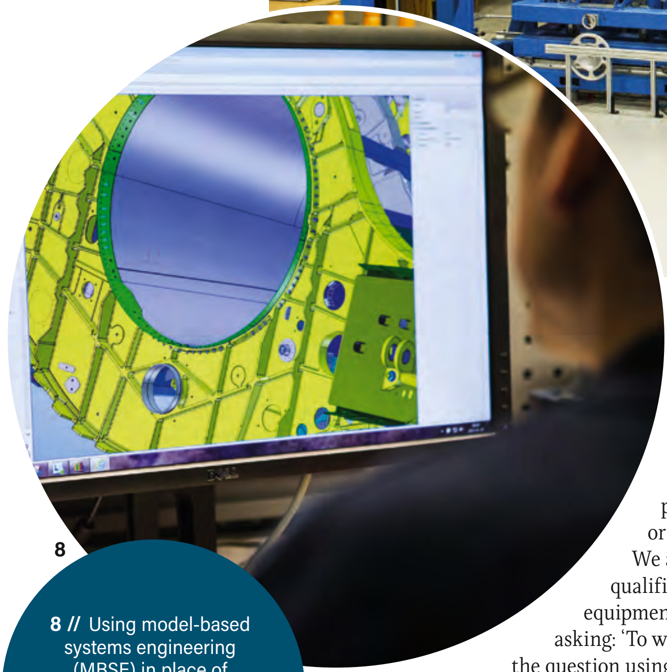
7 // The increased-area wing of the Gripen E/F is another key advance that has been thoroughly flight tested on the Gripen Demo before the Gripen E takes flight. Seen here is a Gripen E wing on the production line at Linköping



8

8 // Using model-based systems engineering (MBSE) in place of traditional design drawings has helped Saab reduce development and production costs by 40%

a lot of test points and we have developed some software as well to ensure that we can do as many test points as possible during one flight, or during one synthetic test. We also have a really thorough qualification of all test equipment we are using, always asking: 'To what level can we answer the question using this system?' For instance, there are some things you can't answer in a rig or on the ground. And that will be stated in the test points. By doing this, by taking care of a lot of the test points that it is easy to get an answer on, by covering a lot of those in the rigs, we can devote the actual flight test to the tricky parts, which is something I like as a test pilot."

Saab plans to complete three Swedish Gripen E test aircraft, which are additional to the 60 aircraft on order for the Swedish Air Force. The initial prototype will be handed over for flight-testing this summer and will take to the air before the end of the year.

The next two prototypes are both now under construction at Linköping. Saab will complete a further test aircraft for the Brazilian side of the program. This will undergo initial tests in Sweden before being handed over to Brazil, where it will trial certain elements specific to the Brazilian aircraft, including a local communications suite, different weapons, and a large-area display cockpit. Saab is currently establishing a Brazilian development and flight test center at Gavião Peixoto, in partnership with Embraer. Ultimately, a full production line will exist in Brazil, and this will also be responsible for the two-seat Gripen F, which to date has only been ordered by Brazil.

THE NEXT PHASE

Many test requirements have already been verified and the number of live flight-test points has been dramatically reduced thanks to work undertaken using test rigs in flight sciences laboratories, simulation modeling, and live test flights using the aforementioned Gripen Demo aircraft.

Once the first Gripen E has taken to the air, the certification period is currently planned to run from mid-2018 to the end of 2023. When this is complete, the Gripen E will mark full operational capability with the definitive MS22 software configuration (the current Gripen C/D is currently at the MS20 standard).

Now, after all the preparation work in the Gripen Demo, and using synthetic aids, Marcus Wandt is looking forward to exploring the flight envelope and characteristics of the Gripen E. "Some of the handling qualities, where the dynamics come into play, can only be explored in the Gripen E. You can have a full-motion simulator, but that's only motion, it's not vibration, it's not workload. It's not the same thing.

"With some of the test points you have to go up there and fly to make sure that the control system in the human brain does not interfere with the aircraft," Wandt continues. "We have to see what happens with the pilot-in-the-loop in given situations. Using the simulators we can take it all the way to 'this is definitely ready for flight', and get that warm and fuzzy feeling prior to the flights. But then we have to go and fly to verify that the model is real. And when we've done that, we can use the model again to fill out some of the test points and take it to the next level." \\

Ahead of the cur

The latest testing from the C-130J Hercules Wing Fatigue Test Program (WFTP) has pioneered a number of innovative non-destructive inspection techniques

When the wing of a Lockheed Martin C-130J Hercules failed in December 2015, it was a cause for celebration by scientists and engineers in the UK and Australia. The reason for the celebration was that the failure marked the conclusion of the physical testing phase of the international collaborative C-130J Hercules Wing Fatigue Test Programme (WFTP), conducted at Marshall Aerospace and Defence Group's facility in Cambridge, UK.

The WFTP was designed to provide fatigue data under representative Royal Air Force and Royal Australian Air Force flight loads, to establish a structural life of type (SLOT) for the Hercules and optimize the safety by inspection regime under which the type currently operates.

WFTP GENESIS

The UK and Australia were early customers for the latest version of the Hercules, which entered production in the early 1950s, and both began introducing the new aircraft to service in the late 1990s.

Although Lockheed Martin, the original equipment manufacturer, had conducted C-130 structural and fatigue testing as part of its certification of earlier variants, the RAF considered that configuration differences introduced into the C-130J design warranted a new full-scale fatigue test program under representative load conditions.

With similar concerns and a similar operational profile for its own C-130Js, the RAAF expressed an interest in the program and was subsequently invited to collaborate on a bilateral basis. The management arrangements were agreed and established in 2001.

Marshall Aerospace had long been a C-130 specialist and had conducted fatigue testing on the earlier C-130K variant for the RAF at its Cambridge facility, making it a natural choice for the latest testing activity.

Australia's physical involvement with the WFTP began in 2003 and a large number of personnel worked within the program until physical testing ceased at the end of 2015.

"The test program was pursued to confirm critical structure, to determine the structural life of type of the C-130J wing and to generate data to support improved in-service management of critical wing structure," says RAAF Group Captain Joe Medved, director of aviation engineering within Directorate General Technical Airworthiness – Australian Defence Force (DGTA-ADF).

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1 // The fracture surface shows crack front progression marks, which can be tracked back to particular repeated flight events throughout the history of loading


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2 // The montage shows the C-130J wing test article with superimposed maximum and zero load cases

Personnel from Australia's Defence, Science and Technology Organisation (DSTO, now Defence Science and Technology Group), DGTA-ADF and Air Lift Systems Programme Office (ALSPO) are involved, together with their counterparts in the UK, including the Defence Evaluation and Research Agency (DERA, now the Defence Science and Technology Laboratory) and QinetiQ.

Over the tested period, which began in 2003 and runs until the end of 2016, a squadron leader engineer from the DGTA-Aircraft Structural Integrity (ASI) branch and a scientist from DSTO/DST Group is embedded with Marshalls to facilitate a successful outcome for the ADF.

2
Number of lifetimes tested

40
Hydraulic jacks used

62,500
Flight hours before failure

METHODOLOGY

Because Marshall had previously carried out C-130K testing, much of the existing infrastructure was able to be repurposed, including the wing fatigue test rig.

Prior to the beginning of testing, two RAF C-130Js were fitted with a flight load monitoring system and gathered inflight load information during more than 750 flights.

"Accurately applying the complex maneuver and turbulence loads encountered was a significant undertaking and one that required considerable expertise and technical fidelity," comments Robert Ogden, C-130J task leader with DST Group's Airworthiness and Life Evaluation Section.

"From those 750 or so flights, approximately 250 were selected as representative of RAF and RAAF flying and as a result represented the loads to be repetitively applied to the full-scale fatigue test."

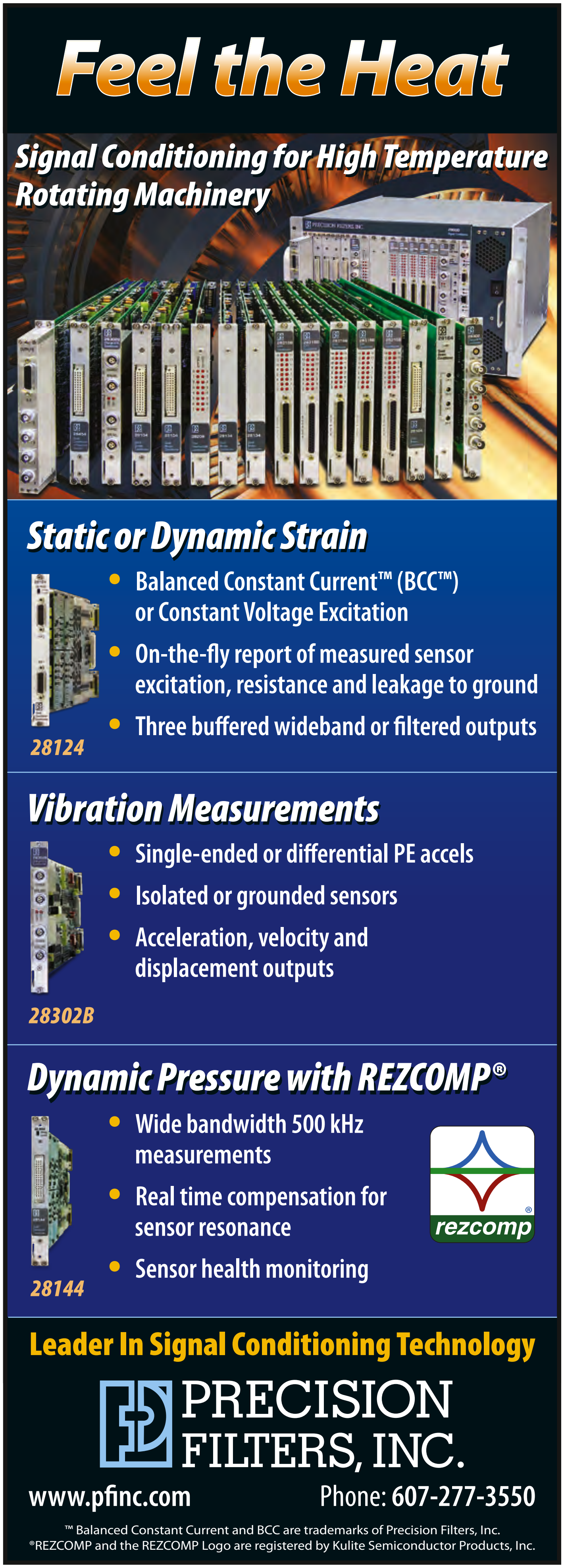
A new-build C-130J wing was purchased from Lockheed Martin for the purpose. However, because RAF and RAAF Hercules were built earlier and therefore had an earlier structural configuration, the test article required modification to bring it back to a representative standard.

Modified C-130K nacelle structures were fitted, to enable the application of representative gust and engine torque loads, and a representation of a section of fuselage around the wing-to-fuselage attach fittings was added, to allow simulation of additional loads caused during cabin pressurization and depressurization.

"Simulating these load distributions on the test article was achieved through the complex interaction of 40 hydraulic actuators on the wing and engine nacelles," Ogden added.

Specifically, 24 actuators were attached to the wing section, 12 on each outer wing, mounted in pairs in order to apply shear, bending and torsion loads. Pressurization loads on the center wing section were simulated by four actuators (two fore and two aft) to apply lateral loads to the 'fuselage' sidewall, together with an airbag pushing upward on the center wing section.

"We expected it to fail where it did"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3 // The test rig at Marshall Aerospace is based upon a modified structure utilized for a previous RAF C-130K wing fatigue test

Each of the four nacelle structures had three actuators connected, to apply engine torque loads as well as vertical and lateral gusts and inertia loads.

TESTING MILESTONES

The testing program had multiple complex phases and was marked by a number of milestones as the program progressed: from conception, the development of flight loads, the design of the test rig itself, development of test loads and the actual conduct of the test proper.

Testing was planned to verify the durability of the wing structure over 62,500 flight hours, representing two design lifetimes, and was followed by a residual strength test phase to ultimate failure, to demonstrate residual load carrying capability and, ideally, to experience catastrophic failure to inform SLOT determinations.

One of the early functions of DST Group was to provide a level of technical leadership on the program and it performed work on analysis of the flight load spectrum for RAF and RAAF C-130Js, including coupon testing and verification of Marshall's testing system. It also set data capture requirements and verification of the accuracy and repeatability of the loadings to be applied to the test article. The organization also provided on-site technical representation, together with DGTA-ASI, between 2003 and late 2015.

Besides the small team embedded with Marshall Aerospace, a dedicated team at DST Group's facility at Fishermans Bend in Melbourne supported the test program.

During the course of fatigue testing, damage was identified through routine inspection at a number of areas within the wing structure, most notably around the wing-to-fuselage interface. These locations were carefully monitored for damage progression as testing moved toward conclusion.

At the completion of 50,000 hours of testing, damage was artificially induced at a number of locations across the center and outer wing, with the aim of obtaining crack propagation data over the remaining 12,500 flight hours of testing to support optimization of the extant safety by inspection program. After successful completion of 62,500 hours of fatigue testing, static loads simulating 1.2 times the design limit load were applied to demonstrate the residual strength capability of the wing.

After multiple application of the residual strength loads, the test article catastrophically failed across the wing lower surface at the wing-to-fuselage interface. This is a known fatigue critical area and subject to inspection as part of the existing safety by inspection requirements. Squadron Leader Aaron Jozelich, an engineer with the

WFTP OBJECTIVES

The primary goal of the bilateral UK-Australian C-130J Wing Fatigue Test Programme is to provide a basis for certification for fatigue management of the RAF and RAAF's C-130J Hercules fleets. The data will be used to determine the structural economic service life of yype (SLOT) of the C-130J wing structure in accordance with adopted certification standards of the United Kingdom and Australia. The test data will also be used to support aircraft structural integrity (ASI) management via the optimization of existing safety by inspection and structural 'Safe Life' philosophies.

The program is being managed in five separate increments, which began with the formal agreement between the UK and Australia in December 2001 and a project definition study (PDS) and the establishment of contracts with industry. This was followed by spectrum development work, which fitted an operational loads management (OLM) system to two service aircraft, before the physical structural testing using a new-build C-130J wing box structure.

With the failure of the structural test article at the end of 2015, the WFTP moved into the final phase – structural teardown and analysis of the failed components, to be undertaken in Australia. The results of the WFTP will now be used to validate inspection procedures and subsequent structural repairs to the C-130J wing structure. "The data we have gathered during the physical test campaign and the results of the teardown inspection over the coming months will allow us to design new safety by inspection regimes for the C-130J," explains Air Commodore James Hood, director general, technical worthiness, ADF.

"Structural integrity programs give us confidence to keep aircraft in service for a longer period of time"

RAAF's ALSPO and the final liaison officer in the UK, explains: "We expected it to fail where it did and we were tracking multiple damage sites in that area for quite a number of hours before the eventual failure.

"We expect we will be able to accurately trace failure progression through a sequence of events following teardown of the test article and we are quite happy with the outcome that we were able to achieve," he adds.

STRUCTURAL TEARDOWN AND RESIDUAL WORK

The wing test article is now being shipped to Australia, where it will be the subject of a detailed teardown inspection and analysis of damaged areas. Teardown work will be carried out at RAAF Richmond, west of Sydney, by Airbus Group Australia Pacific – the contracted maintenance provider for the RAAF C-130J fleet, together with DST Group and ALSPO.

Once the wing has been completely dismantled, specialized non-destructive inspection techniques will be applied to the structure to probe for critical fatigue cracks. Damaged components will then be sent to Fishermans Bend for fractographic analysis by DST Group scientists, who are world-renowned leaders in this field.

Fractographic analysis will enable crack growth rates to be established under known conditions, which will then be interpreted to actual RAAF usage to establish a SLOT and optimize the safety by inspection program.

The ultimate goal is to have results from the WFTP fully implemented into the RAAF C-130J Maintenance Programme by 2020 and this work will be undertaken by QinetiQ Australia, as an active partner in the completion of the activity.

205
Strain gauge channels fitted to test aircraft

69
Flight parameters (primarily 1553B) measured

750+
Flights available for test spectrum development

The interpretation of results is being left to the individual partner nations, but the intellectual property resulting from the C-130J WFTP is jointly owned by the UK and Australia. Test data is also available to Lockheed Martin to support RAF and RAAF fleets and, subject to agreement by the RAF and RAAF, may also be used in the future by other C-130J users in support of their own individual fleets.

"It enables us to be an informed customer, and the sovereign capability allows us to bring aircraft into service that may have incomplete fatigue data and complete the necessary work here," concludes Air Commodore James Hood, director general of technical airworthiness for the ADF.

"Structural integrity programs such as this give us a higher level of confidence and allow us to keep aircraft in service for a longer period of time." \\

4

4 // One of the four engine nacelles under test, with applied loads to simulate engine torque loads as well as vertical and lateral gusts and inertia loads

// PAUL E EDEN

Responsibility for Royal Air Force Tornado and Typhoon operational test and evaluation rests with 41 (Reserve) Test & Evaluation Squadron. Unique for its two-type fleet, engineering and flight test capabilities, it supports an extensive trials program

Double measu

res

1 // Number 41(R) TES gave Typhoon FGR4 ZK315 special centenary celebration markings. Here it flies with one of the unit's Tornados (Photo: Steve Davies)

2 // BAE Systems keeps a two-seat Typhoon for trials work at Warton. It's finished in 41(R) TES markings (Photo: BAE Systems)

Sitting in the heart of rural Lincolnshire, England, just a mile or two northeast of the hamlet of New York and presided over by the imposing battlements of Tattershall Castle, Royal Air Force Coningsby is home to the UK's Quick Reaction Alert (South) station. Its frontline Typhoon squadrons ensure two armed jets are ready to launch 24/7.

The busy station also houses the RAF's Typhoon operational conversion unit and, most famously, the Battle of Britain Memorial Flight. Nowhere else in the world do frontline warplanes share the circuit with Spitfires, Hurricanes and a Lancaster, while the sharp-eyed 'spotter' will notice that the workhorse Tornado GR4 is also no stranger to Coningsby's runway.

Easily overlooked and regularly misunderstood, 41 (Reserve) Test & Evaluation Squadron (TES) is the RAF's only two-type fast-jet unit, with varying numbers of Typhoons and three Tornados on strength. It works closely with industry and the frontline, trialling new capability and reacting to service issues as they arise.

The RAF has two frontline fast-jet types, while the F-35B Lightning II remains under test with 17(R) TES at Edwards Air Force Base, California. The Lightning's planned move to the UK in 2018 will herald the beginning of the end for the Tornado, or the GR4 as it is known, with an out of service date (OSD) around 2019. In the meantime, the GR4 is heavily committed to Operation Shader, the UK's contribution to air strikes against Islamic State in Iraq and Syria. Indeed, the Tornado GR1 and GR4 between them have been in near continuous combat since 1991.

There has been a dramatic expansion in Tornado capability over those 25 years, with new weapons and extraordinarily more capable avionics. Since 41(R)'s formation as a TES in 2006, its weapons integration and software evaluation effort for GR4 has continued apace, with only a moderate slow down in recent weeks.

2
months-long 41(R) TES deployment to the USA for the High Rider exercise

4
major Typhoon trials programs underway

OPERATIONAL ANALYSIS

Six MoD operational analysis (OA) civil servants are embedded in 41(R) TES. They are typically high-achieving graduates with a mathematical, science or engineering-based degree, often with post-graduate education to master's or PhD level.

Alongside the trials managers, pilots and engineers, the analysts are a fundamental component of the test team, which collectively designs, delivers and reports on a wide variety of trials.

Operational analysis was first used to describe the scientific assessment of military scenarios in 1938. It came to prominence during World War II, when Solly Zuckerman advised Air Chief Marshal Tedder and General Eisenhower on which transport nodes should be bombed for the greatest impact on German logistics.

Physicist Reginald Jones was another key OA personality. His work included study of the German Knickebein radio navigation system and subsequent development of a method to jam its signals.

Today, 41(R) TES's OA staff lead the development of test objectives, ensuring their conclusions have scientific basis with the required level of confidence. The squadron's OA requirements cover many areas, including assessing targeting pod accuracy, radar system evaluation and understanding overall weapon system performance. The weapons and sensors on modern aircraft produce amounts of data unimaginable even 25 years ago, creating a major challenge, but high-power computing, modern data processing techniques and statistical methods ensure that the best evidence-based advice reaches the frontline.

3 // These Tornados were en route to China Lake for a High Rider detachment (Photo: 41(R) TES Archive)

The squadron also has a long-established Typhoon relationship with BAE Systems, based on planned upgrades in the aircraft's capability through defined phases of software development and capability insertion. Now the Typhoon workload has expanded greatly, under Project Centurion, which is transferring the full suite of GR4 capability over to the Eurofighter in time for the Tornado's OSD.

TYPHOON TESTING

Squadron Leader Mahmoud 'Mo' Abdallah commands the Typhoon Trials Flight. He has major Typhoon trials mapped out in a demanding schedule that will take the squadron until late 2018, with much of the work focused on delivering Centurion.

"We've been testing the latest P1Eb Further Work software package for Tranches 2 and 3, which will go out to the frontline at the end of the year," he says. "It took up a lot of our capacity up to September 2016, but at the same time we also completed a huge volume of work connected with the latest radar software. It's the version that Centurion will be declared on in December 2018; it enables Meteor firing and is expected to be very robust.

"In June we began work on DASS [defensive aids sub-system] Package 2, which includes MAWS [missile approach warning system] and is again required for Centurion. Pretty much every DASS and radar trial requires four jets and we embedded smaller trials in each effort.

"At the same time we're involved in the ASRAAM Block 6 program. The latest block is scheduled to replace the other in-service variants from late 2017. It's been going on for a couple of years and we're doing a lot of industry development testing, with lots of captive carriage gathering data, plus occasional firings. But in a trial this summer we had an enhancement to the forward detent assembly that mounts ASRAAM and for this we fired 40 missiles."

> **"None of the airframes in either 'fleet' are identical"**

These four major trials have been in addition to a long list of minor tasks, the combined result keeping the squadron extremely busy. Other work this year has involved close cooperation with BAE Systems. Brimstone carriage, Storm Shadow release, NVG and helmet assessment trails have seen 41(R) personnel at the manufacturer's Warton base, which is something of a home-from-home for the unit's aircrew.

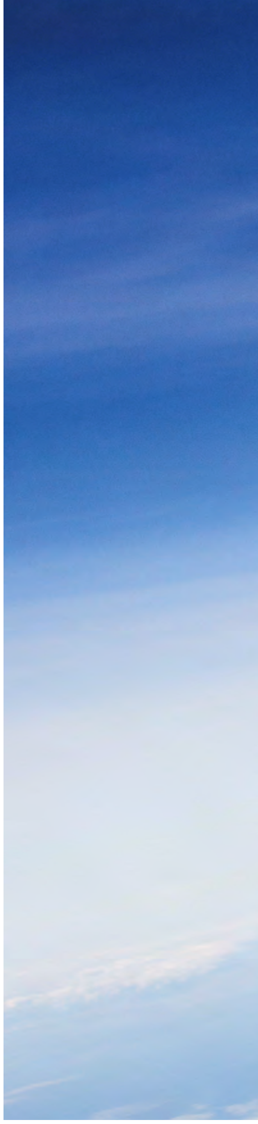
Later this year, the squadron will take an early look at Typhoon's next software load, P2Ea, which is scheduled for delivery in the New Year. Abdallah explains: "Flying under BAE's governance, we'll be able to say: 'Before you seal this software load off, we think you should tweak these areas.' It lets us catch things before the door is closed."

INDUSTRY PARTNERS

There is a distinct sense of partnership at 41(R), where personnel talk of their BAE Systems, MBDA and QinetiQ

5 // The squadron's engineering cadre is unusually large as a result of its mixed fleet (Photo: LAC Jack Welson/ UK MoD ©2016)

4 // 41(R) TES Typhoons on Coningsby's busy flightline (Photo: UK MoD ©2016)



colleagues as they might regular squadron mates. Paul Ascroft, technical manager for Typhoon P1E and P3E capability and overall BAE Systems technical lead for Project Centurion, describes the concept from the industry perspective.

"There is a close working relationship between BAE Systems' flight operations team and 41 Squadron, with dialog on a regular basis on the progress of development activities. The coordination of key events is managed through the Combined Test Team community, a mix of key industry and customer individuals that maximizes the work performed between industry flight test and the UK customer.

"As part of the Phase 2 Enhancements contract on Typhoon we've defined customer flight test activities to gather feedback through development on the maturity of the product. The close relationship enables us to maximize these activities and gather the operational type feedback as well as information against the contractual requirement. Additional customer flight testing performed in advance of full operational evaluation also provides invaluable feedback into the development program."

TORNADO TRIALS

Squadron Leader Dave 'Wills' Wilson manages 41(R)'s Tornado trials. He perceives a reduction in Tornado work, but also identifies the possibility of trials continuing almost up to the jet's OSD. "I came back to the squadron in 2010, when there was a series of major trials going on. Once they were complete it was supposed to go quiet, but so far that hasn't happened!

"We ran major communications and Link 16 trials, then it was into Brimstone 2 work, including firings at China Lake. After that we integrated TCAS II, which was an unusual program that generated a lot of interest. We were left with Brimstone 2 to finish, which brought us through to the beginning of this year.

"Since then we've been working on the Common Jamming Pod to replace Sky Shadow. There's usually a new software drop for the aircraft every 12 to 15 months as well, and testing that generally takes up to three months. Then we get notifications of anomalies noted in-theater and these become an immediate priority.

"We've also just finished a Phoenix trial – it's a generic name for our software testing – and a life-preserver trial. I've been on the unit, on and off, for

“Ideally you’d fly on at least one of your sorties, particularly if something contentious crops up”

6 // The words ‘Seek’ and ‘Destroy’ on the centenary jet’s foreplanes are from the squadron’s ‘Seek and Destroy’ motto (Photo: Steve Davies/www.fjphotography.com)

3
Tornado GR4s remain in the squadron’s fleet

40
missiles fired in intensive Block 6 ASRAAM trials

100
The squadron celebrated its centenary in 2015/2016

around 12 years, and since those two trials finished things have gone just a little quieter for the first time.”

DOUBLE TROUBLE

The unique nature of 41(R) TES makes particular demands on its personnel. Its aircrew are a mix of test pilots and flight test engineers, all graduates of the Empire Test Pilots’ School at Boscombe Down, and evaluator pilots and navigators. The latter, posted in from the frontline, bring with them an intimate knowledge of the latest tactics and challenges, their fresh experience ensuring the squadron remains in-touch and relevant.

The major challenges reside with the unit’s engineers, not least in the complexities of operating two very different airframes built according to design philosophies 40 years apart. The Tornado is essentially a ‘metal’ airplane with flight control and mission avionics systems; the Typhoon is a composite machine, driven by multiple computers through a complex digital architecture. These differences mean that 41(R) effectively maintains two engineering teams for day-to-day support, one maintaining the three Tornados, the other working with the Typhoon fleet, which is established at five but swells according to requirements; there were seven in July.

Further complicating the engineering task is that none of the airframes in either ‘fleet’ are identical. The squadron has the only pair of Tranche 3 jets in RAF service, for example, while its other Typhoons are all to different software standards, each supporting unique capabilities. Thus the engineers juggle the serviceability and deeper maintenance issues faced by any squadron, with the need to ensure that the jet with the required capability is serviceable ready for the trial only it can fly.

Both types are wired to collect test data on solid-state recorders installed on ‘pallets’, which on the Typhoon slide inside the gun bay with the 27mm cannon removed. It takes information from each of the jet’s multiple databuses, potentially generating several gigabytes of information per trial, feeding 41(R)’s embedded data and operational analysts.

Flight test engineer Flight Lieutenant Laura Frowen is engaged in trials with the Litening targeting pod. She explained the test process from an engineering point of view: “I’m part of the trials management office. We get the initial request, then do all the prep work and paper work to set it up and run it, typically over three to four months. Usually it’s all done from the ground with 41 Squadron, but ideally you’d fly on at least one of your sorties, particularly if something contentious crops up or if your pilot is trying to explain something they’ve seen and it doesn’t come across well in the debrief.

“We try to keep a two-seat Typhoon on the squadron for that reason, but sometimes it’s also useful to have two pilots, for supervision or safety – NVG [night vision goggles] tanking trials would be a good example, where the flying pilot wears the NVGs and the back-seater observes.

“Most of our work is operational test, so the safety case for it has already been made and we’re looking at how we’ll use it at a tactical level and whether it will function in the environment we want to put it in.”

In the scenario Frowen describes, the trial has been expected and planned for some considerable time, but 41(R) also reacts to emerging requirements, typically solving issues that emerge on the frontline. How are these approached?

“It depends on the nature of the trial. It might be a capability urgently required but outside the release to service on the frontline, in which case we take that and our test pilots generate a trial and report back on how it should be done. If it’s an issue, often with the software

> **"Once we've seen the fault we can say why it happened, and how to avoid or work around it"**

behaving not exactly as expected – perhaps it won't allow a '9' to be entered from the multifunction keys – we may be able to understand it very quickly.

"We might write a brief trials program to investigate, then go out and look for it in a safe and repeatable manner. Once we've seen the fault we can say why it happened, how to avoid or work around it, and give some advice for the interim while we send it back to industry."

Flight Lieutenant Andy Power leads 41(R)'s trials and modifications team (TMT), sitting between the Project Teams that manage equipment programs at Ministry of Defence level and the squadron. "My team ensures all the paperwork and equipment is in place ready for a trial to begin. We produce the service modification leaflets – written instructions that will be delivered to end users so that they know, for example, what modification they're doing and how to do it.

"We also produce reports and recommendations that go into the modification process. We'll perhaps look at the military utility of a piece of equipment, noting issues, working out how it should be handled, transported and so on."

Like Frowen's 'number 9' example, Power says that while much of the work TMT's highly experienced engineers perform is extremely technical, some is essentially simple: "It could be that every time we remove a panel we 'round' the screw heads and a different type of screw is required." TMT adds that detail to its report so that it has no chance of becoming an issue on the frontline.

HIGH RIDER

No matter the platform, nature or urgency of the task, one factor generates more challenges than any other – the weather. Speaking in mid-July, Frowen and a test pilot colleague ruefully explained how since the beginning of June they had been attempting to satisfy a series of test points requiring clear visibility from 20,000ft to ground level – but the weather defeated them every time.

For this reason, and because of the facilities on offer, 41(R) TES makes an annual High Rider deployment to the USA. Given its uniqueness, the squadron takes its aircraft with it; the cost in tanker and logistical support is easily offset by the intensive trials completed.

This year the squadron departs Coningsby late in September and Wills expects to return around late November or early December. The work will focus on DASS testing for Project Centurion and fifth-generation platform integration with the F-35.

"Then we'll be back and working up for the next round of trials," Abdallah says. "Early in 2017 it'll be P2Ea, then some Meteor and Storm Shadow work, plus Laura Frowen and a couple of pilots are embedded in a Litening demonstration with BAE Systems." The work that goes on in 41(R)'s Coningsby enclave may not be well understood or particularly well known, but it is essential to the frontline and seemingly relentless. \\

7 // A salvo of three Brimstones fired during a 41(R) TES Tornado trial (Photo: 41(R) TES Archive/ UK MoD ©2016)

7

8 // A Typhoon main operating base, Coningsby is an ideal location for 41(R) TES (Photo: UK MoD ©2016)

8

// ANTHONY JAMES

Time travel

1 // The Airbus E-Fan 1.2 was unveiled at the recent EAA AirVenture 2016 show in Oshkosh, Wisconsin, USA

Just how long will it be until we see hybrid and electric aircraft in commercial service with airlines? Airbus Group's Andy Anderson, who will open this year's Electric & Hybrid Aerospace Technology Symposium in Cologne, Germany, says it could be sooner than you think

Bright, risk averse, no-nonsense engineering minds don't like to be pinned down by pesky journalists asking awkward questions, but when it comes to contemplating hybrid and electric flight, an obvious place to start is to ask just when are we likely to see such aircraft enter commercial service.

A precise answer is hard to provide, given all the variables such a scenario involves, and perhaps this is why Andy Anderson, Airbus Group's recently appointed chief operating officer for the Corporate Technology Office, having previously served as acting chief technology officer, is reluctant to respond to the question, at least without adding a little more context. He settles on the following: "We would like to have something in the region of a 70- to 90-seater within 30 years," he says. "It would not be purely electric; it would probably be a hybrid configuration."

Anderson envisages such an aircraft as the natural conclusion of the Airbus Group's ambition of ultimately delivering emission-free quiet flight – a goal that has spurred the manufacturer into beginning work on a dedicated test facility near Munich, Germany, to focus on the development of new electric and hybrid aircraft propulsion technologies. With construction due to start early next year, the E-Aircraft System House is scheduled to open by late 2018, when it will be jointly operated by Airbus Group Innovations (the Group's global innovation network) and the company's three divisions: Airbus, Airbus Helicopters, and Airbus Defence and Space.

However, the aircraft manufacturer's exploration of electric flight is already well underway, with much of its effort to date embodied in its all-electric, twin-engine

2 // The E-Fan 1.2 features a gasoline engine that increases the E-Fan's range by charging the batteries in flight, which in turn power electric motors driving two ducted fans

THREE PILLARS

When talking about Airbus Group's current research and work into electric flight, Anderson is keen to emphasize there's more going on than just testing aircraft components: "It's not only the aircraft that we have to look at," he says. "There are three pillars to this whole program: the first one is the aircraft itself, of course, but also what infrastructure do we need to support electric and eventually hybrid flight for large aircraft, and finally you have to consider how pilots will react to flying an all-electric aircraft. It's like an electric car – because people couldn't hear the engine, they were a little unsure at first and it will be the same with aircraft – if you don't hear things, then you wonder if there is something wrong, but the difference is you are up in the sky and not on the ground. It's a mixture of market and user acceptance, as well as certification. All three of these pillars are considered in parallel whenever we do something in the aircraft."

E-Fan demonstrator aircraft, which successfully crossed the English Channel in July 2015.

"Now we've taken that same aircraft and, in a very agile technology development process that started in February, we have converted it into a hybrid version that flew for the first time at the end of June this year," explains Anderson. "So the first step that we've done is to take the all-electric E-Fan and change its architecture slightly and make it into a hybrid [with an electric/gas engine]. We can now start testing how a hybrid architecture actually works."

Known as E-Fan 1.2, the experimental hybrid aircraft in question was on static display at the 2016 EAA AirVenture show in Oshkosh, Wisconsin, USA, in July. "We did not fly it in Oshkosh because we haven't got enough hours for certification yet," explains Anderson. "We did this conversion in just four months – now it's back from Oshkosh, we will continue with the certification program of that aircraft as an experimental aircraft with the aim of flying it successively this year to understand the different aspects that one has to consider when one is investigating hybrid flight."

Of course, it's quite a leap to go from a two-seater aircraft such as the E-Fan to a commercial passenger jet, but Anderson sees it as a crucial first step: "E-Fan is one of the demonstrator blocks in the overall E-Systems roadmap," he says. "Everything we learn out of E-Fan – be it E-Fan 1.0 as a pure electric aircraft or the current E-Fan 1.2 hybrid version – all of that learning flows directly into the E-Systems program."

60
Total engine power of E-Fan 1.0 in kilowatts, following a 60% increase in its battery capacity since 2014

10
Airbus Group and Siemens plan to jointly develop prototypes for various propulsion systems with power classes ranging from a few 100kw up to 10MW

CONSIDERABLE CHALLENGES

One obvious stumbling block along the road to electric flight is presented by the current 'state-of-the-art' in battery technology. "The market for qualified batteries of the size required for commercial aviation is just not there," admits Anderson. "The batteries are all going into other applications at the moment. Obviously there will be batteries [on the aircraft], but they will be in a configuration that allows for emergency situations or take-off and landing, which means that for the immediate future, we are focusing on hybrid configurations."

However, Anderson believes batteries could easily provide all the power necessary for much smaller aircraft, such as the E-Fan: "If you think of general aviation, you're looking for something like a three-hour endurance, and I think the industry will get there quite quickly in providing that," he notes. "But when we talk about a 70-90-seater aircraft, I don't think there will be the battery power to fly a sustainable 1,500-2,000km stretch. Obviously if something miraculous happens in the battery world, which is perfectly possible and so we would hope, then the architecture that we are working on at the moment will not change. We will simply leave the fossil-burning motor component out."

3

3 // Airbus Group's Andy Anderson says he would like to have "something in the region of a 70-90-seater within 30 years"

4

4 // Cockpit of the E-Fan 1.0 technology demonstrator that successfully crossed the English Channel in July 2015

With pure electric flight for larger aircraft currently ruled out in favor of hybrid solutions, Anderson must also consider the type of fuel such a system will use. "We are just watching at the moment and helping form what the fuel might be for the hybrid component or the motor component," he says. "Airbus Group is not a fuel manufacturer, but we keep a close eye on what is happening in the area of fuel cells, and so on. We know that there will be a motor – and so what we are focusing on is getting the whole functional chain working – from motor to electric system in a distributed form such that we can accommodate whatever becomes the accepted fuel in the future. This could be a simple biofuel that cuts down the mineral kerosene part, or some other fuel source. Whatever it is, we will help promote it in terms of a green future and a better environment."

However, Anderson is of the opinion that any future hybrid passenger jet will need to take off and land using electric power only, to address likely legislation governing airport noise. "What we've also seen is how important the noise aspect will be," he says. "Therefore we'll probably aim to take off and land purely electrically, before switching to hybrid operation at cruise height."

TESTING FOCUS

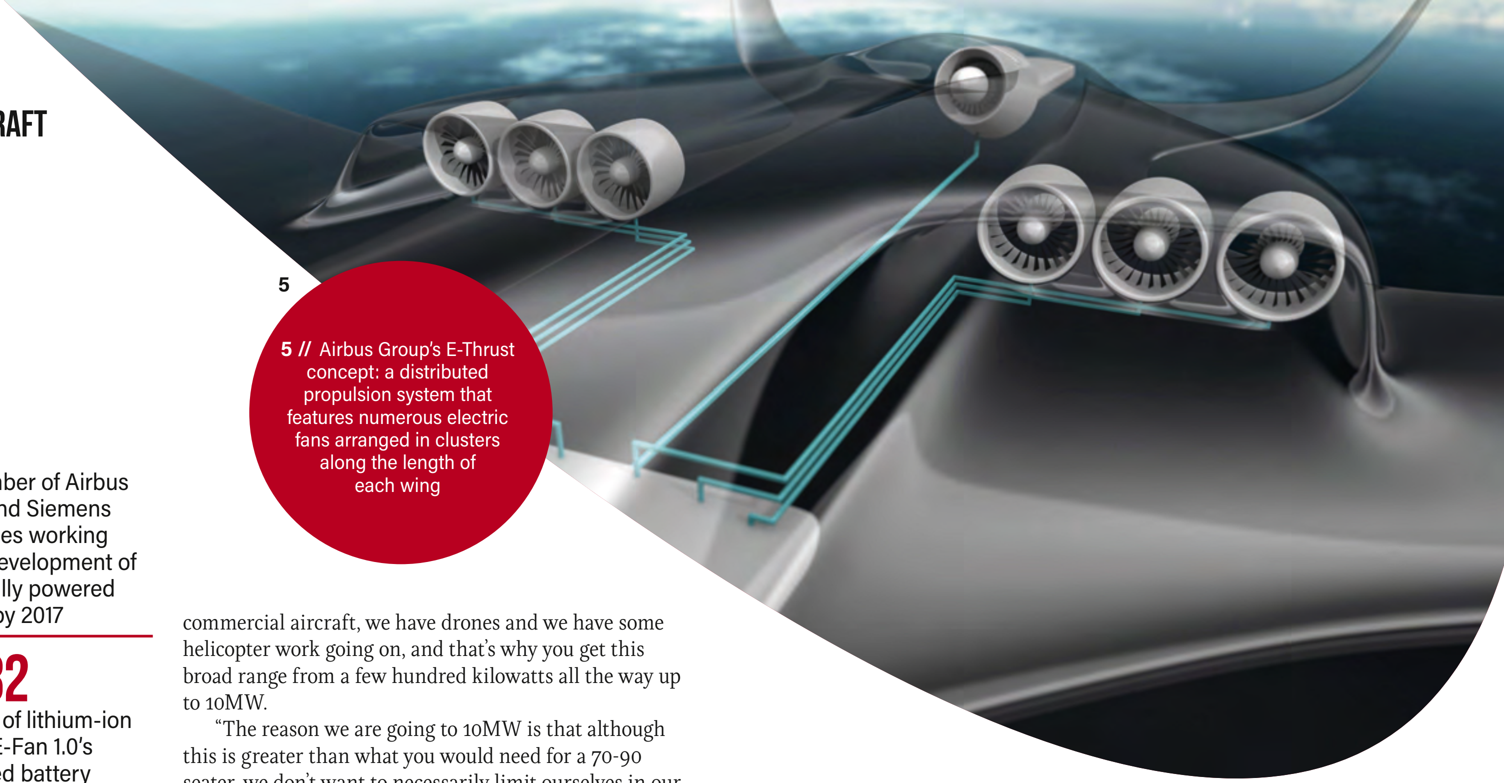
Anderson is reluctant to give too much away with regard to the details of ongoing testing work, but says valuable lessons have already been learned from E-Fan, particularly with regard to e-FADEC, the optimized electrical energy management system integrated into the aircraft that automatically handles all electrical features, thereby simplifying the monitoring and controlling of the systems, and reducing pilot workload.

"E-Fan is a testing platform," he says. "It's a demonstrator that we fly and it has helped us test electrical distribution; we've understood how the e-FADEC energy management system works, and what we need for e-FADEC. Now E-Fan 1.2 is back from Oshkosh, we will start testing the hybrid configuration. In parallel, at the E-Aircraft System House and at our existing test facility in Ottobrunn, Germany, we have ground demonstrators that are testing motors and generators, and coming up with the requirements that we need to have sizeable 'building blocks' that we can use in larger aircraft."

The 'size' of some of those building blocks undergoing component testing, at least in terms of their energy output, is considerable: "It goes from a few hundred kilowatts up to about 10MW," says Anderson. "That's the region we want to go up to for doing ground testing on. Just about every division in the Airbus Group has one or other project that will use the E-Aircraft System House to test a component or a functional chain. It's not only

DRIVING FORCE

Despite the giant leaps made by the automotive industry in recent years regarding hybrid and electric vehicles, Anderson sees little opportunity for immediate technology transfer. "The mission profile of a car is very different to an aircraft," he says. "The battery profile and battery chemistries are very different in each case. Weight is not so much of an issue for a car as it is for an aircraft, for example. And in terms of power, cars are looking at 150-200kW, while we're looking at 2-10MW of power – it's a different ballpark. Certification is also very different in the aircraft industry to the automobile industry. However, we have lots of discussions with the automobile industry, and we do lots of testing of automotive components. We understand their application but the mission is different. We can learn, but we can't reuse, or at least the level of reuse is limited."



5 // Airbus Group's E-Thrust concept: a distributed propulsion system that features numerous electric fans arranged in clusters along the length of each wing

200
The number of Airbus Group and Siemens employees working on the development of electrically powered aircraft by 2017

2,982
Number of lithium-ion cells in E-Fan 1.0's enhanced battery system, which was upgraded prior to its historic Channel crossing flight

commercial aircraft, we have drones and we have some helicopter work going on, and that's why you get this broad range from a few hundred kilowatts all the way up to 10MW.

"The reason we are going to 10MW is that although this is greater than what you would need for a 70-90 seater, we don't want to necessarily limit ourselves in our research activities. If you go down into the lower power categories, we have tested a whole host of motors for their end generators and for their performance ratio [kilowatts per kilogram], from all sorts of different applications, from electric motor bikes to racing cars. We do this to understand how that technology is moving. We can then scale that up into the megawatt range that we need to power a future 70-90 seater, where we will need at least a couple of megawatts per wing. Ultimately, we want to test electrical distribution, control of motors, control of distributed propulsion and eventually the complete large electrical functional chain.

"There are so many components, and just about every component in the electrical chain is new. So we're testing to see how to get those components into the most efficient and powerful configuration. Materials for motors, generators, cabling and power switches will also play a huge role when it comes to the design of these components for the future."

EXCITING TIMES

E-Aircraft System House represents a significant investment for Airbus Group, and although Anderson won't be drawn on financials, he is willing to talk staff numbers: "What I can say to you is that by the middle of 2017 we will have more than 200 people working on electric and hybrid propulsion. At the moment there are in the region of 60 to 65 staff working either full- or part-time, but by next year we will have more than 200 people working in the program, which we do in partnership with Siemens. I think this shows just how committed Airbus Group is to meeting the challenges and requirements regarding carbon dioxide and toxic gas emissions, as well as noise emissions. In 2010, we signed up to a 75% reduction of CO_2 emissions by 2050 compared with the values for the year 2000, in a market that's growing at around 4% per year. We have a huge commitment to meeting these targets, and I think our investment demonstrates that."

Finally, when one considers the implications distributed propulsion enabled by electric flight could mean for aircraft design, it's hard not to get excited, and Anderson does little to douse this enthusiasm: "The minute you can go to distributed propulsion, you have the opportunity to change the envelope of the aircraft substantially," he says. "When you can control the motor or a number of motors independently, electrically, it has a huge impact on how large an area you need for the tailplane, for example, and what the tailplane configuration could look like. There's a whole host of things to come out of that, which I think in the very long term will open up the envelope for aircraft in general." \\

NOT TO BE MISSED!

Airbus Group's Andy Anderson will open this year's Electric & Hybrid Aerospace Technology Symposium, this November, in Cologne, Germany. The event will feature over 50 speakers over a full two days, and will cover all aspects of electric and hybrid aerospace activity, from commercial aviation to military applications.

Leading industry speakers include Mark Husband, lead engineer – electrical systems and technologies, Rolls-Royce; Dr Evgeni Ganev, chief engineer, Honeywell International; and Neil Garrigan, senior program manager, electrification, GE Global Research.

Leading academics taking part include Prof. Leo Veldhuis, section head flight performance and propulsion, Delft University of Technology; Prof. Andreas Strohmayer, Institute of Aircraft Design, University of Stuttgart; and Prof. Brian German, Langley associate professor, Georgia Institute of Technology.

Asked what he plans to say when opening the conference, Anderson is characteristically to the point: "I think the message really is that hybrid electric propulsion is here, it will happen, and Airbus Group will definitely be part of making it happen."

Visit www.electricandhybridaerospacetechnology.com now for more information and see our conference preview on page 80.

MEET ANDREAS HAUSER, RUAG AVIATION'S GO-TO WIND TUNNEL MAN AND AERODYNAMICS EXPERT

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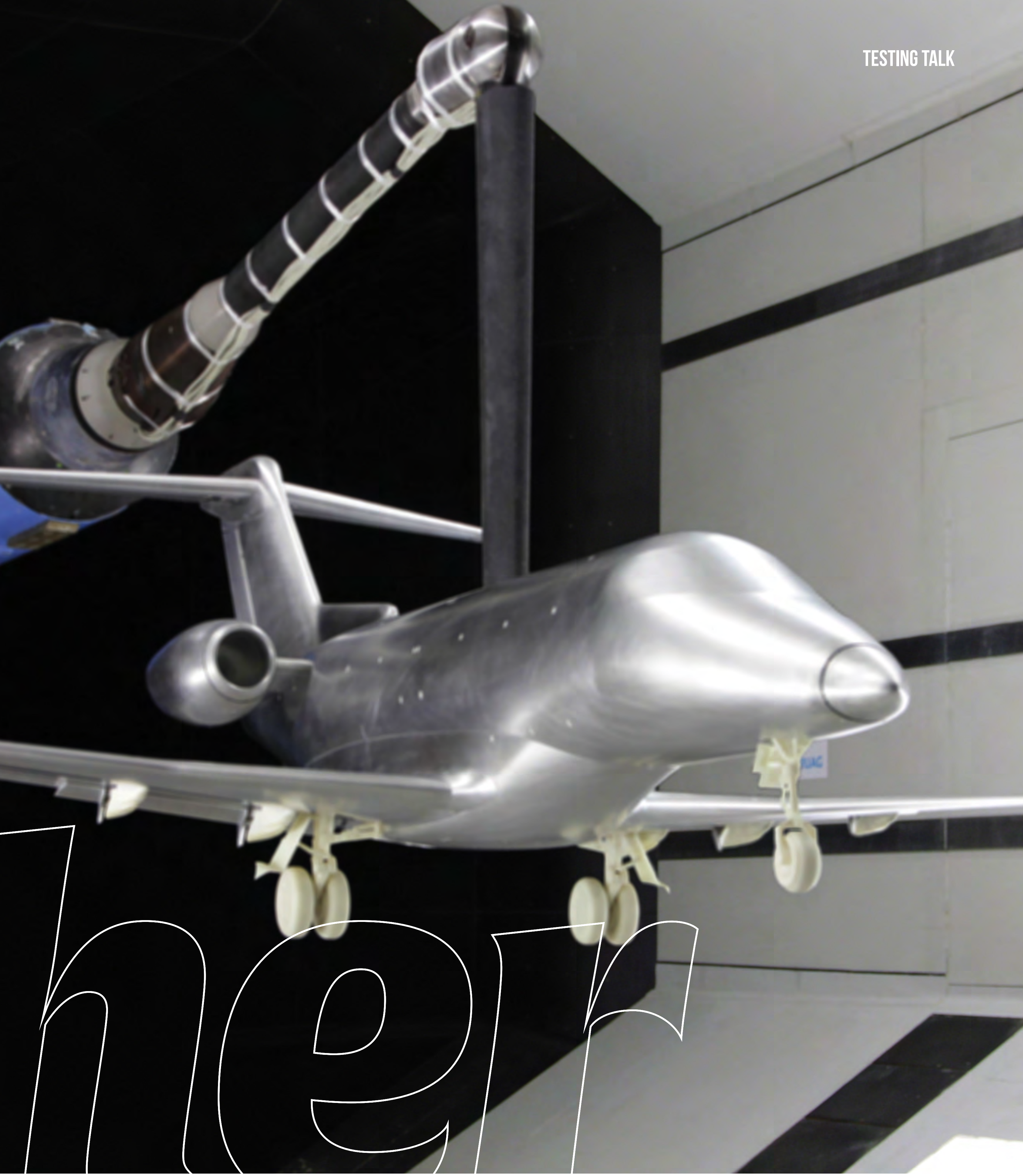

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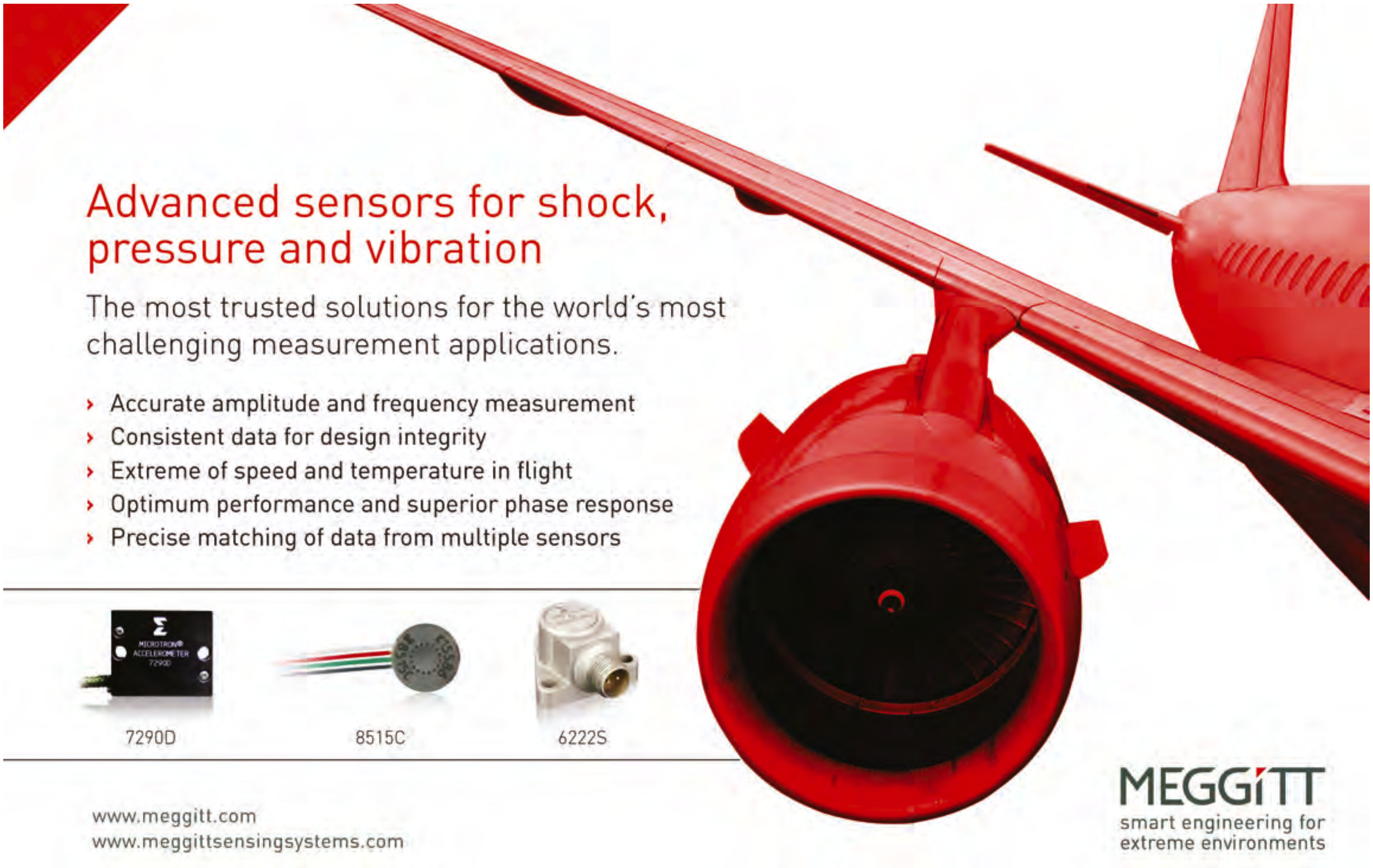
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1 // With its 7x5m test section, RUAG Aviation's Large Subsonic Wind Tunnel in Emmen (LWTE) is one of the largest in Europe

// WHEN DID YOU FIRST DECIDE ON AVIATION?

The fascination for aviation came to me very early, at the age of five years, when my father – a keen private pilot – took me along for rides. I gradually progressed from building plastic display models and balsa gliders, to experimenting with piston-powered models and reading books by Kelly Johnson and Neville Duke, all of which inspired me to pursue a career building airplanes.

// WHAT WAS YOUR FIRST TESTING JOB?

My initial wind tunnel testing job was part of my diploma thesis at the Swiss Federal Institute of Technology in Zurich (ETH Zurich), where I was challenged to identify and improve the stability behavior of the Mako AT-2000 trainer aircraft from MBB/DASA (now EADS). Suddenly I was thrown from the textbook world into the harsh reality of wind tunnel testing with measurement drift, electrical and mechanical interference, delays with external suppliers, as well as occasional conflicts with colleagues over the schedule for the use of singular measurement equipment. Back then it was a one-man show, which in hindsight was perfect for learning all the different aspects that wind tunnel testing involves. In today's environment, all the activities are streamlined to be as efficient as possible. Clearly defined working processes, checklists and the reliance on experts in their specific technical area are crucial in meeting customer requirements. On the other hand, limited time, financial and knowledge resources, acquisition pressure and infrastructure upkeep weren't really part of my initial testing experience.

// WHAT WERE THE MOST VALUABLE LESSONS FROM THOSE EARLY YEARS?

To be on site, to talk to the customer and all involved technical personnel, to discuss potential issues and ensure you know everyone's expectations. Open communication is essential for large and complex testing projects. Listen to the advice of testing staff; they might have lived their share of testing history or have an interesting new idea. Identify and foresee options – there are always pitfalls and dead ends in a testing environment. Have a backup plan if something fails or doesn't perform as anticipated.

// WHAT IS YOUR CURRENT POSITION?

My official job title is manager of the Department of Aerodynamics at RUAG Aviation. It involves the line management of two teams: the engineering and testing team, and the measurement and computing team. Beyond this, a large portion of my time is spent on customer acquisition, business development, coordination with upper management, technical consultation, raising and coordinating infrastructure and R&D funds and activities, and personnel issues.

// TELL US MORE ABOUT RUAG'S WIND TUNNELS

RUAG operates two low-speed wind tunnels: the Large subsonic Wind Tunnel Emmen (LWTE), which is used for aviation and automotive customers; and the Automotive Wind Tunnel Emmen (AWTE), which focuses on the needs of the racing community and the car industry in general. With an open test section and a moving belt system for road simulation, the latter can accommodate car models up to 50% scale. The more powerful LWTE has a 7m wide and 5m high closed test section. The tunnel is a closed loop, single return design. It can be run up to 70m/s (155mph) or Mach 0.2. The LWTE is an atmospheric wind tunnel meaning that the pressure in the test section corresponds to ambient pressure. The airspeed is generated by two counter rotating fans with eight blades each, connected to two electrical engines delivering a combined 3MW (4,000hp) shaft power. The tunnel is equipped to accommodate aircraft models with various support options as well as truck and train models and full-scale cars. But we welcome also oddball tests. Over the years, we have tested everything that is exposed to wind: sports, buildings, windmills, boats and so on.

It should be noted that we test in the low-speed region. The focus in LWTE is therefore often on aircraft configurations such as take-off, landing and maneuvering. For high-speed cruise testing you would need a facility providing transonic wind speeds.

> ***"Open communication is essential for large and complex testing projects"***

"We like to have the model on site two to four weeks prior to the test entry to install all the necessary sensors and gauges"

// HOW LONG IS A TYPICAL TEST AND HOW IS DATA CAPTURED?

The test preparation usually starts several months before the scheduled wind tunnel entry, depending on whether the customer provides an already existing model or whether RUAG is subcontracted to build it. The hot phase of a typical test usually starts with the initial data preparation, approximately six weeks prior to entry in the tunnel. If possible, we like to have the model on site between two to four weeks prior to the test entry to install all the necessary sensors and gauges. While simple models can be installed in less than a day, more complex models such as powered models with abundant instrumentation may require up to a week to have all the systems set up and verified.

Aeronautical test campaigns usually last between two and five weeks. The main information is derived from the model-internal six-component balance (lift, drag, side-force, pitch, roll and yaw moment). These balances are designed and manufactured in-house and come in various sizes so that they are optimally matched to expected loads on a specific model. Additional sensors (and resulting data) include inclinometers for the exact angular position in pitch and roll; static and dynamic pressure ports at specific locations on the model; hinge moment balances on control surfaces; and balances for additional components such as landing gears, external stores, antennas, etc.

Even more extensive instrumentation is required for testing models with power simulation, where the condition of the engine(s) has to be tightly monitored and finely controlled. In the last couple of years, increasingly, microphone arrays are used to assess the acoustic performance of the aircraft in parallel to aerodynamic tests and PIV (particle image velocimetry) setups are installed to investigate in detail the flow around the model.

Preliminary data is directly presented during the test run on the engineer's screen and post processed immediately after the run. A full quality assessment is made during and immediately after the test to ensure reliable data. Data acquisition is usually performed at several hundred hertz and for quasistatic results is averaged over typically one to three seconds. Data volumes can range from a few megabytes up to several terabytes, especially for dynamic, time-resolved measurements with high sampling rates.

2

2 // RUAG Aviation uses MGCplus technology from Hottinger Baldwin Messtechnik (HBM) for data acquisition in its wind tunnels

// WHAT IS THE LARGEST MODEL YOU CAN FIT INSIDE THE TUNNEL?

With the tunnel width at 7m and a general rule of thumb is to keep the span below 70% of the tunnel width, a good sized model can have up to 4.9m wingspan. Wind tunnel models with 5m span can and have been tested in the tunnel. But often, the models are smaller (3-4m) to remain compatible with other smaller facilities or because other factors limit model size, such as maximum angle of attack, model weight, or cost.

// WHAT PROGRAMS ARE YOU CURRENTLY WORKING ON?

We are supporting a number of aviation and automotive manufacturers in the development of new products. Our main customer is Dassault Aviation, but we can't talk about specific programs currently running in the tunnel, although we can say that all Dassault business jets since the Falcon 900 have been tested in our facility. We also work with most European aerospace companies, as well as some important overseas players. Many of the major German car manufacturers (and their suppliers) come to the tunnel for soiling tests where the performance of windshield wipers and rear-view mirrors are tested under simulated rain conditions.

3 // For static measurements, the sampling rate is typically 100Hz for each of the 144 channels and the integration time is in the order of a few seconds

// WHAT ARE SOME OF THE CHALLENGES PRESENTED BY WIND TUNNEL TESTING?

Testing with wind tunnel models which are equipped with powerful engine simulators (propeller or jet) demands high levels of competence, as well as adequate preparation time. Safety is a major concern as the power concentrated in miniature motors smaller than a small can or milk bottle can easily exceed the power installed in a passenger car. Model propellers typically run up to 13,000rpm, while fans may be required to achieve much higher rpm.

// TELL US MORE ABOUT THOSE ENGINE MODELS. HOW DO YOU ENSURE THE CORRECT POWER LEVELS?

For powered testing, wind tunnel models are equipped with active engines – driving the propellers/fans at the correctly scaled speed and torque – so that the airflow over the wing generated by the propulsion system can be realistically simulated and its effect determined. But as you reduce a full-scale aircraft down to a model, the scaling laws reduce the required power level at a lower rate, thus increasing the necessary power level per volume. So that's the challenge – to deliver sufficient power to these small nacelles to correctly simulate the flow over the wing.

At RUAG, we use hydraulic motors to drive the propeller or fans. We have found that hydraulics represent an interesting and cost efficient alternative to the electric or compressed air powered motors used in other facilities.

Our hydraulic power station can provide up to one megawatt of controlled power to independently drive between one and four individual motors installed on the model. Our repertoire of available motors goes up to 800kW (for real propeller testing).

// HOW HAS WIND TUNNEL TESTING CHANGED OVER THE YEARS?

Efficiency! There is a clear expectation from the customer to get more data and on shorter notice out of a wind tunnel test. This means that lead times need to be reduced, for example for model manufacture, even though the models become more complex as an increasing number of sensors (pressures, local balances, accelerometers, deformation temperatures, and so on) are incorporated. We also see an increased interest in time-resolved measurements of unsteady or highly dynamic phenomena, including aeroacoustics – areas in which we are heavily investing.

Other new advanced measurement techniques such as particle image velocimetry (PIV), thermography and optical deformation measurements are of increasing interest to many OEMs. For these types of measurement systems, we collaborate with experienced suppliers. This ensures that the deployed hardware is up to date and that the systems are operated by experts with in-depth technical know-how. By continuing to work with a limited number of partners, we can guarantee that they are familiar with our infrastructure and environment as well. This is a perfect win-win example for the customer, the system provider and the tunnel operator.

"Our repertoire of available motors goes up to 800kW"

// HOW DO YOU ENSURE SAFETY FOR TECHNICIANS AND CONFIDENTIALITY FOR CUSTOMERS?

As an ISO9000-certified company, we work according to clear processes and standards. Our unit is periodically audited while continuous improvements to the facility and periodic checks ensure that safety is maximized.

The confidentiality of customer projects is of very high importance to us. A badge access system allows the clear separation between customers and the outside environment as well as between multiple customers. A monitored area to store sensitive models has been established in the last year. A dedicated IT network, fully separated from the RUAG network, allows us to provide customer specific IT-security. Periodic customer security audits provide us with a valuable outside view of our confidentiality setup, and help keep the facility and its information security up to date.

4

4 // The LTWE can accommodate a wide variety of aviation tests, including jet, propeller and rotorcraft wind tunnel models

// HOW HAVE YOU IMPROVED TESTING EFFICIENCY?

There are several ways to improve tunnel testing efficiency. The two major factors are processes and experience. Adhering to well-established standard processes keeps all participants in the information loop, avoiding idle time and getting engulfed in unnecessary activities, while also enhancing safety, thus reducing cost and time. A lot of testing efficiency can also be won with the model design. Model concepts/designs that favor quick model changes can make a big difference.

// WHAT DOES IT COST TO HIRE?

Wind tunnel testing costs are strongly dependent on the complexity of the test (required infrastructure, equipment, sensors, test personnel). Therefore, the prices can greatly vary. We are happy to provide interested parties with a specific quote!

Generally, booking lead times are about six months before the test entry. But this strongly depends on booking status, length of required slot and customer flexibility. If a slot is available and the customer is ready to jump in, much shorter lead times are possible.

"A lot of testing efficiency can also be won with the model design"

// ANY PARTICULAR TESTS STICK IN YOUR MIND?

I have been privileged to work on several highly interesting tests in my career. Most memorable were the 10-year development of the Future Large Aircraft, now known as the Airbus A400M; the successful Boeing-Rolls-Royce-RUAG collaboration with the goal of investigating and testing novel counter-rotating open-fan concepts; and the first aeroacoustic test with Dassault.

// HOW DO YOU SEE WIND TUNNEL TESTING CHANGING – IS CFD A THREAT?

We see the use of CFD more as an additional and valuable tool in the development of new aircraft. We also often use CFD in our department as a support tool. Effects in the wind tunnel itself – interference between the model, tunnel and support system – can be studied in more detail. Investigations in the outer region of the development envelope can also be predicted numerically, provided that a validation case is available. This is one instance where the need for experimental data is crucial.

// FINALLY, WHAT HAS BEEN THE BIGGEST ADVANCE IN AERODYNAMICS IN RECENT YEARS?

The two fields we have seen evidence of are new and more efficient propulsion systems, which also have to be modeled, integrated in the wind tunnel models and tested in detail; and a stronger focus on reducing the aeroacoustic signature of an aircraft very early in the development cycle. Initial conceptual tests with an added aeroacoustic campaign are becoming more common. \\

MODEL BEHAVIOR

RUAG Aviation's Andreas Hauser praises the role of rapid prototyping in helping advance the complexity and accuracy of models used during low-speed wind tunnel testing: "Parts that are under a lot of stress, such as wings, horizontal or lifting surfaces, will continue to be made from solid materials such as steel or aluminum," he notes. "However, wheels or attachments that are lightly loaded are now made using rapid prototype material, which saves a lot of time and cost, while accuracy has also greatly improved. If a customer wants to modify a model to evaluate five or six different doors or antenna covers, for example, we can manufacture and have those parts available on the model and in the tunnel in just a few days using the latest 3D printing technology."

Hauser says working with models helps keep costs down, but they still have to be accurate enough to correctly model airflow: "For example, if you have a 1:10 scale model, then you have to be ten times more accurate in building the model than the original because you have to rebuild the surface, the gaps between the flaps, and replicate the angularity of the wing to match the original." Once testing is complete, the models are stored at RUAG for two to three years until flight testing is completed: "If an unexpected phenomena shows up during the test flights, we can quickly go into the tunnel and test this out," says Hauser. "The models are often stored for as long as the real aircraft is in operation."


Shock

tactics

NIAR's brand-new test facility for direct effects of lightning boasts a powerful generator – and an expert lab director

1 // High current damage or 'arc attachment' testing in progress at NIAR's new lab, using a powerful generator to create and drive a full threat lightning arc into a test article

2,000
size in square feet of the NIAR lightning test facility

67
approximate maximum charge in kilovolts for repetitive charging that the capacitors are designed for

50
typical charge in kilovolts for testing to save wear on the capacitors

Currently available for commercial and government testing and research, a new facility for testing the effects of lightning on aerospace materials and components is now open at the National Institute for Aviation Research (NIAR), at Wichita State University. The lab, in operation since January 2016, has already hosted industry clients and conducted FAA and NASA research.

Located at NIAR's Environmental and Electromagnetic Effects Lab, on the former site of the Boeing Aircraft Company in Wichita, Kansas, the new facility has a footprint of 2,000ft² and features a powerful high-current generator, capable of reproducing the awesome forces generated during a lightning strike.

"The generator complies with the environment specified in SAE ARP5412 in regard to the high-current idealized waveforms of components A, B, C and D. This environment and waveforms are used for all high-current testing described in the test standards, such as ARP5416 and RTCA DO-160 Section 23, used to certify aircraft, as well as the qualification of components installed in aircraft," explains facility director Billy Martin. "We currently do not perform full threat 'airplane' tests but similar to most lightning labs in the world, we conduct full threat or derived test level tests on aircraft components."

> **"We conduct full threat or derived test level tests on aircraft components"**

The lab does perform full-vehicle lightning tests, but Martin points out that they are accomplished using a generator that injects an idealized waveform at a much reduced amplitude [e.g. 1/100 of external environment] into the aircraft structure at various entry points, while measuring the resulting voltages/currents at equipment interfaces, wiring bundles, hydraulic lines, fuel lines and aircraft surfaces/structures. The measured results are then extrapolated to the full threat and used for various system-type testing.

"Most manufacturers do not like you to inject the full lightning threat into the aircraft because it can result in considerable damage to structures and systems, so the testing is done at lower levels and extrapolated upward," says Martin.

CURRENT CAPACITY

The high-current generator can produce in excess of 200kA within the timing parameters required as per ARP5412 for component A testing, 10C for component B and 200C for component C. In addition, the generator can be configured to perform zone 2 testing of 100kA for component D. "We also have a 650kV Marx generator that is used for zone 2A high-voltage attachment tests," continues Martin. "This generator produces a compliant voltage waveform A, as per ARP5412, while we are in discussions about developing a 2MV Marx generator for zone 1 high-voltage attachment tests. All the components exceed the various parameters requirements of ARP5412 Lightning Environment and Idealize Waveforms, with regard to peak amplitude, rise time, action integrals and coulomb (charge) transfer."

2 // 72 'C' bank batteries provide up to 200 coulombs of continuing current in less than 2 seconds

TWA 800'S LEGACY

By far the largest impact on direct-effects testing has been made in the conductive current testing requirements that followed the TWA 800 accident in July 1996, and the resulting 14 CFR 25.981 rule. The now infamous incident saw a Boeing 747-100 explode and crash into the Atlantic Ocean near New York, resulting in the loss of life of everyone on board, with the authorities at first believing the most likely explanation was a terrorist attack. However, a four-year NTSB investigation eventually settled on an explosion of fuel/air vapor in the fuel tank following a possible short circuit as the most likely cause. As a result, new procedures were developed to prevent future such explosions, with great emphasis on electromagnetic and direct effects of lightning testing. "This has resulted in a huge increase in the volume and complexity of fuel-system components and their testing, with the introduction of structural fastener testing, in both 'normal' and 'faulted' fastener designs," explains NIAR's Billy Martin. "The FAA, industry and industry committees have worked hard over the past several years to attempt to bring some sanity to this area. We have made a lot of progress but there is a lot of work remaining to be done."

Martin says that the generator, in meeting all the requirements of the environment and waveform parameters of ARP5412, as well as the various test parameter requirements of ARP5416 lightning test methods, "is equal to or in excess of any commercial generator currently operating in the world for this type of testing".

The generator has actually been 'overdesigned' with additional component A capacitors, which can be charged to only 50kV and still meet the requirements, although Martin notes that they are rated for repetitive charging at approximately 67kV. "This is done to help extend the capacitors' life as they are very expensive and have a very long lead time."

Another aspect of the generator design is that it produces a unipolar waveform, rather than a 'ringing' damped sinusoidal waveform (both are allowed for testing per ARP5412), to help extend the life of the capacitors. It can be charged in less than a minute, though Martin says that they typically charge at a much slower rate as the setup time required for these tests is very long, so there's little need for such rapid charging. "It should be noted that the A and B bank are charged separately and are actually separate generators, as is the C bank," he says. "They are charged separately but are all fired at the same time."

IN-HOUSE EXPERTISE

But it's not just the generator that makes the new facility so special. Martin himself is the current chairman of the SAE AE-2 Lightning Committee, offering a unique perspective and understanding of the latest testing procedures and the reasons behind them.

"The main advantage of participation in this and other committees is being fully aware of the requirements – both the why and the how," he says. "It is also critical to be aware of the direction any changes to the standards may be taking, in order to prepare for these type of changes, which may require development of new equipment or training."

Martin is keen to stress that this information is available to any member of the relevant industry committees – not just the chairman. "It is a major reason companies send engineers to support these technical committees," he says. "Knowledge is power, and knowledge of the requirements, as well as the ability to influence the general direction or method of the procedures being implemented, help you prepare for and increase your ability to comply with the requirements. That knowledge results in a reduction of risk and the economic impact of these types of requirements."

When he started as chairman of the SAE AE-2 Lightning Committee, Martin noticed that fewer than 20

engineers would attend most meetings, but now they are more likely to attract up to 80. "This is due to the rapid expansion of electrical/electronic systems performing primary safety functions on the aircraft, which in turn has dramatically increased the economic impact of complying with rules associated with electromagnetic environments. As a result, the industry needs labs capable of addressing these requirements."

Beyond an increasing reliance on electronic systems, Martin highlights some further trends that have influenced lightning testing: "We have seen a large increase of satcom radome installations in the past several years, which has resulted in changes to the test procedures for secondary attachment, such as swept stroke testing.

"In addition, the general proliferation of composite material into primary and secondary structures has also increased the need for direct effects 'arc attachment' testing [on this type of material]. However, this type of testing is repetitive and can be extrapolated from one aircraft to another."

The implementation of advanced materials into all areas of aircraft structure has further increased the amount of testing required on the direct effects of lightning, as well as affecting the certification of systems, because the coupling mechanism, resulting in indirect effects, is very different (and more stringent) for composite structures than for metal structures. "NIAR is currently conducting research into the development of various types of databases, which industry can use to reduce the amount of repetitive testing required for certification," Martin says. "NIAR has already accomplished this in regard to structural testing of composites and we are attempting to bring that same model to EME certification."

WHAT CAN GO WRONG

Asked to describe some typical failures that can occur during testing, Martin struggles at first due to the sheer number he has seen over the years. He eventually boils it down to two main types of failure – structural and system related.

"The former usually involve current density and the ability to disperse a large amount of current in a short time," he explains. "Typically for a composite structure, it is the initial attachment that causes the failure. If what is known as 'arc root disbursement' [the ability of the structure to adequately disburse the current flow] is not sufficient, the surface can be damaged. This can be quite severe, including large delamination of the structural plies, which can cause lots of problems for the structure, as well as for systems under the structure.

"For metal structures it is the long dwell time that causes the major issues, such as melting bonding straps and pitot tubes. Other failures include antenna damage and windshield damage. There is also the risk of damage to wing tip lights, which if punctured could result in attachment of the lightning channel to the wiring, resulting in wire explosion. It is also possible, in very rare cases, to result in possible fuel tank explosion, if not designed to disperse the current as quickly as possible.

"The majority of failures of systems due to lightning are a result of catastrophic damage to internal components, but lightning can also cause function disruption. By failure I mean the unit being damaged or burned up as a result of the energy being coupled into the interface. Functional upset means that the function the system performs is temporarily disrupted, such as displays blanking, systems becoming disconnected and data being corrupted."

"The majority of failures to systems due to lightning are a result of catastrophic damage to the internal components"

3 // The lightning generator control room enables safe observation and operation of direct effects testing

4 // The lightning generator 'A' banks can deliver 200,000A in 500 microseconds

4

"Most strikes occur to aircraft outside of thunderstorm clouds"

During his career, Martin has seen failures ranging from units catching on fire to displays giving misleading information, which could result in the pilot flying the aircraft into the ground. However, he says most problems caused by damage from lightning can be prevented with good electrical bonding, wire bundle shielding and wire bundle routing, which should all be considered at the outset and engineered into the design.

In terms of what can go wrong from a safety perspective regarding those actually carrying out the testing, Martin pulls no punches. "The voltages and currents used during this type of testing are extremely hazardous and can cause serious injury, even death," he says. "We are safety-driven in everything we do and have instituted multiple interlocks and safety measures, but ultimately it comes down to training and the test engineer. I have seen lab walls blown apart by explosions, pieces of test articles blown across the room and embedded in the wall, and windshields shattered with the glass shredding the insulation on the ceiling. In all these cases, if proper safety procedures had not been followed there could have been serious injuries."

As a result, NIAR has extensive training requirements for all engineers performing such tests: "If engineers don't follow safety procedures, it is cause for dismissal," adds Martin. "I cannot stress enough the importance we place on safety, and I can proudly report that in the 20-plus years I have run labs, I have never had a person working for me who has had to take time off work due to an accident."

WHAT ARE THE CHANCES?

So should passengers be worried about their aircraft being hit by lightning? "There is a risk of an aircraft being struck by lightning anytime it is flying near electrified cloud systems," responds Martin. "Notice I did not say thunderstorm activity, because most strikes occur to aircraft outside of thunderstorm clouds. It also depends where you are flying because you are much more likely to be struck flying over Florida in the summer than over Seattle. The FAA says that on average aircraft are struck by lightning every 1,000 to 3,000 hours of operation."

However, Martin says passengers have every reason to feel safe, as a direct result of the testing that manufacturers carry out prior to certification. "There have been aircraft lost as a result of fuel explosions caused by lightning, and I believe there have been some military aircraft lost due to lightning attachment, but as far as I know there have not been any commercial aircraft lost directly to lightning since the 1970s, although lightning has been involved in several accidents."

Still not convinced? "Modern aircraft are designed and certified to be safe in all aspects of thunderstorms, including lightning," Martin says, reassuringly. As for those passengers with a fear of thunderstorms, he replies in typical matter-of-fact fashion: "One of the main reasons that most strikes to aircraft occur outside of thunderstorms is because pilots typically do their best to avoid flying into a thunderstorm in the first place."

Martin himself estimates he has flown over three million miles on commercial airlines alone, as well as multiple trips on private aircraft during his 25 years with Cessna before he joined NIAR. "Yes, I have been on aircraft struck by lightning," he says. "At least three times I know of and a couple of times that I strongly suspect we were struck. On one of these occasions I was actually returning from running tests that had resulted in a catastrophic failure condition, so I was hoping that the engineers involved in the design of that aircraft had done their jobs."

Fortunately, such engineers now have a new state-of-the-art facility at which to conduct future tests, much to the relief of nervous flyers everywhere. \\

OPEN FOR BUSINESS

NIAR's Billy Martin says the new lightning lab is currently gearing up for a "fuel system research program for the FAA", while further test dates are available on a first-come, first-served basis.

"The cost can vary depending on complexity, but in general it is US$600/hr (minimum of four hours) or US$4,500/day," he says. "We have already conducted several tests for commercial customers, including panels representing aircraft structures, aircraft structures themselves, components attached to the aircraft (for example antennas, lights, pitot tubes), transient devices and transparencies. We have recently completed research testing for NASA, as well as a Kansas Aviation Research and Technology research program, with the goal of creating and publishing an industry- and FAA-endorsed fuel tank lightning protection design handbook."

// ROB COPPINGER

Cosmic cuisi

ne

Should current tests prove successful, fresh food will play a major role in keeping future astronauts alive and healthy

1 // The Veggie growth chamber on the International Space Station (ISS) is illuminated by its red light (Photo: NASA)

2 // Sunday dinner for the whole crew on ISS mission Expedition 36 (Photo: ESA)

Protein pills, dinner in a bite-size cube – astronaut cuisine was foreseen (by sci-fi writers, at least) as small and quick to consume, but the reality became squeezable pastes. The future, however, is fresh food, which will be a key part of any Mars or moon crew's life-support system, grown on board the spaceship. The fresh food in question is expected to be leafy greens such as lettuce, as well as tomatoes and other vegetables, and the technology to grow it is now being tested on the International Space Station (ISS).

In August 2015, astronauts ate lettuce grown on the ISS for the first time, cultivated in a vegetable production system project called, rather unimaginatively, Veggie. This project seeks to provide ISS crews with a fresh source of nutrition.

NASA has a space food systems team that provides for its astronauts as well as for the Canadian, European and Japanese ISS crew members. The food team develops recipes and sample meals for testing, as well as designing containers and packaging appropriate for the long-term storage needed – up to two years – on the space station. The NASA test kitchen is where new recipes are developed and also eaten – an essential part of the testing process. The equipment used by NASA's kitchen includes freeze-driers, 40-gallon (150-liter) steam-jacketed kettles, standing mixers, burner stove tops, double convection ovens and a canning machine.

NASA has created about 100 recipes, including smoked turkey, mashed potatoes, bread products and cherry and apricot cobblers (see 'What's on the menu'). One of the reasons NASA makes its own food is that for decades supermarket products have had a high level of salt and fat relative to what such recipes would naturally have. While NASA's recipes have a much lower level of salt and fat, they have more spices and herbs to replace

100
number of recipes created by NASA for astronauts' food

70
power consumption in watts of the Veggie project

30
additional crops being considered for space farming in the MELiSSA program

2

3

3 // Assorted snacks and dehydrated food to be consumed on the ISS (Photo: NASA)

the taste enhancement salt provides. These healthier recipes also have to meet the special requirements of a space station. These include limited storage space, simple preparation – as there is no conventional kitchen on the ISS – and ease of consumption in zero gravity. Then there is the astronauts' sense of taste, which becomes dull in space due to fluid shifts within the body from the weightless environment. To counteract this, spicy sauces are a popular addition.

TESTING FOR PATHOGENS

Once a food meets all these criteria and is being cooked, NASA tests for a range of pathogens, which are bacteria, viruses or other microorganisms that cause disease. NASA's ISS food system manager, Vickie Kloeris, explains, "We have a specification for each product for testing. We have tests for salmonella, *E coli* and certain other pathogens, to make sure we don't have levels in products that could cause illness in orbit."

Crew members also have the opportunity to add to the usual NASA selection with personal favorites. The agency's food team can repackage beverages, cookies, candy and other dried goods that the astronauts select for their menus, after they have been tested.

Once the food is designed, cooked, tasted and tested, it needs to be processed in such a way as to keep it edible for a long time. The most popular methods used are thermo-stabilization, irradiation and freeze-drying. Thermo-stabilized meat, vegetables and fruit are heated to destroy microorganisms and enzymes. NASA also heat-treats desserts. Irradiation will also kill microorganisms. Foods that are freeze-dried include dishes such as beef stroganoff, cream of mushroom soup, and fruits and vegetables.

Immediately after production, freeze-dried products are canned for a longer shelf life until packaged for launch, when they are put into transparent plastic pouches. Thermo-stabilized food is produced all-year round, while freeze-dried items are packaged six to eight months prior to launch to maximize their onboard life.

Kloeris's team runs moisture analysis of freeze-dried products to make sure they are as dry as they need to be to prevent bacterial growth. Another test

"Today's plastic pouches of freeze-dried meals will slowly give way to astronaut farmers"

FOOD HAS BEEN DESIGNED TO AVOID CRUMBS BECAUSE THEY ARE A BIG PROBLEM IN WEIGHTLESSNESS

4 // Food lab scientist packages food for spaceflight (Photo: NASA)

4

3,200
the number of calories that a male astronaut on the International Space Station can consume

1
metric ton of food and drink is needed by one astronaut per year

determines total aerobic plate count, which is the test that counts all the bacteria in the food that grow in the presence of oxygen. This test is run by commercial food companies, but NASA requires a much lower bacterial count. Kloeris says, "Nothing would be more miserable than having a food-borne illness in micro gravity. It wouldn't kill you, but you might wish it had."

NASA also has a further 100 or so beverages, some of which are also made from commercially available powdered drink products. The powder is weighed out and placed in a container that allows water to be directly injected by an astronaut to hydrate it. These powdered beverages include various types of coffee and tea, milk and lemonade, and they are packaged for launch on an as-needed basis.

NASA and ESA astronauts cite some Russian foods as favorites, but the Institute for Biomedical Problems, which oversees cosmonaut diet, was not available for comment during the writing of this article.

ESA and the Japan Aerospace Exploration Agency provide what are called specialty foods for their astronauts. Subject to the same standards as food that is commercially available, the key difference is that it must also be capable of being stored at room temperature for up to two years. To make things easier, the space agencies operating the ISS have agreed to accept the testing of each other's foods. When ESA and Japanese food items are packed by NASA, they are assumed to be safe.

ON THE (HEALTHY) MENU

NASA has created a vast array of food formulations for astronauts to choose from. The provision of three ingredients is key to astronaut food: Omega 3 fatty acids and two types of antioxidant – flavonoids and lycopene. The Omega 3 is obtained through a variety of seafood choices NASA provides. Flavonoids are plant-based compounds that fight inflammation and promote healthy arteries.

Lycopene is a naturally occurring chemical that gives fruit and vegetables their red color, and which fights cell damage and cancer. NASA foods with lycopene include vegetables with curry sauce, pasta with shrimp, spaghetti with meat sauce and minestrone soup.

The flavonoid recipes encompass green tea, orange juice, granola with raisins, and apricot cobbler. All vegetables also contain flavonoids.

The NASA menu includes vegetarian and vegan food choices. Vegetarian dishes include chili, rice pilaf, candied yams and waffles. Vegan dishes include tomatoes and eggplant, wild rice salad, shortbread cookies and baked tofu.

"For the production and sterilization of the food we prepare in Europe, we've been working with a French company called Hénaff," explains a spokesperson for ESA. "It is very experienced in thermo-stabilization of its own products, and through its research and development lab we are preparing and producing some of the ESA space food." The company, based in Brittany, in northwest France, is known for its terrines and pâtés, which are sold worldwide.

SPACE GARDEN

While astronauts have a relatively wide choice of recipes and drinks, fresh food grown on the spacecraft is viewed as having important nutritional and psychological benefits. NASA has been studying growing food in space and the lettuce eaten last year was the latest stage in the agency's Veggie project.

This project aims to grow lettuce, peppers and cabbage as additional sources of nutrients for astronauts. The Veggie production system is a plant growth chamber. It was built by Orbitec, and it has already grown flowers, as well as lettuce. The unit consumes 70W and has an array of red, blue and green LEDs to provide the radiation for photosynthesis. "Blue light is important as that is how plants orient phototropically," says NASA's Dr Ray Wheeler, lead scientist for advanced life-support activities in the Exploration Research and Technology Programs Office at NASA's Kennedy Space Center. "You don't have gravity to orient growth so you need blue light."

The LED wavelength for blue is 450nm and for red it is

NASA ASTRONAUT JOHN GLENN WAS THE FIRST MAN TO EAT IN SPACE IN 1962

"If you don't have the right light, you won't get a plant"

630nm. The LEDs are most efficient at those wavelengths. All processes on board a spacecraft need to be energy efficient and plant growing studies have shown that about one gram of dry plant mass can be harvested for each mole of radiation. A mole in this case is a measurement of the number of photons impacting a given area during a specific time.

Because there is ample carbon dioxide on the ISS, up to 5,000 parts per million (on Earth it is 400ppm), the light levels on the station are the limiting factor in a plant's photosynthesis and growth. "The most important aspect of testing Veggie was the light quality and it comes down to wavelength and photons, along with water and atmosphere. If you don't have the right light, you won't get a plant," explains Dr Matthew Mickens, a NASA plant biologist and colleague of Wheeler's.

The next Veggie machine, being launched on Space Exploration Technologies' 12th cargo resupply flight in 2017, could join the first in providing more fresh food. However, the Veggie team is also planning a chamber that uses far more infrared light. It is expected to provide a substantial productivity boost for plant growth.

5 // NASA astronaut Kjell Lindgren (center) and Japan Aerospace Exploration Agency (JAXA) astronaut Kimiya Yui (right) participate in a food-tasting session

FOOD FROM WASTE

NASA is not the only agency studying gardens in space. ESA has also been working on a way to grow food in space, but for a regenerative life-support system needed for a mission to Mars or a lunar base. Before such a mission is realized, ESA is planning to have a regenerative life support system tested on the ground with human volunteers after 2025. That life-support system will be based on the Micro-Ecological Life Support System Alternative (MELiSSA) technology that the ESA is developing.

A 20-year long project that is expected to continue for another 20 years, MELiSSA uses the astronauts' bodily waste and the carbon dioxide exhaled help grow the food they will consume. With a pilot plant at the Universtat Autonoma de Barcelona in Spain, this project aims to understand the behavior of artificial ecosystems for long-duration space missions.

NASA'S SKYLAB SPACE STATION IN THE 1970S HAD A FREEZER FOR FOOD – NO SPACECRAFT HAS HAD ONE SINCE

MELiSSA is based on the principle of an aquatic ecosystem and has five compartments. The first three contain bacteria that will break down waste and produce carbon dioxide and food for plants. The fourth contains the crops that produce oxygen and water and will be eaten by the astronauts, who are considered the fifth compartment.

Like Veggie, MELiSSA is experimenting with fast-growing lettuce, but the project is considering 30 crops, including wheat and soya beans. The MELiSSA road map envisages flight experiments on the ISS with MELiSSA technology, a ground demonstration using animals by about 2020, and a trial with humans after 2025. This will be followed by an unmanned moonlander testing of MELiSSA and eventually, after 2030, in-space testing with an actual regenerative life-support system.

From pills to paste to paella, the reality of astronauts' food has improved since the first imaginings of science fiction in the 1950s and actual manned spaceflight in the 1960s. Today's plastic pouches of freeze-dried meals will slowly give way to astronaut farmers, who grow crops that also provide the oxygen the crew breathes. \\

6 // The MELiSSA Pilot Plant – a unique facility in Europe for the demonstration of Closed Loop Life-Support Systems (Photo: Universitat Autonoma de Barcelona)


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// ROB COPPINGER

Spin to win

Weightlessness wastes muscle and weakens bone, endangering lives in missions to the moon and Mars. Recreating the gravity we experience on Earth, even for short periods, could open up the solar system to manned exploration

"These investigations will determine minimum g levels for maintaining physiological conditioning"

1 // A NASA-provided Short Radius Centrifuge at University of Texas Medical Branch in Galveston with test dummy (Photo: NASA)

2

2 // A volunteer in a bed-rest study with his body angled 6° below the horizontal at the head end (Photo: DLR)

Lack of gravity on spaceflights causes astronauts a variety of physical problems that continue after their return to Earth. Plans to send humans to the moon and Mars for long-duration missions will be undermined if these health issues stop astronauts carrying out their work – or worse, endanger their lives.

A complete theory of gravity eludes science (see *Gravity and centrifugal force*). While much of science fiction has presented a future with astronauts walking around spacecraft corridors, there is no prospect of an onboard gravity generator. So, centrifugal force is the only alternative to recreate the 1*g* that we experience on Earth.

Recreating that environment could mean spinning an entire Mars spaceship, according to NASA researchers. The Mars spaceship envisaged in NASA's most recent design reference mission (DRM), DRM 5, is nuclear powered, has a mass of 327 metric tons and is 91.3m long, but this design provides no artificial gravity.

Other ideas for Mars spacecraft range from tumbling end-over-end (pitch-axis rotation) to spinning the ship around its longitudinal axis with habitats located radially to provide a centrifugal force to simulate gravity. The tumbling end-over-end concept has a 112m-long spacecraft with a 16.6m-diameter habitat that is 56m from the ship's center of rotation to produce the desired 1g effect.

"Scientists felt the previous US-Soviet work had too few test subjects"

It may not be necessary, however, to spin an entire Mars ship, nuclear engines and all. Experiments with artificial gravity using centrifugal forces go back to the 1950s. Today, NASA engineers have a concept for a module that would be part of a Mars ship, or the International Space Station (ISS), and in which astronauts would sit and be spun at 24rpm for limited periods of time. This may be as good as a constantly spinning spacecraft, but research is yet to confirm that.

NASA'S PLAN

NASA researchers have drawn up a proposed detailed artificial gravity research plan that ultimately includes astronauts using a centrifuge on the ISS. This would be a small centrifuge that astronauts would sit in.

Dr Gilles Clement works for KBRWyle – a laboratory providing government services and a contractor to NASA. Clement is also the lead artificial gravity scientist within NASA's human research program. "In the overall AG [artificial gravity] research plan, these proposals address the gap in knowledge of the relationship between the *g* dose and the physiological responses," he says. "The outcomes of these investigations will help to determine what minimum *g* level is needed for

3

3 // Masks measure how much oxygen is consumed and how much carbon dioxide is exhaled by the bed-rest volunteers, to better understand the impact of weightlessness (Photo: CNES-E)

GRAVITY AND CENTRIFUGAL FORCE

On Earth we exist in a gravitational field generated by the huge mass of the planet. Gravity is a weak force, weaker than electromagnetism, and it needs the full size of the Earth, 6 x 10^{24} metric tons of it, to produce the 1*g* field. All life on Earth has evolved within this 1*g* field and when humans, and plants and animals, live in a lighter gravitational environment, their physiology changes.

Since the end of the NASA Apollo program in 1972, manned spacecraft have only flown in low Earth orbit (LEO), which is at an altitude of between 180km and 2,000km. At this altitude, the term micro-gravity is used, as it is not an environment without gravity. At the altitude of the International Space Station, about 400km, gravity is 0.9*g*, about 90% of what it is on Earth. Astronauts, and other objects, float because they are actually in free-fall around the Earth, traveling fast enough that they do not fall back to the surface.

Centrifugal force is a 'fictitious' force as it is unlike a real force such as gravity, or the nuclear force. But human beings do experience centrifugal force, depending on their mass, speed of rotation, and distance from the point around which they spin. An object, or person, traveling in this circle behaves as if it is experiencing an outward force –any increase in mass, speed or distance will increase the outward force.

maintaining physiological conditioning. An AG level above this minimum value will then be recommended should AG be created in the spacecraft that will carry humans to Mars."

A centrifuge for human use already flown into space was the European Space Agency's (ESA) off-axis rotator. This was a chair on a short arm that spun the occupant. It was flown inside the Spacelab module housed in the cargo hold of the Space Shuttle Columbia on its Neurolab mission in 1998. The spinning seat generated artificial gravity levels of 0.5*g* and 1*g*. The tests spun astronauts for seven minutes. Eye movements and perceptions were recorded and the experiment indicated that the test subjects perceived sustained levels of 0.5*g* and 1*g* as artificial gravity.

A centrifuge module for animal testing was built for the ISS by the Japanese Aerospace Exploration Agency. But, its use was canceled along with other elements of the ISS when the Space Shuttle fleet was retired in 2011, which cut short the number of modules that could be launched. Despite this setback, centrifuge experiments have taken place more recently on the ISS with fruit flies.

The research that has been conducted on the ISS uses a tiny centrifuge that is part of the Fruit Fly Lab. That laboratory module arrived at the ISS in January 2015 on a Space Exploration Technologies' Dragon supply spacecraft. Fruit flies are used to discover the mechanisms of human health and disease because the two species share the same basic biochemistry.

The lab's tiny centrifuge can simulate the levels of gravity found on Earth, the moon and Mars. Half of the flies were weightless during the study and half were exposed to simulated Earth gravity. Some of the flies' food contained a microbe to infect the insects. The researchers compared the ability of the two groups of flies to resist infection by this food-borne microbe, along with a group of flies that remained on Earth. The mission studied generations of fruit flies, in particular, their genes. NASA expects a series of yearly sequels to follow the 2015 debut mission. The results of the original 28-day Fruit Fly Lab-01 mission are still being analyzed and have not been made public.

3
percentage height gain by astronauts in micro-gravity

18
length in meters of the longest centrifuge arm in the world, which is operated by Russia's space agency

20
maximum gravitation force (*g*) that centrifuges used by space agencies can induce on test subjects

SPINNING PEOPLE

While near-term space-based centrifuge studies will involve animals, next year will see 16 human subjects experience centrifugal forces in Cologne, Germany, and in Toulouse, France. The German Aerospace Center (DLR) is leading a bed-rest study that will also involve people spending time in centrifuges.

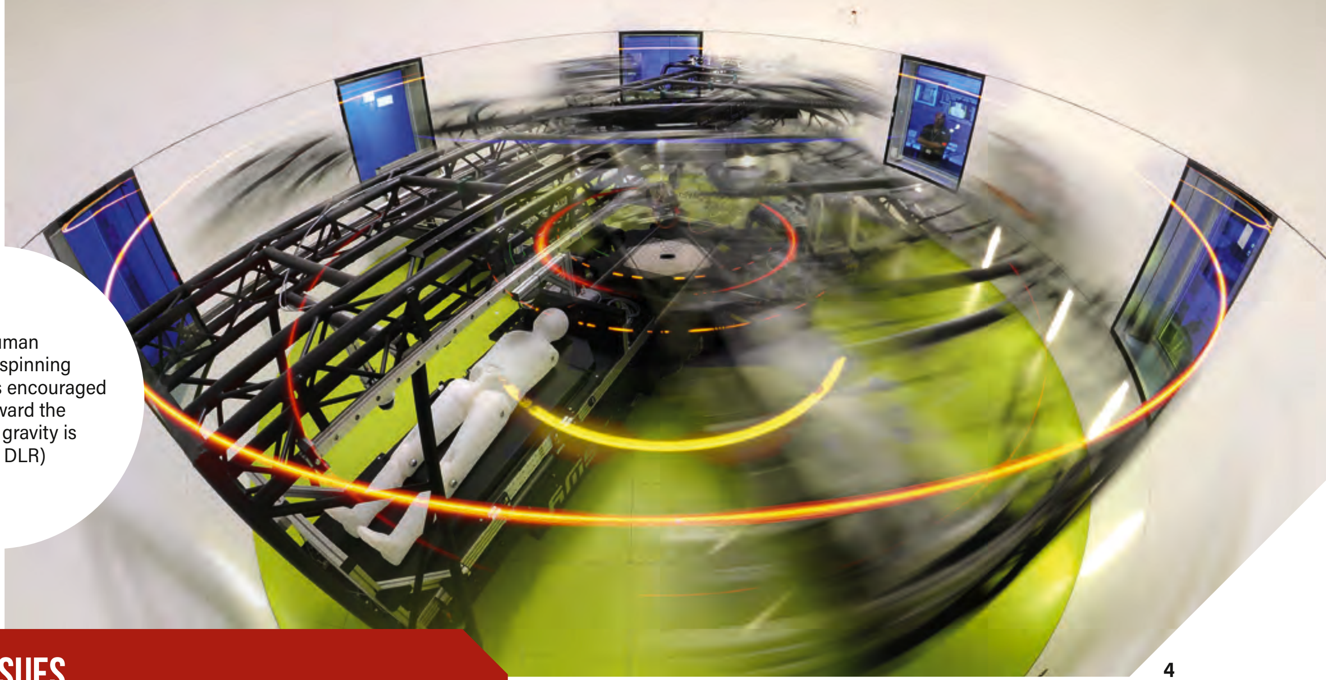
The ESA and the French space agency, Centre National d'Études Spatiales (CNES), are also involved, along with NASA, whose detailed plan also calls for ground-based human studies. But these Cologne-Toulouse studies are not the first.

The earliest centrifuge experiments with human subjects took place in 1958 in the USA at the Naval Medical Research Laboratory in Pensacola. But that was not a bed rest study – it involved a slowly rotating 10m-diameter room, complete with facilities for people to live there for periods from one day to three weeks.

The Soviet Union's Institute for Biomedical Problems, which still exists, has used a small rotating chamber and a larger 10m centrifuge with human subjects. It found that test subjects were able to cope with a rotation of 12rpm and sleep, and that after several days they could adjust to the spinning environment.

The reason for the new DLR/CNES/ESA/NASA ground-based studies is that, overall, scientists felt the previous US-Soviet work had too few test subjects. However, the test results showed that people could live in spun environments and some of the physical problems astronauts have in-orbit can be alleviated. ESA's human research office head, Jennifer Ngo-Anh, says that artificial gravity is being investigated because it was thought to be the most promising countermeasure against the deleterious effects of weightlessness.

"We are at the very beginning of artificial gravity research," Ngo-Anh says. As such, she could not say whether a rotating Mars ship or a ship's centrifuge module with a spinning chair, or something else, would be the answer to micro-gravity's health effects.



4 // Envihab human centrifuge – by spinning people, blood is encouraged to flow back toward the feet as artificial gravity is created (Photo: DLR)

SPACE HEALTH ISSUES

Astronauts suffer a variety of health problems from the micro-gravity environment of low Earth orbit. Muscle and bone loss are two health effects most often referred to. Muscle is lost simply because of the lack of physical activity that comes with a micro-gravity environment. There is very little gravity for the legs and arms to push against. The bone loss is thought to be caused by a lack of what is called mechanical loading by gravity. Bones are maintained with calcium because of this constant downward pressure and without it the bones deteriorate. This bone loss is also linked to kidney stone formation and fractures in bones.

Another particular concern to space agencies is astronaut eye health and changes to vision, which is affected by the rise of fluid in the body in a micro-gravity environment, causing what is referred to as intracranial pressure – fluid around the brain and eye structures.

Other problems astronauts get are spinal disk damage, heart rhythm irregularities, difficulties standing up and coordinating their limbs, and back pain.

"We may have artificial gravity paired with some exercise"

Next year's work in Germany will take place at DLR's Envihab center in Cologne, which has a short-arm centrifuge provided by the ESA.

Under this centrifuge bed rest study, the test subjects will lie down for 60 days, during which they will have periods in a centrifuge to see if this type of artificial gravity can stop negative health effects. In bed-rest studies, volunteers are kept in beds with the head-end tilted 6° below the horizontal and with one shoulder touching the bed at all times. This inactivity, and head-down angle, creates the same effects in the human body as micro-gravity – blood flows to the head and muscle is lost (see *Space health issues*). The centrifuge will see blood encouraged to flow back toward the feet with the expectation that it will also stop the negative effects of inactivity on the test subjects' health.

Future studies could include exercise for the astronauts while they are being spun. The DLR centrifuge can have an exercise bike attached to its end. "We may have artificial gravity paired with some exercise," says Ngo-Anh. Nutrition is another possible dimension. Ngo-Anh explains that additional calcium and vitamin D in astronauts' diets had not been effective enough as a countermeasure, but in future a 'cocktail' that includes a range of vitamins may be more effective.

The joint study will characterize changes in the muscles, the senses and related physical movement, the heart and lungs, the blood flow around the brain and the eyes, or anatomically speaking, the musculoskeletal, sensorimotor, cardiovascular, cerebrovascular and ocular systems. It will also look at cognitive performance, thinking and behavioral health. The test subjects will be examined for two weeks both before and after the 60 days in bed in the centrifuges.

They will be split into three groups. Group one, the control group, will not use the centrifuge and will comprise eight people. Group two (another eight) will be spun for 30 minutes per day. The third group of eight will experience six spins lasting 5 minutes each over a period of 55 minutes. There will be 5 minutes of rest between each spin, so 25 of the 55 minutes will see the subjects at rest. Bed-rest studies, without centrifuges, have been carried out before; ESA and DLR ran one with 12 volunteers for 60 days, which ended in November 2015.

According to Clement, the results of this centrifuge study could lead to follow-up joint bed-rest work that will examine the effects of a combination of gravities, exercises and nutrition. Ngo-Anh says that further collaboration with NASA depends on the outcome of the first 60-day study. In Clement's view, one gravity level of interest could be that on Mars. In a bed-rest test this is achieved by placing the human subjects in a 'head-up' position at 28.3° for eight hours per day, to simulate the effects of the 0.38*g* that astronauts would experience on the red planet.

Recent science-fiction films *Interstellar* and *The Martian* showed two centrifugal gravity concepts: the entire *Interstellar* spacecraft spinning, and *The Martian*'s Mars ship's rotating section.

The reality that NASA, DLR, CNES and ESA are working toward is equally likely to be that module with a spinning astronaut chair. But at what rate it spins and how often astronauts have to experience that to counter the damaging effects of micro-gravity is yet to be discovered by work that is soon to start here back on Earth. \\

20
percentage of muscle mass lost by astronauts without exercise on spaceflights lasting just 11 days

31
weight on Mars in kilograms of an average man weighing 83kg on Earth. He would weigh just 13.7kg on the moon

// ANTHONY JAMES

ELECTRIC CONVERSATION

The world's first international conference dedicated to the increased electrification of commercial and military aircraft returns to Germany this November

Volt future aircraft: ©NASA/BOEING/SCIENCE PHOTO LIBRARY

OVER 50 SPEAKERS!

electric & hybrid aerospace

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The second Electric & Hybrid Aerospace Technology Symposium will bring together aerospace industry R&D engineers and heads of design and engineering to discuss, debate and analyze future possibilities for the hybridization of aircraft and even the possibility of pure electric-only commercial flight.

Organized by UKIP Media & Events, the publisher of *Aerospace Testing International* magazine, the conference takes place November 9-10, 2016, at the Koelnmesse, Cologne, Germany.

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electric & hybrid aerospace TECHNOLOGY SYMPOSIUM 2016

Day 1 WEDNESDAY, NOVEMBER 9

NOVEMBER 9 & 10, 2016 COLOGNE, GERMANY

ROOM A

KEYNOTE PRESENTATIONS

Electric flight in Airbus Group
Andrew Anderson, chief operating officer, Airbus Group, GERMANY

Bridging the technology gap for hybrid-electric propulsion
Mark Husband, lead engineer – electrical systems and technologies, Rolls-Royce, UK

NASA investments in hybrid-electric technologies for large commercial aircraft
Dr Nateri Madavan, associate project manager, NASA, USA

Future development of hybrid-electric propulsion systems for low-emission aviation
Dr Frank Anton, head of electric aircraft, Siemens Corporate Technology, GERMANY

Considerations for next-generation propulsion and integrated systems
Neil Garrigan, senior program manager, electrification, GE Global Research, USA

Toward hybrid-electric propulsion – Safran's view
Dr Pierre-Alain Lambert, head, energy & propulsion, Safran Tech R&T Center, France

THE PATH TOWARD MORE-ELECTRIC AIRCRAFT

Electrical-variable engine (EVE) hybrid propulsion system: performance impacts and technology considerations
Michael Armstrong, vision systems lead, Rolls-Royce North American Technologies, USA

Introduction to Aerospace Technology Institute and electric and hybrid technology
Mark Scully, head of technology – advanced systems & propulsion, Aerospace Technology Institute, UK

Scaling of electrical power systems for hybrid-electric aircraft propulsion
Dr Peter Malkin, strategic research advisor, Newcastle University, UK

Integration for electric and hybrid-electric aircraft
Simon Taylor, chief technologist, Fokker – GKN Aerospace, NETHERLANDS

MORE-ELECTRIC AIRCRAFT & ASSOCIATED TECHNOLOGY

Building blocks for transport-class hybrid and turboelectric vehicles
Amy Jankovsky, subproject manager, hybrid gas-electric propulsion, NASA Glenn Research Center, USA

Superconducting turboelectric propulsion system as enabler of future hybrid aircraft
Dr Dmitry Melyukov, project manager, Airbus Group Innovations, RUSSIA

Structurally functional design of a full-electric aircraft power complex
Prof. Sergey Khalyutin, CEO, NaukaSoft, RUSSIA

Model-based sizing and analysis of hybrid-electric propulsion architectures
Alexander Schneegans, managing partner, PACE Aerospace Engineering and Information Technology, GERMANY

Impact of electric aircraft on thin-haul commuter aviation operations
Prof. Brian German, Langley associate professor, Georgia Institute of Technology, USA

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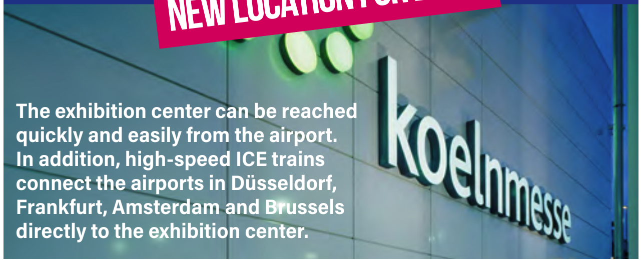

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electric & hybrid aerospace
TECHNOLOGY SYMPOSIUM 2016

ROOM B

ALTERNATIVE AIRCRAFT DESIGN & TECHNOLOGY

Fuel cell hybrid power modules for aircraft applications
Prof. Josef Kallo, head of energy systems integration, Deutsche Zentrum für Luft- und Raumfahrt (DLR), GERMANY

Aircraft design for hybrid-electric flight
Prof. Andreas Strohmayer, professor, Institute of Aircraft Design, University of Stuttgart, GERMANY

DACAPO (Distributed autonomous cabin power) – the energy-autonomous cabin
Ronny A Knepple, head of energy systems, Diehl Aerospace, GERMANY

Delft University Unconventional Configuration (DUUC) concept aircraft with propulsive empennage
Prof. Leo Veldhuis, section head flight performance and propulsion, Delft University of Technology, NETHERLANDS

Electric drives for electric green taxiing systems
Dr Evgeni Ganev, chief engineer, Honeywell International Inc, USA

A design procedure for a hybrid-electric aircraft
Prof. Teresa Donateo, associate professor, University of Salento, ITALY

Fuel cell system developments at Safran
Dr Théophile Hordé, technical manager, Safran Power Units, FRANCE

Feasibility study on hydrogen and electric aircraft compatible with society
Dr Takayuki Kojima, Japan Aerospace Exploration Agency, JAPAN

Model-based systems engineering (MBSE) from concept to take-off
Frédéric Chauvin, A&D industry solution experience director, Dassault Systèmes, FRANCE

More electrical flight instruments, from aircraft to UAVs and airships
Andreas Koetter, business manager innovation, Altran SAS & Co, GERMANY

SPEAKER SPOTLIGHT

PIERRE-ALAIN LAMBERT

HEAD, ENERGY & PROPULSION DEPARTMENT, SAFRAN TECH R&T CENTER

What are the main challenges presented by hybrid-electric propulsion?

Delivering significant propulsive power levels (from 1MW upward) through electrical technologies needs a huge effort to develop relevant generator, motor, power electronics and electrical distribution. Batteries as the energy-storage medium are considered to be the most critical items in realizing the integrated performance targets of hybrid-electric propulsion systems. In fact, battery-specific energy levels need to be 300 to 400% more than those delivered by today's best-performing units to have a meaningful impact on short-haul regional aircraft. Regarding fuel cells, prohibitive balance-of-plant mass, and a question concerning the wide-scale availability of liquid hydrogen as a chemical energy source, means it would probably be a good candidate in providing auxiliary power rather than primary propulsion.

From an architectural perspective, a lot of paperwork has been performed in the past 10 years in aerospace research, highlighting the different merits of various aircraft and propulsion system architectures, ranging from classical tube-and-wings arrangements with some degree of electrical assistance to the gas turbines, up to very futuristic flying wings with turbo-electric distributed propulsion configurations. In response, Safran has formulated a series of technological roadmaps both pragmatic and agile in nature, and readily adaptable to any future airframer requirements.

Regarding the industrial challenges, hybrid-electric propulsion is a departure from the classical, loosely coupled breakdown between a propulsive system (such as a CFM56 engine and its closest equipment) and the aircraft using it. Concepts such as turbo-electric or distributed propulsion imply much deeper interaction between propulsion and airframe. In that respect, the traditional role and influence of the propulsion system integrator during product development programs may expand considerably. However, quite uniquely in the industrial aerospace community, Safran, through its different businesses, is in a position to appropriately integrate all needed technologies for hybrid-electric propulsion, from power sources (gas turbines, reciprocating engines) to the propulsive module (ducted fan), including artefacts facilitating electrical generation, distribution and motorization.

What testing, if any, have you conducted to date?

By adopting a hardware-in-the-loop approach, we are studying the hybridization scenarios of an APU with a battery and a fuel cell. Here, only the battery and the fuel cell are physical components, while the gas turbine is simulated by a real-time model. This enables us to save both time and cost, as the gas turbine technologies are not considered to be critical items for such architectures. We have also demonstrated the coupling of a helicopter engine with an electric motor for fast reactivation and transient response assistance. On a twin-engine helicopter, that technology could open the possibility to deactivate one engine in cruise flight, leading to a double-digit percentage fuel-burn saving. Today, we are designing a dedicated facility to experimentally demonstrate all the possible electrical hybridization modes of a dual-core turbofan, either in transient or in steady-state operation.

Your presentation will focus on 'parallel hybridization' – what is it, exactly?

Parallel hybridization is a concept in which the electrical motor is connected to the shaft of the gas turbine (high-pressure or low-pressure spools, depending on the applications). Its main purpose is to assist the operation of the gas turbine, either in steady-state or in transient operation. For instance, such a concept may allow a helicopter engine to be sized for max take-off power only, and have all subsequent power output requirements ensured by electrical assistance. This can also be used to resize the engine compressor with reduced surge margins, using piloted electrical power input to guarantee a safe transient operation. All studies performed show that such concepts may strongly benefit from a greater integration between propulsive and non-propulsive systems, to mutualize critical electrical components such as the batteries.

What do you think will power a large commercial jet in 2050?

Unless a major, disruptive breakthrough is made, I suspect full-electric 200-pax aircraft will not be part of our landscape by 2050. One must really keep in mind that electric propulsion is all about emissions reduction, which has to be considered as a whole, including electricity production itself. I would rather favor a clever mix between hydrocarbon-based energy generation and some degree of hybridization for stored energy and motive power, leading to aerodynamically optimized fixed-wing or rotorcraft. As systems reflecting the 'More-Electric Aircraft' architectural philosophy reach peak levels of performance, a natural evolution could be the implementation of partial turbo-electric propulsion systems that exploit opportunities given by boundary layer ingestion and wake filling. Since such an approach will still produce a considerable deficit in relation to emissions/noise targets set by the European Commission Flightpath 2050 and the NASA Aeronautics Research Mission Directorate, over time, this will lead to pathways where series/parallel hybrid-electric concepts will start to emerge.

Day 2 THURSDAY, NOVEMBER 10

ROOM A

ALTERNATIVE PROPULSION, ELECTRIC MOTOR SOLUTIONS & ENERGY STORAGE

The 'Build, Learn, Fly, Spiral' development approach for NASA's electric propulsion aircraft
Starr Ginn, deputy aeronautics research director, NASA Armstrong Flight Research Center, USA

Integrated BLI propulsion system
Ivan Popovic, project lead for hybrid-electric propulsion, Rolls-Royce, UK

Designing energy-storage devices for hybrid propulsion systems
Dr Mohamed Rashed, senior research fellow, Nottingham University, UK

An e-motor architecture developed for propeller-based aerospace applications
Dr Tim Woolmer, chief technology officer, YASA Motors, UK

A techno-economic perspective of a turboelectric distributed propulsion aircraft
Dr Devaiah Nalianda, lecturer in gas turbine engineering & technology, Cranfield University, UK

Powerful redundant engines for electrically powered aircraft
Andreas Rohr, development engineer, Acentiss, GERMANY

Electric propulsion: challenges and opportunities
Dr Mike Benzakein, AVP aerospace and aviation research, The Ohio State University, USA

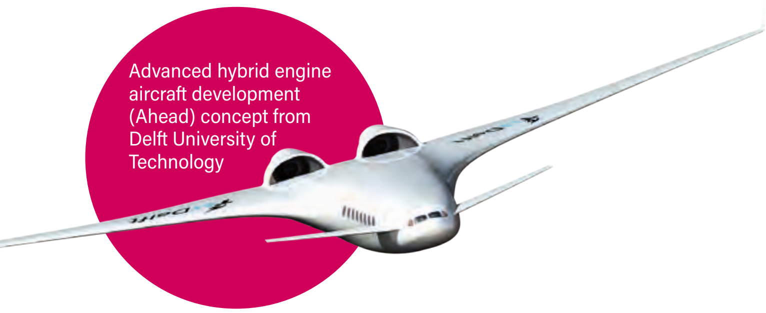
From MEA/MEE toward future hybrid propulsion
Dr Noriko Morioka, general manager, new technology project group, engine technology department, research and engineering division, aero-engine and space operations, IHI Corporation, JAPAN

Disruptive electric machine technology for aircraft propulsion
Carl Goodzeit, consulting engineer, Texas Consultants, USA

Electrical machines for hybrid aircraft propulsion
Dr Chris Gerada, professor of electrical machines, University of Nottingham, UK

Safe and silent – the distributed propulsion architecture of the Antares-H3
Andor Holtsmark, engineer, Lange Research Aircraft, GERMANY
Axel Lange, CEO, Lange Research Aircraft, GERMANY

Innovative power-dense e-drives for aviation – design and potentials
Oliver Blamberger, managing director, Compact Dynamics, GERMANY
Friedrich Mörtl, head of sales, Compact Dynamics, GERMANY



Advanced hybrid engine aircraft development (Ahead) concept from Delft University of Technology

SPEAKER SPOTLIGHT

SIMON TAYLOR

CHIEF TECHNOLOGIST, FOKKER – GKN AEROSPACE

What is Fokker - GKN doing to realize hybrid-electric aircraft?

We are developing technologies that reduce required installed thrust and onboard energy demands through, for example, reductions in drag and in maximum take-off weight (MTOW). The latter is being addressed through the application of materials and fastener-less joints enabled through thermoplastics or bonding of fiber metal laminates, in conjunction with appropriate analytical methods and structural design methods, such as post-buckled design.

This is further supported by appropriate structural health monitoring (SHM) as part of the aerospace systems 'smart structure', which may include impact detection, shape, strain and temperature sensing.

Drag reduction efforts include natural laminar flow (NLF) and hybrid laminar flow (HLF); structurally integrated systems that significantly reduce protuberance and form drag; as well as developing sustainable coating technologies that reduce skin friction and ice accretion.

From an electrical systems perspective, we are working on the means to manage and reduce the electrical consumption, as well as heat dissipation within the fuselage, through management of the electrical architecture integration. One example here is our work on optical ice detection to reduce power consumption.

What are some of the challenges?

Let's take an example from the electrical ice protection system that we are developing based upon the system in operation on the B787. Particular challenges include efficiency improvement and the safety of high-voltage systems from both the perspective of damage potential (including redundancy and availability), and any degradation effects of partial discharge on the constituent materials.

We are developing engineering and test methods to solve these challenges. We use our own icing wind tunnel for development of both the electrical ice protection system and also the laser ice detector, the latter of which is set to be flight tested next year.

As a Tier 1 supplier within aerospace, a key focus is to ensure participation within tests and operational experience to ensure the attainment of the appropriate system-level knowledge.

From a testing perspective, it is pertinent to ensure operational performance through the testing of suitably aged products, as well as any potentially necessary repairs where part of the challenge to be overcome is in the development of not only the test method, but also in the substantiated aging of test specimens. This is of particular importance in order to ensure the reliability and availability of the future aerospace system such as will be necessary to guarantee the viability and performance of structure-embedded systems and coatings.

Describe a typical commercial aircraft in service in 2050

Certainly such aircraft will require a low MTOW and low drag – including some wake ingestion and boundary layer ingestion (BLI) – as well as reduced drag, including a high degree of flow laminarity benefiting lift and installed thrust, as well as effective thermal management. This may require changes such as tail-integrated powerplants and fuselage-integrated landing gear. The aircraft itself is likely to have a lower cruise velocity than comparable aircraft of today.

By 2050, higher specific energy density of electrical accumulators, as well as most likely fuel cell systems, will improve the capability of pre-2050 and 'new' aircraft.

The biggest change by 2050 will most likely be in the common emergence of more radical configurations exhibiting BLI and/or wake ingestion through the application of more blended wing body (BWB) configurations for the large commercial aircraft (LCA) market, although it is quite possible that smaller commercial aircraft may remain a tube and wing configuration, but with a more radical, integrated propulsion system.

One may hypothesize that the LCA segment will be hybrid electric for single-aisle replacements and turboelectric for twin-aisle replacements. In order to reduce emissions, one may consider a multifuel solution with potentially short-range aircraft operating all electric in the below 100-seat class.

There have been many papers on this subject and the debate has not yet been concluded. We will need to continue to watch this space as critical enabling technologies evolve.

View the full program online
WWW.ELECTRICANDHYBRIDAEROSPACETECHNOLOGY.COM

ROOM B

POWER & ELECTRICAL SYSTEM ARCHITECTURE

Flight demonstration of a lithium-ion battery system under high C-rate operation
Dr Akira Nishizawa, section leader, Japan Aerospace Exploration Agency, JAPAN

Designing electric power system architectures for hybrid propulsion aircraft applications
Dr Patrick Norman, lecturer, University of Strathclyde, UK

Ultracapacitors and hybrid devices: fast charge-discharge and high efficiency
Vadim Utkin, CEO, Yunasko, UKRAINE

Progress in state estimation for lithium-ion batteries
Matthias Vetter, head of department, Fraunhofer Institute for Solar Energy Systems ISE, GERMANY

Advanced embedded platforms and IMA for distributed power controls
Mirko Jakovljevic, solution architect – integrated critical systems, TTTech, AUSTRIA

Modular electric power systems for aerospace vehicles
Gregory Semrau, systems engineer, Moog, USA

Adaptive dual-spool power system architecture – challenges, solutions and benefits
Manish Dalal, executive director – electrical power systems, GE Aviation, USA

FUTURE GENERAL AVIATION TECHNOLOGY & CONCEPTS

Industrializing hybrid and electric aircraft
Gregory Bowles, director, European regulatory affairs & engineering, General Aviation Manufacturers Association, BELGIUM

Hybraero – next-generation hybrid aviation propulsion
Neil Cloughley, managing director, Faradair Aerospace, UK

Hypstair: the world's first certifiable serial hybrid-electric powertrain for general aviation
Dr Tine Tomazic, director of R&D, Pipistrel Ajdovscina, SLOVENIA

Cockpit displays for electric and hybrid aircraft
Steven Jacobson, senior vice president, product development, Avidyne Corporation, USA

Model-based system performance simulation analysis for hybrid-electric aircraft
Nir Kastner, research associate, German Aerospace Center (DLR), GERMANY

**This program may be subject to change.*

SPEAKER SPOTLIGHT

NATERI K MADAVAN
ASSOCIATE PROJECT MANAGER, ADVANCED AIR VEHICLES PROGRAM, NASA AMES RESEARCH CENTER

Describe NASA's latest hybrid-electric and distributed propulsion work

NASA is developing technologies and using advanced concept studies and system models to inform and guide its research. Some promising architectures being explored include the SUGAR Volt, with a parallel hybrid-electric propulsion system in a strut-braced wing airframe; and two turboelectric, distributed propulsion concepts – the superconducting N3-X and an ambient temperature STARC-ABL. We have identified a range of critical enabling technologies that are needed: high efficiency, flight-weight, megawatt-class electric machines and power electronics; high-voltage and high-frequency power distribution and protection schemes; integrated power and propulsion controls; thermal management systems; and enabling materials. We are making progress in many of these areas – subscale component tests will be conducted this year, and megawatt-level component and system-level testing will follow. We also plan to build and fly a sequence of smaller-scale flight demonstrators (x-planes), such as the X-57 'Maxwell' (see page 7) that is currently being readied, that will serve as stepping stones on the path to realizing electrified commercial aviation.


SUGAR VOLT hybrid concept

How far away are we from a hybrid-electric large commercial aircraft? And is an all-electric passenger jet ever likely to happen?

Both hybrid-electric powertrains and turboelectric power generation appear feasible for the Boeing 737/Airbus A320 class of transport aircraft in a 30-year horizon. However, the economic viability of such aircraft will depend on a large number of technical, as well as market, factors that are difficult to predict. With regard to all-electric solutions, the take-off-and-climb power and total energy needed for standard mission durations for this class of aircraft lead to extremely high energy-storage requirements; some truly game-changing breakthroughs in terms of stored energy density will be needed before all-electric large commercial aircraft can be realized. Since human ingenuity knows no bounds, it would be foolish to state that this is unlikely or can never happen.

What has been the biggest breakthrough?

There has been a broad range of recent advancements in the electronics industry that have had a tremendous impact in making electrified aircraft propulsion viable. Developments in wide-band-gap devices and pulse width modulation control are making improved power systems, with higher efficiency and specific power possible. Steady improvements in battery power density and volume requirements are also encouraging, since even fully turboelectric aircraft will likely use batteries to perform energy management, load leveling, and other functions. We are really excited by recent advances in megawatt-class electrical machines. Such high specific power, high-efficiency electric motors and generators could enable systems that do not rely on superconducting technologies and will be critical to realizing electrified commercial aircraft in the not-too-distant future.

How have advances in CFD helped in the test and development of such vehicles?

CFD is a critical and indispensable part of the aircraft design and development process – not just for electrified – but for all aircraft. Aircraft design is becoming increasingly multidisciplinary in order to account for the tight integration and coupling between power, propulsion, aerodynamics, structures and control systems. This is especially true for potential electrified aircraft concepts. CFD has made tremendous advances in recent years in a wide range of areas, including efficient and accurate high-fidelity numerical algorithms, turbulence modeling, and unsteady separated flow prediction. With the rapid improvements in computing hardware, such high-fidelity techniques are gradually becoming integral to the design process. Other relevant CFD advances include, but are by no means limited to, efficient multidisciplinary design and optimization frameworks, improved grid generation and flow visualization techniques, fast and efficient immersed boundary and other methods for rapid design evaluation, and improved conceptual modeling tools. Note that NASA does not just use CFD to design aircraft, we continue to play a major role in advancing the state-of the-art in CFD.


Conceptual rendering of a 737 hybrid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FLEXIBLE AND SCALABLE

Flexibility and scalability are often promised, but without any specific details being given. AIM offers a conceptual view with clear answers and a way to achieve these twin goals

// The ANET functional concept includes software support for an API, Python scripting and PBA.pro configurations

The flexible and scalable test system concept described here is a standalone avionics databus interface device that can be operated over standard Ethernet. Such devices have become popular because of the achievable distances between an avionics bus connection point and the control station.

The Ethernet standard itself is implemented and available on lots of hardware and operating system software platforms, so OS-specific/native device drivers for the interface are no longer needed.

The best Ethernet topology for avionics testing applications depends on the testing program, roughly categorized into the military and commercial areas. With commercial programs and applications, the threshold for using wireless technologies is lower than for military applications. However, a flexible approach should allow operation of such a standalone interface, via either wired or wireless Ethernet, to address unique needs.

In real life, avionics systems typically implement multiple databuses of the same or different types, so that multiple interface devices may also be required. Expansion simply by multiplying the number of interface devices implies multiplication of network cabling, power supplies and more Ethernet switches to connect interface devices to the testing network.

This issue requires scalability. It means having an 'environment' that has common infrastructure resources for devices with Ethernet-based interfaces such as a shared power supply and a single common Ethernet connection point for more than one interface device. Consequently a particular kind of docking station for multiple devices can serve these requirements by having a single, common power supply, as well as an Ethernet switch. Another feature of a docking station is wireless Ethernet capability, which could be offered as a common infrastructure element.

However greater flexibility is achieved when the interface devices, hosted by a docking station, can be used in a standalone mode. A simple solution for this is to have a breakout adapter box or cable for dockable interface devices.

Scalability and flexibility for hardware installations apply equally to software. The basic requirement is an Ethernet interface using an application program interface (API), or test and analysis software that meets the customer's needs. Due to the nature of the network communication, further processing capabilities in interface devices can cope with tasks that need to be executed close to the databus connection point and independently from a host processor, which can include more sophisticated data acquisition/recording, analyzers and gateway functionality. With today's smart SOC (system on chip) components, local processing power and an open software environment such as Linux, such interface processing capability can be efficiently implemented.

AIM has implemented this tool concept for handling avionics databus protocols such as MIL-STD-1553, ARINC429 and STANAG3910. With accessories and features such as the ADocks, software support for API, Python scripting and various PBA.pro configurations, the AIM ANET interface device family has a range of building blocks for off-the-shelf flexible, scalable test systems. \\

SMART TRANSDUCER SETUP

A smartphone app automates the process of placing and integrating transducers into analysis software using sensors from any manufacturer

// Scanning the data matrix code gives the transducer's orientation and identity. It is then tagged with its location and automatically integrated into the analysis software via the cloud or a cable

Setting up a noise or vibration test can take a long time – far longer than the measurement itself. The person setting up must place each transducer, record its position and orientation, trace the cable to the data acquisition hardware, and then manually type the data into the right fields in the software. For every transducer. Not only is this process time consuming, but it is also complex and repetitive. This makes it ripe for accidental human errors, such as assigning the wrong transducer to the wrong channel, or entering an accelerometer's alignment incorrectly. Added together, small errors like these can waste days.

A new concept from Brüel & Kjær aims to simplify and automate the process, to speed it up while reducing errors. The Transducer Smart Setup concept uses a smartphone app. Testers simply scan a data matrix code on the side of the transducer, and the smartphone app retrieves the transducer's identity and calibration information. For accelerometer measurements, scanning the data matrix code also gives the essential degrees of freedom (DOF) alignment. And the app also works on transducers without the special data matrix codes.

Once the tester has cataloged all the transducers on a test object, the complete setup is uploaded to the cloud direct from the smartphone. It is then retrieved from the cloud by the PULSE Reflex analysis software platform. Here, the transducers are all automatically recognized and have all their necessary information automatically assigned to them. This avoids considerable time spent on manual input: with a modal test involving 40 accelerometers, this can save hours. Critically, the shortcut through the cloud removes the necessity of knowing which transducer's cable goes into which port. Testers can even unplug and plug them back into a different port, and the software figures out which one goes where. There is no need to trace one cable through a spaghetti-like mass.

But what about transducers without data matrix codes, such as older Brüel & Kjær transducers or ones from other manufacturers? Here, instead of recognizing a transducer from its data matrix code, the tester scrolls through the options in the app to select it from a list. The tester then adds alignment information (for accelerometers) by rotating an interactive diagram using a finger until it visually matches the correct accelerometer.

As well as making ad hoc testing setups simpler, the smart setup concept also helps with planned tests. Prior to the placement and integration of the transducers, the tester predefines the test in PULSE Reflex. Transducers without data matrix codes are normally added at this stage as well, but it only has to be done once – the software then remembers them forever. With the test setup defined in PULSE Reflex, instead of writing down the test setup and then setting up manually, the tester simply uploads the setup to the cloud – from where it is retrieved by the smartphone app.

So when it comes to the messy business of setting up, for example, an accelerometer on a tailplane, the tester simply scrolls through the smartphone app and selects that location from a list of options. It does not matter which transducer is used at which location; they are only paired when the tester sets up that particular transducer and not before. This automated matching between transducer and software removes opportunities for errors to creep in during setup, by automating as much as possible and limiting the choices for anything that can't be automated.

Overall, time is shaved off transducer setup procedures by reducing manual input tasks. For large, planned tests, the setup tasks that remain are moved earlier in the workflow, back to when the test setup is defined. Here, a single test engineer can perform more of the test definition on a single PC running PULSE Reflex, before even touching the test object. And once the test object becomes available, the team needs far less time with it before testing begins. \\

FIBER-OPTIC JOINT VALIDATION

Structural integrity is only as good as the joining methods used. Testing and validating these is solved with high-definition fiber-optic sensing

The introduction of composite materials in aircraft manufacturing has created challenges in the joining of complex assemblies. The methods for joining and inspecting metal-to-metal assemblies are well tested. These same processes for composites, which require a greater use of special bonding adhesives for joints, are less clearly understood.

At issue is not just a joint's integrity at the time of manufacture, but also its strength over the aircraft's service life. Adhesive selection, surface preparation, joint assembly and curing are all variables that impact the integrity and strength of adhesive joints used in aircraft production.

To address these complications, great progress is being made in refining joining methods and this is particularly true for joints using adhesives. In parallel with methodological advances is similarly rapid progress in the technologies used to validate joint strength and reliability. This is where high-definition fiber-optic sensing (HD-FOS) is poised to play a leading role. HD-FOS, with its ability to be embedded within joints and to provide measurements of strain in millimeter increments, is the ideal technology for characterizing and validating new adhesive-based joining methods.

The HD-FOS sensor is constructed using standard fiber-optic cable and comes in lengths from 1-50m. The sensor is bonded to a structure's surface similar to traditional electrical strain gauges and is flexible enough to be routed in a serpentine pattern to increase sensor coverage across the structure. In composite applications, the fiber-optic cable can actually be embedded within the structure.

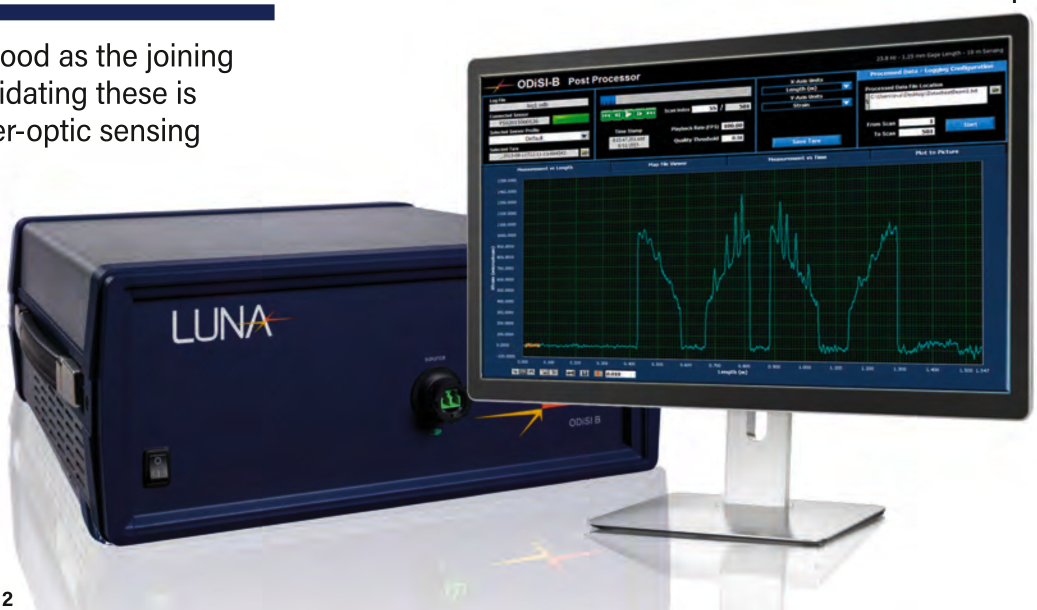
The fiber sensor comprises a series of densely spaced virtual strain gauges, whose gauge length and location are defined by the software in Luna's optical distributed sensor interrogator (ODiSI). The sensor can be configured to provide strain measurements every millimeter along the fiber. As the test progresses, gauge lengths and locations along the sensor can be virtually configured by changing software settings without physically changing the location of the HD-FOS fiber sensor.

University of Mississippi researchers embedded HD-FOS sensors in a double lap shear joint fabricated in accordance with ASTM D 3528-96. With the fibers embedded, the test article was gradually loaded in tension until reaching its failure point. Strain measurements were taken every 1.25 seconds in 1cm increments along the length of the embedded sensor. This test was repeated under identical conditions without the embedded sensor. Results demonstrated that embedded sensors had no impact on the strength of the joint under test. Data provided by the embedded HD-FOS sensors offers a complete characterization of the strain profile within the adhesive joint. Comparisons of test results to finite element analysis (FEA) predictions shows excellent correlation.

HD-FOS can also be used to validate the performance of adhesive joints used to bond dissimilar materials. Researchers at the Norwegian University of Science and Technology (NTNU) investigated the structural behavior of composite patch repairs applied to notched metal I-beams in a four-point bending test. The embedded sensors in the adhesive layer provided a view into the nonlinearities associated with debonding and crack growth at the metal notch even before these events were visually evident. In this case, HD-FOS measurements correlated well with FEA predictions in the linear region.

Luna's ODiSI, with high-definition fiber-optic sensing for strain, offers unprecedented visibility into the performance of adhesive joints for bonding composite structures and dissimilar materials. Events and material behavior are reported from the joint interface, the data provided by embedded fiber sensors is highly valuable and cannot be obtained by any other test technology. \\

1



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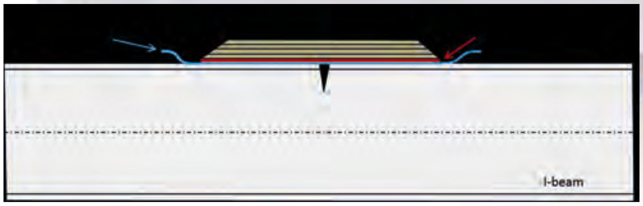


1 // Luna's ODiSI-B high-definition fiber interrogation system

2 // Schematic of fiber sensor embedded in adhesive joint of composite patch repair on notched I-beam

QUIETER AIRCRAFT CARRIERS

Identifying the causes and location of noise on a US Navy aircraft carrier was tackled with Siemens' LMS testing solutions

Noise is part and parcel of the working environment when your 'office' is a US Navy aircraft carrier. On the flight deck during take-off, the noise level can exceed 150dBA in many areas, but wearing hearing protection is not an optimal solution in the long term. LMS Testing Solutions helped facilitate the investigation into finding an efficient way to cut down noise levels in the entire vessel.

Aircraft noise permeates into the lower gallery decks, directly under the flight deck, where many crew members live and work. In this area, the sound levels go beyond the US Navy exposure limits of 85dBA. In many of the offices and cabins under the flight deck, noise levels can sometimes reach 105dBA during take-offs. The other issue is that these spaces are typically highly reverberant, making the situation worse. To reduce the noise successfully, it was important to understand what the dominant noise sources were and how acoustic energy flows from these sources into the ship compartments.

To achieve this, the US Navy partnered with Noise Control Engineering (NCE), specialists in noise and vibration measurement and control for marine applications. Jeffrey Komrower, senior engineer at NCE, opted for the LMS testing solutions to validate noise reduction techniques on the aircraft carrier USS Dwight D Eisenhower.

LMS SCADAS Mobile hardware data acquisition system, combined with LMS Test.Lab software from Siemens PLM Software, proved to be the ideal tool to perform high-level measurements on specific areas of the carrier. More than 100 channels of instrumentation, including microphones and accelerometers, were distributed throughout the flight and gallery decks to collect critical data for over 100 launches of jet aircraft.

Thanks to the ultra-compactness of the LMS SCADAS Mobile and its high-accuracy signal conditioning for a large number of acoustic and vibration channels, NCE was able to characterize the source levels straight from on-deck microphones and measure the resulting noise levels in the gallery deck spaces. Placing accelerometers on the flight deck underside and ship bulkheads also enabled measurements of transmitted vibration levels that could re-radiate as acoustic energy into the spaces.

All the data was post-processed and analyzed with LMS Test.Lab to validate the acoustic predictions performed with Designer-Noise, a software program designed by NCE to predict noise levels on surface ships.

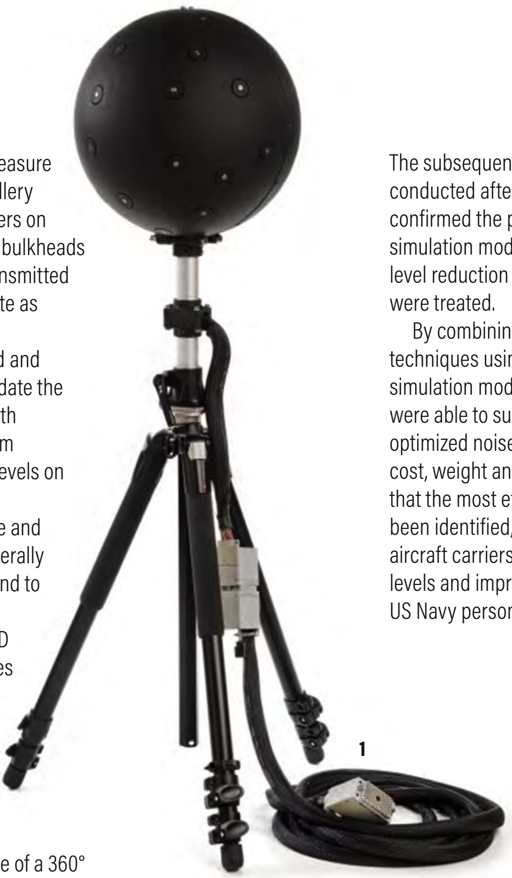
The numerous possible airborne and structure-borne paths make it generally difficult to identify the key cause and to develop an effective plan for noise control, but not when using LMS 3D Solid Sphere Array. The system uses a spherical beam-forming technique to indicate the path of the dominant noise sources and its 36 microphones are made to capture noise from all directions. The device has been built for quick and accurate capture of a 360° acoustic image of a room and helps users locate acoustic hot spots after just a few seconds of measuring.

Taking measurements with the LMS 3D Solid Sphere array enabled the US Navy to discover that the main noise source in the targeted sections was the radiation streaming from the vibrating structural bulkheads. The high acoustic energy released by the aircraft impinges on the flight deck and transmits through the ship structure, causing the bulkheads to vibrate. The high radiation efficiency of these structural bulkheads thus gives way to vibrational energy being transmitted to high acoustic energy in the compartments.

With this information at hand, NCE was able to take action and reduce the surface vibration – and thus effectively decrease the overall noise. The solution was to apply spray-on damping material on the structural bulkheads, which was lighter, easier and faster to apply than traditional damping tiles.

The subsequent set of measurements conducted after the damping was installed confirmed the predicted result from the simulation model. There was a 5-7dBA noise level reduction in the compartments that were treated.

By combining innovative experimental techniques using LMS testing solutions with simulation modeling, the US Navy and NCE were able to successfully develop an optimized noise-reduction plan in terms of cost, weight and treatment efficiency. Now that the most effective treatment solution has been identified, it will be applied to other aircraft carriers, helping further lower noise levels and improving the health and safety of US Navy personnel. \\



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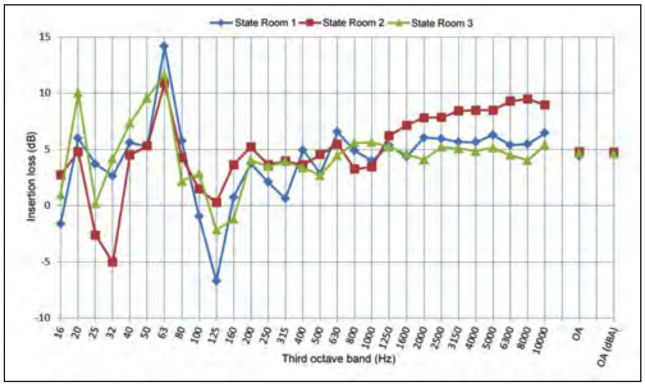

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1 // Siemens LMS 3D Solid Sphere array

2 // Graph of noise levels recorded in state rooms on the aircraft carrier

PIEZO SENSORS FOR ROCKET MOTORS

Combustion pressure testing is needed in any rocket program to ensure success. Without reliable testing equipment, rocket motor combustion instability can ruin your launch

1 // A selection of PCB Piezotronics' Integrated Circuit Piezoelectric sensors suitable for use in rocket motor testing

Rocket motor combustion instability caused by pressure fluctuations and acoustic resonances in the combustion chamber may reduce engine performance, induce structural vibration, and possibly lead to catastrophic failure through breakdown of the nozzle or other motor components. Even with modern computing power, it is difficult to model this instability in three dimensions during rocket motor design and it can be hard to eliminate.

Dynamic quartz piezoelectric pressure sensors assist design engineers in studying combustion instability problems. ICP (integrated circuit piezoelectric) pressure sensors are rugged, hermetically sealed and structured with acceleration-compensated quartz sensing elements that detect rapid pressure transients and pulsations. Quartz piezoelectric pressure sensors monitor dynamic pressure while subjected to high static background pressure.

Combustion instability is a combination of internal combustion and flow processes with natural acoustic resonances. Acoustic modes are primarily a function of combustor geometry. Unstable combustion occurs when pressure pulses are in phase with oscillations in heat release and resultant gas expansion. Liquid rocket motors are also affected by injector patterns, while solid motors may be impacted by something passing through the nozzle, such as unburned propellant or a sudden increase in burning surface area due to propellant voids in the fuel. Combustion instability leads to unsteady thrust, creating structural vibrations, an uncomfortable ride for astronauts or the payload, difficulty with guidance systems, and in extreme cases, catastrophic motor failure.

Test engineers can measure combustion instability problems with experimental analysis. Prior to the availability of solid-state quartz piezoelectric sensors, test facilities relied on strain gauges. The limits of this technology were temperature, resolution and lack of high-frequency response. The temperature problem was often solved with a standoff tube that moved the sensor away from where the operating temperature could be maintained. However, the tube itself is an acoustic resonator and is not very useful for the kilohertz bandwidth that is required to study instabilities.

Strain gauge technology needs to operate at or near full scale, which is typically up to 20-30mV output, but test engineers need to measure tiny pressure pulses of only a few percent of full scale. The chance of noise across long cable runs compounds the problem, since test cells are often large outdoor structures, with control rooms and signal conditioning electronics located far from the sensor, making small changes in pressure hard to detect.

Quartz ICP pressure sensors, structured with naturally piezoelectric, stable quartz sensing elements, are well suited to measuring rapidly changing pressure fluctuations over a wide amplitude and frequency range. The sensors are AC-coupled and designed to operate in very high static pressures. For example, a sensor rated for 1,000psi (69 bar) dynamic pressure has a maximum pressure rating of 5,000psi (345 bar) and a broadband resolution of 0.020psi (0.001 bar). Solid-state construction and hermetically sealed housings provide undistorted high-frequency response and durability, even in adverse environmental testing conditions.

The maximum operating temperature for quartz rocket motor sensors with ICP output is 250°F (121°C). However, rocket motors with long burn times can exceed this temperature in tens of milliseconds, so helium-bleed and water-cooled PCB Series 122, 123 and 124 sensors are designed expressly for measurement of combustion instability in rocket motor combustors.

The helium-bleed concept involves flowing cool helium around the body and diaphragm of the quartz transducer. This enveloping gas cools the transducer, insulates it against the hot combustion gases, fills the passage in front of the sensor, and greatly improves the frequency response of the connecting passage by a factor of three. Water cooling via an internal passage surrounding the sensing element gives maximum thermal stability and extends sensor operating temperature. Combined with a ceramic coating on the outer adapter for ablative purposes, water-cooling and helium-bleed ICP output pressure sensors can operate at extremely high temperatures in rocket motor combustion environments during long burning tests and high soak temperatures after shutdown.

Combustion instability due to acoustics in rocket motors is a common design problem that is not easily modeled. Water-cooled, helium-bleed quartz ICP pressure sensors detect rapid pressure transients, pulsations, turbulence, noise and spikes. The pressure sensors monitor dynamic pressure while subjected to high static background pressure. The ICP output features on-board electronics to provide conditioned output signal and ease of use. All these features assist in measuring very small dynamic pressure instabilities, enabling the test engineer to find the source and correct the design problem. \\

QUALITY FUEL NOZZLE AUDITS

A key requirement for aero-engine fuel nozzles is to pass a quality audit. During this testing, the spray produced by the fuel nozzle is examined to ensure that the spray pattern is acceptable and the drop size is within specified ranges.

In the past, the spray pattern was obtained using a mechanical patternator and the drop sizes were measured using diffraction instruments. However, mechanical patternators have very high measurement errors. In addition, for smaller flow rate nozzles, a quality audit using mechanical patternators is time consuming.

In the past few years En'Urga has developed an optical patternator that is currently used by several aero-engine nozzle manufacturers for the end-of-line quality audit. The optical patternator, SETscan, is based on a patented Statistical Extinction Tomography system.

The SETscan patternator can audit more than 1,000 nozzles during an eight-hour shift. Both the spray pattern and the surface areas of the drops are provided, eliminating the need for a separate drop size measurement. For very high flow-rate nozzles, x-rays are used instead of laser sheets so that obscuration problems are avoided. \\

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NEW A350 COOLING TEST STAND

As a specialist in creating innovative test systems, Test-Fuchs was selected to solve the challenge of designing an all-new and customized testing system for the new cooling systems of the Airbus A350. The unit, also usable on Airbus A380 and Boeing B787 aircraft, tests various air-conditioning components (to a low tolerance of 0.3°C) .

This system saves space and time by splitting the test system sections into two parts. Hydraulic and electrical supply systems are on the upper level; the lower part has elements needed by the operators to adapt the components and carry out the tests.

Operation is extremely user friendly – the horizontal position of the air stream can be changed with only one hand, to adapt to the different components quickly and easily.

The intelligent components of the A350 communicate with the test operator via a bus connection, providing real-time information from a wide range of systems as well as the component under test. The operator controls the tests from an adjustable desk, with four monitors for easy test surveillance. In this project Test-Fuchs met an extremely tight schedule, through its engineering expertise and many years of experience in project management. Next to safety, time has become a crucial issue in the world of testing. Other aircraft manufacturers have also shown interest in this system. \\

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UAV TESTING AT SEA

One of the latest projects for the Swedish Defence Materiel Administration Flight Test Centre (FMV FTC) was the first flight of a rotary wing UAV from a helipad of a Visby-class corvette. The project was a capability demonstration for the Swedish Armed Forces to see if it was possible to perform autonomous take-off and landing of this kind of UAV from a naval vessel.

FMV FTC was the design organization responsible on behalf of the UAV vendor and performed the test by incorporating the unmanned aircraft within its design organization approval (DOA). After reviewing the vendor's design process and its technical documentation, the necessary additional airworthiness testing was performed, that is, electromagnetic compatibility (EMC) and mandatory ground runs.

The next step was to draft the permit-to-fly application for the Swedish Military Flight Safety Directorate. FMV FTC also had full responsibility for the flight test management. This included defining and developing the test scope, drafting ground and flight test plans as well as test cards and, in the end, performing the actual flight trials, collecting flight test data and drafting the flight test report with recommendations.

Seven sorties were flown during the flight test campaign, including several autonomous take-offs and landings on a Visby-class corvette.

The flight test team includes experienced and well-trained experimental test pilots and flight test engineers, who provide a foundation for success. The organization offers its experience and expertise in support of customer needs, i.e. as project pilots, subject matter experts and test directors in customers' projects.

FMV FTC can also take full responsibility for your flight test activities and serve as your 'Flight Test Department' for as long as required. Its knowledge can be your expertise! \\

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WIRELESS CABLE TESTING

What works in manufacturing doesn't always work in the maintenance world. The DIT-MCO HT-128 handheld cable test system works in difficult environments such as field maintenance and *in situ* wire harness testing. The handheld tester has found acceptance in both fields because of its simplicity of operation.

The benefits of testing cables for opens and shorts is clear, but are frequently omitted in a maintenance program because of the difficulty of accessing test connections and linking cables back to the wiring test unit. Instead, technicians use meters and spend hours probing for bad connections. This is not only slow, but it's practically impossible to detect shorts between pins due to the large number of tests required to find the problem. The HT-128 solves these problems by incorporating the tester into a handheld device with wireless communication. When linked, the HT-128s provide full test coverage on multiple branched cables. There are no long test adapters and there is no bulky test equipment.

Each handheld unit provides 128 test points. Simply connect a short test adapter to the harness and start the test. The communication protocol allows the handheld unit to be separated up to 50m (160ft)

Battery powered, the HT-128 can be taken anywhere. MRO facilities love the ability to test without removing cables. Manufacturers love the flexibility it offers. In both cases, costly test adapters can be eliminated and throughput increased.

Using the HT-128 requires minimal training as it incorporates a familiar touchscreen interface. \\

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DIT-MCO

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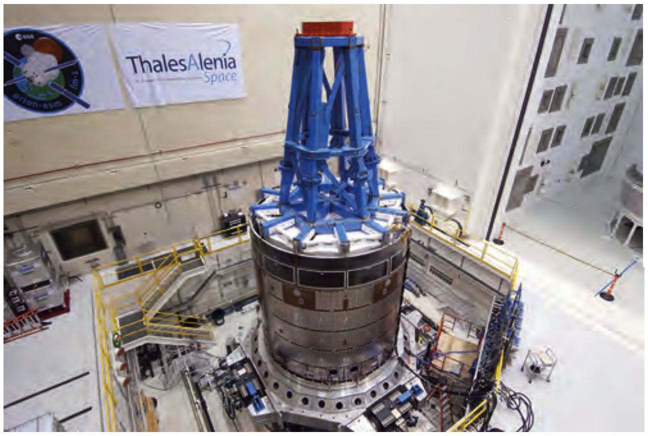
SPACECRAFT SHAKER

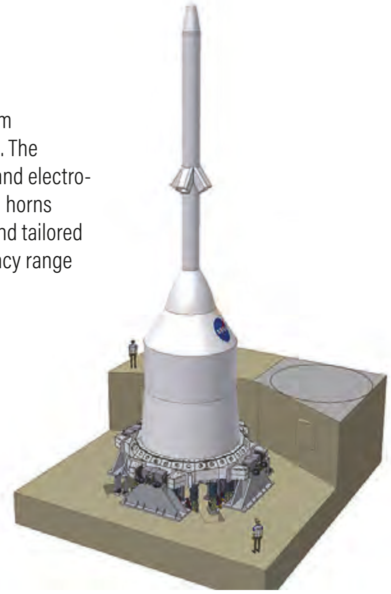
The combined efforts and technology of NVT Group partner companies Team Corporation and Data Physics has played a key role in supporting NASA's effort to upgrade the Space Power Facility (SPF) at NASA Glenn Research Center's Plum Brook facility in Cleveland, Ohio, in order to permit acoustic and vibration testing of larger spacecraft.

A Team Corporation three-axis, servohydraulic vibration system with 6-DOF is located in the vibroacoustic highbay at SPF, and is referred to as the Mechanical Vibration Facility (MVF). The original application of this system is limited to single axis excitation, however the response of the remaining 5-DOF are minimized by the off-axis actuators making it a full 6-DOF system.

This configuration allows for sequentially testing all three axes without removing or lifting the test article from the 6.7m (22 ft) aluminum table. The excitation force is generated by four horizontal and 16 vertical actuators and a Data Physics SignalStar Matrix multi-shaker controller provides control for the vibration test.

Located in the vibroacoustic highbay is the reverberant acoustic test facility (RATF) chamber. The RATF includes various supporting subsystems, including a horn room with 23 servohydraulic Team Corporation acoustic modulators. The combinations of servohydraulic and electro-pneumatic noise modulators and horns provides an extremely variable and tailored acoustic spectrum in the frequency range 25-10,000Hz. \\





AUTOMATED CALIBRATION

Conducting mechanical tests of aerospace structures can be a highly complex and potentially risky task. To mitigate risks and ensure the accuracy and integrity of testing results, regular calibration of test system electronics is critical. However, performing full end-to-end calibration on large structural test setups can be difficult and time-consuming, if not entirely impractical.

MTS metrology experts recently developed automated methods for performing partitioned calibrations on both FlexTest digital controllers and MTS FlexDAC 20 data acquisition units. Validated and supported via measurement uncertainty analysis, these automated calibration methods are designed to verify and document that the MTS controller or data acquisition units used in testing are operating within stated performance specifications.

There are numerous benefits of automated calibration compared with manual techniques. As the manufacturer of both FlexTest and MTS FlexDAC 20 products, only MTS can communicate directly to the hardware, enhancing calibration precision and efficiency.

Automated calibration eliminates the risk of introducing manual errors, and automated report generation ensures data integrity. Automated calibration also reduces system downtime. Calibrating a FlexTest controller now takes less than half the time than with manual methods and an MTS FlexDAC 20 unit can be calibrated in minutes rather than the hours previously needed.

Both automated calibration methods are performed on-site by trained MTS field service engineers, however customers with large numbers of MTS FlexDAC 20 units and/or limited-access facilities can purchase their own data acquisition calibration equipment.

MTS can show how automated calibration of its MTS FlexDAC 20 data acquisition and FlexTest controller units can enhance the efficiency of structural test processes and ensure the accuracy and traceability of critical test results. \\

PRECISE BOUNDARY LAYER MEASUREMENTS

While all industry sectors have challenges, aerospace testing can be one of the harshest, pushing microphones to their limits. Measurements often need to be taken in high speed, turbulent air flows where it is important that the microphone itself does not affect the quality of the measurements.

Boundary layer measurements are increasingly important, particularly in the aeronautical and automotive industries. Here there is an interest in separating the acoustic signal from the flow-induced turbulent noise.

Boundary layer theory dictates that measurements must be made exactly on the surface of the structure as the statistics of the flow deviate quickly with increasing distance from the boundary. Moreover, care must be taken not to alter the geometry of the structure as such an action may drastically change the flow.

G.R.A.S. provides a toolbox of methods for measuring in boundary layers. Depending on the parameters critical to the given measurement, an optimal solution exists for the application. \\

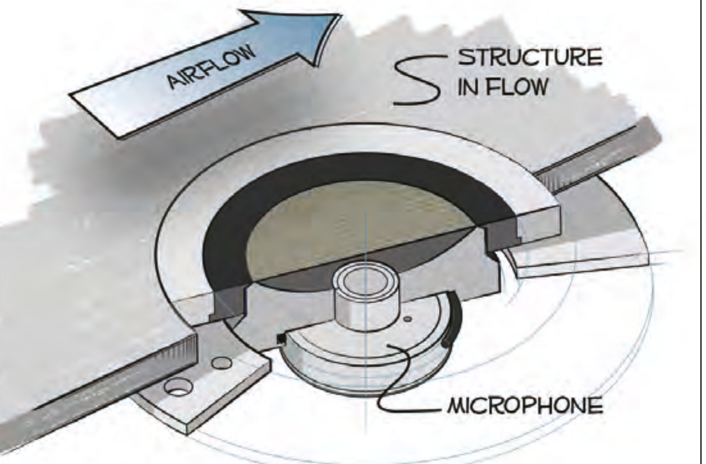


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Photo: The Helicopter Museum

The speediest Lynx ever

The helicopter speed record set 30 years ago by a modified Lynx aircraft still stands – and is not likely to be broken any time soon

The world speed record for a turbine helicopter – 400.87km/h (249.1mph) – was set 30 years ago on August 11, 1986, by a Westland Lynx (G-LYNX). The achievement is still recognized by the Fédération Aéronautique Internationale and no one has succeeded in going faster in a rotor-driven helicopter since. (The 293mph Eurocopter X3 is in a different class as it uses pusher propellers in addition to its rotor.)

On that day in August, chief test pilot John Trevor Egginton was joined by flight test engineer Derek Clews for the record attempt, which was conducted in four flights over the Somerset Levels in western England over a required 15km (9.3-mile) length course.

The first Lynx Westland WG.13 prototype (of 13 built) first flew on March 21, 1971. The Lynx became known as the world's first fully aerobatic helicopter as it could fly loops and rolls. G-LYNX (its commercial registration mark) made its first flight in May 1979.

For the test flight and speed record, the former company flight test helicopter was modified with two more powerful versions of the Rolls-Royce GEM 60 engines. Equipped with digital electronic fuel controls and water-methanol injection, each produced 1,345shp. The latter modification was credited with a 15% boost in power. Modified engine exhausts each provided an additional 600 lb of thrust. The rotors were replaced with British Experimental Rotor Program (BERP) blades, which approached supersonic speeds (Mach 0.97) during the flights while the aircraft's lift-to-drag ratio reached 2:1.

Further modifications to the helicopter to increase stability and unload the tail rotor included changing the horizontal tail plane and vertical fins to those from a Westland WG-30. Aerodynamic drag was reduced by removing external elements including windshield wipers, steps and antennas.

Great secrecy was needed as Westland was concerned that another company might beat it to the record. Over the test course the best two of four flights made were averaged to give the record speed.

Afterward, G-LYNX was used as a demonstrator and test flight aircraft until 1989. Now restored, it is displayed in the Helicopter Museum in the UK. \\

AUGUST 11, 1986
Record flight

WG.13
Model number

42FT/12.8M
Rotor diameter

50FT/15.2M
Length

249.1MPH
Top speed

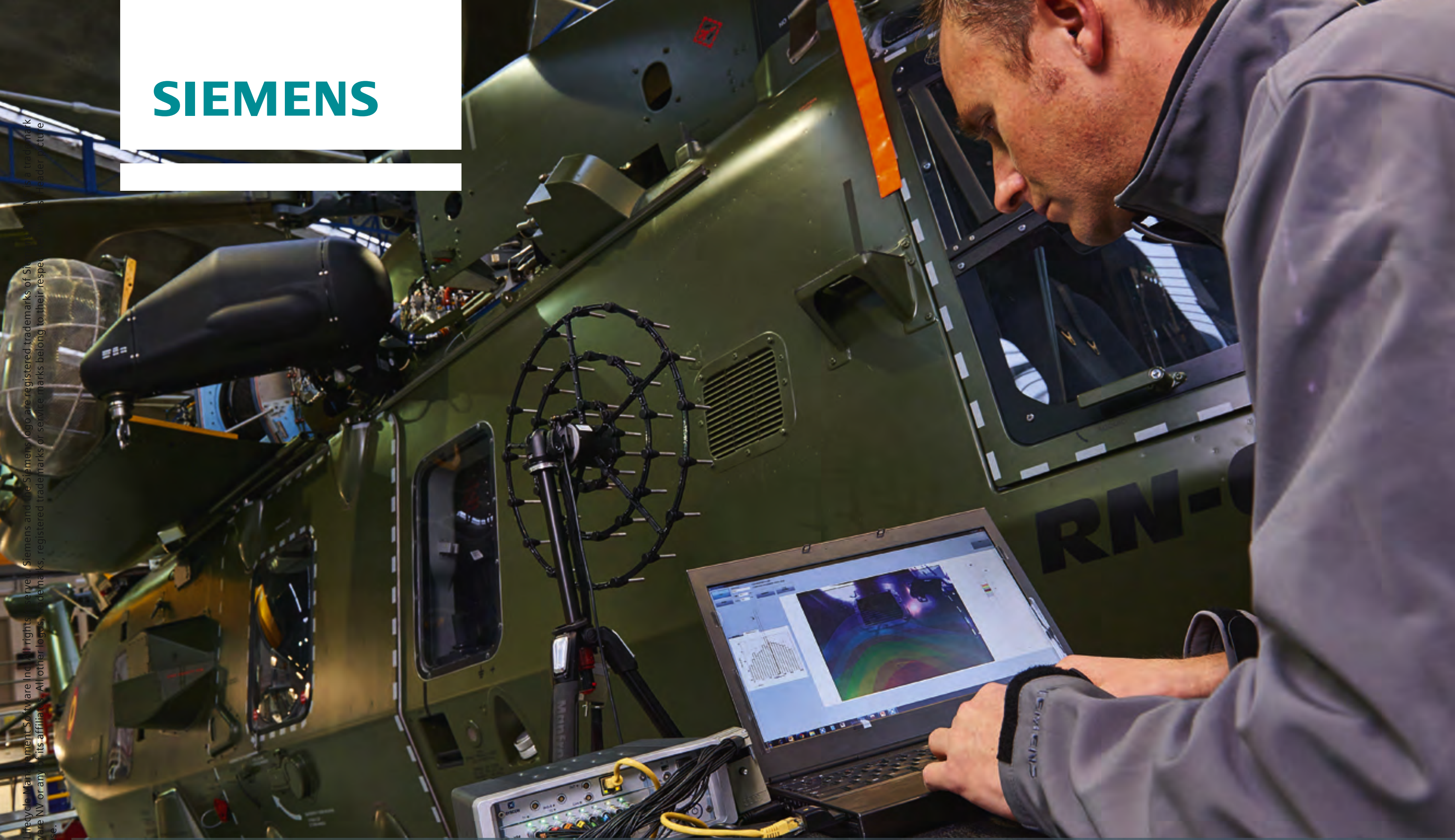
400.9KM/H
Top speed

15KM
Official course distance

500FT
Altitude flown

1,345 SHP
Power of each R-R GEM 60 engine

SIEMENS



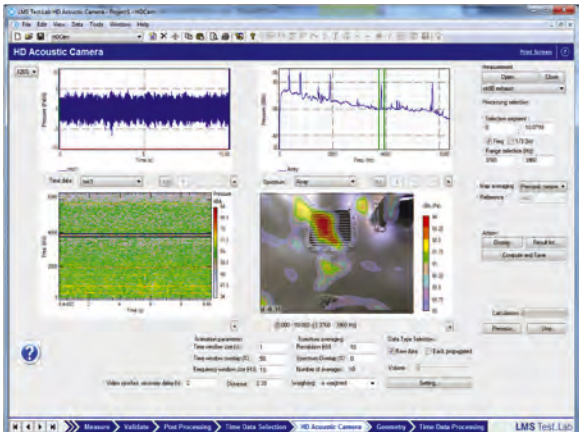
LMS testing solutions for aviation engineering.

First flight ready? You bet.

The days when noise and vibration tests were only about certification are long gone. Today, testing teams must harvest and feedback traceable and action-ready test data from all kinds of in-flight and lab-based campaigns. Their job is to perfectly perform complex tests under extreme deadlines, strict budgets and, most of the time, in tricky environments. Luckily, there are highly productive, application-specific LMS™ testing tools ready to jump right in.

Impressive speed and accuracy aside, LMS testing solutions for noise and vibration engineering from Siemens PLM Software provide real insight, transforming straightforward test data into solid engineering conclusions from design verification to final certification and troubleshooting. So whether your next project is a ground vibration, flutter, shimmy or complete acoustic testing campaign, the right scalable and efficient LMS testing solution is more than ready for you.

For more information, please visit **siemens.com/plm/lms**



Pinpoint sound sources in seconds by combining the LMS Test.Lab™ High Definition Acoustic Camera, the LMS Circular Irregular Array with 45 microphones, and a compact 48-channel LMS SCADAS™ Recorder.

Realize innovation.