AEROSPACE TESTING INTERNATIONAL

JUNE 2015

SOLAR IMPULSE 2

EXCLUSIVE: Mission flight director Raymond Clerc reveals how his team worked to provide capabilities for Si2 that far exceed those of its predecessor

DATA ACQUISITION

The specialists in telemetry rooms on the ground are vital in helping flight crews achieve specific test goals

BOEING 787

Chief test pilot Randy Neville reveals how his work influences engineering decisions across the 787 fleet

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You may have noticed in our last issue that we ran a feature entitled *Plugged-in Planes* (April 2015, p32), focusing on the move toward more-electric aircraft that offer better economics, greater reliability and, of course, a reduction in both air pollution and noise, written by the excellent Ian Goold.

And on the cover of this issue, we have decided to feature Solar Impulse 2, currently making global headlines for completing the longest leg of its around-the-world journey so far, between Japan and Hawaii, and setting a new endurance record for flight in the process. Our cover story looks at the incredible preparation undertaken by the pilots to condition themselves for such long periods in the cockpit, as well as the intricate planning undertaken by the support team behind the project.

As the article describes, the build-up to the around-the-world attempt included several thousand flights conducted in simulators, into which various meteorological parameters were introduced – weather being a primary constraint of the Solar Impulse project, given its need for solar power. The simulations extended to the physical aspects of the cockpit, to ensure the crew would be able to cope with the conditions on mission stages that would last for up to five days.

Hence the team's recent success should come as no surprise – every detail was meticulously planned in true flight testing fashion, which always aims to iron out any unexpected surprises. However, the journey to full electric, solar or hybrid aircraft remains a very long one indeed in terms of their development and full-scale testing. Depending on who you ask, estimates for a fully electric or hybrid commercial passenger aircraft range from 'decades' to 'never' – Airbus has stated its goal is to fly regional airplanes with hybrid engines by 2030, while certain jet engine manufacturers remain skeptical of the whole idea when applied to long-haul flight.

But that's not to say that work isn't already well underway – the major OEMs are working closely with universities and technology partners on various projects across the globe. In fact, Airbus Group Innovations' revolutionary E-Fan aircraft will shortly demonstrate the potential of electric aviation by becoming the first electric-powered aircraft to cross the English Channel. This historic flight – which is planned for July 10 from Lydd, UK, to Calais, France – will take place in the reverse direction of Louis Blériot's landmark crossing on July 25, 1909, with a Blériot XI aircraft.

Meanwhile, researchers from the UK's University of Cambridge, in association with Boeing, have successfully tested the first aircraft to be powered by a parallel hybrid-electric propulsion system, where an electric motor and petrol engine work together to drive the propeller. A test flight at the end of 2014 saw a demonstrator aircraft use up to 30% less fuel than a comparable airplane with a petrol-only engine. The aircraft was also able to recharge its batteries in flight, the first time this has been achieved.

In recognition of the pioneering spirit, scientific inquiry and testing tenacity required to realize the dream of electric and hybrid flight, UKIP Media & Events Limited, the publisher of *Aerospace Testing International* magazine, has launched a conference dedicated to this exciting subject in a bid to bring the world's leading experts together in one place to help speed development and unlock innovation.

The Electric & Hybrid Aerospace Technology Symposium, which takes place on November 17-18, 2015, in Bremen, Germany, 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, as well as pursuing the possibility of pure-electric-only commercial flight.

With key speakers from NASA, Rolls-Royce, Airbus, plus many other leading industry players and academics, the two-day event will cover all aspects of aerospace activity, from commercial aviation to military applications, its purpose being to highlight the ever-growing amount of research into the increased electrification of aircraft and the possibilities and challenges that brings.

As a resident of a village only 10 or so miles from a major airport, I have to say I'm absolutely ready to embrace the age of gleaming, silver flying machines that are near silent and run on completely 'clean' energy. I understand that their arrival may be some way off, but I can't help but believe that they will nevertheless one day grace our skies, ushering in a new era of aviation with a completely clear conscience.

Pure fantasy? Wishful thinking? Perhaps. But the aerospace industry has a habit of proving its doubters wrong – and we very much look forward to welcoming any equally optimistic readers to the Electric & Hybrid Aerospace Technology Symposium this November.

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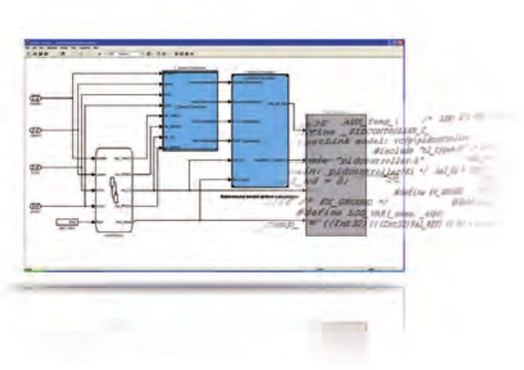

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WORLD TEST UPDATE

1 TURBOMECA AND HAL JV

A memorandum of understanding to establish a joint venture to support customers in India and other countries has been signed by Turbomeca (Safran) and Hindustan Aeronautics (HAL). The arrangement will provide MRO for Turbomeca and HAL TM333 and Shakti engines installed on HAL-produced helicopters. With more than 1,000 engines, India's armed forces are the largest operators of Turbomeca-designed engines in the country. Shakti is the Indian designation of the Turbomeca Ardiden 1, which was co-developed with HAL and produced under license.

Bangalore, India

2 CERTIFIABLE PREDATOR B COMPLETES CDR

A significant milestone has been reached by General Atomics Aeronautical Systems in its independent R&D program to design, develop and produce a variant of the Predator B RPA to be certified for flight according to the NATO airworthiness standard for unmanned aircraft. Certifiable Predator B (CPB) has completed a successful internal Phase 1 Critical Design Review, along with reviews by two prospective European customers. Certification-compliant wings and redesigned tails will complete flight testing on a company-owned Predator B aircraft in late 2015.

San Diego, California

3 DEFENSE SHIELD ANTI-MISSILE SYSTEM TRIAL

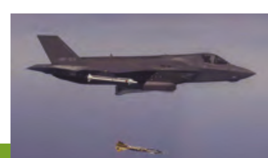
According to the Russian defense ministry, it has successfully test-fired a short-range anti-missile system. This comes after Pentagon officials said that the USA was considering deploying missiles in Europe to counter potential threats from Russia. "The launch was aimed at confirming the performance characteristics of missile defense shield anti-missiles operational in the Aerospace Defence Forces," the defense ministry said, according to Russia's TASS news agency.

Moscow, Russia

4 AIRBUS HELICOPTERS' H160 FLIGHT TRIAL INITIATED

Airbus Helicopters' H160 flew for the first time on June 13, 2015, in Marignane, France. It flew for about 40 minutes in ground effect mode, enabling the test team to check the overall behavior of the aircraft and to verify the measurements. To ensure the H160's entry into service in 2018, Airbus Helicopters is using three prototypes and two helicopter zero integration test means. The first prototype will pursue its flight test campaign, including its first hot weather flight tests this summer; the second prototype performed its first power-on test on June 2.

Marignane, France



5 757 ECODEMONSTRATOR OFFERS GREEN BOOST

The Boeing ecoDemonstrator completed its first flight with 'green diesel' along with two new environment-related technologies when it flew from Seattle, Washington, to NASA's Langley Research Center in Hampton, Virginia, on June 17, using a blend of 95% petroleum jet fuel and 5% sustainable green diesel, a biofuel used in ground transportation. The developments have advanced the ecoDemonstrator program's mission to accelerate the testing and use of technologies to improve environmental performance in the air.

Seattle, Washington

6 F-35B COMPLETES RELEASE OF PAVEWAY IV

The F-35 Lightning II program made aviation history as Royal Air Force (RAF) test pilot Squadron Leader Andy Edgell released two inert 500 lb dual-mode Paveway IV precision-guided bombs from aircraft BF-03 over the Atlantic Test Ranges. The inaugural weapons separation test of the Paveway IV, conducted by the F-35 Lightning II Integrated Test Force, was a milestone for the Royal Navy and RAF F-35 program.

Atlantic Test Range, East Coast, USA

7 ROCKET TESTS MARK STEP FORWARD

China has successfully tested a component for its largest rocket that will be used to put its planned modular space station into orbit. The China Aerospace Science and Technology Corporation recently performed a fairing separation test for the Long March 5B, the heaviest lifting version of the Long March 5 series, capable of lifting a 25 metric ton payload to low Earth orbit. The core module set is for launch in 2018, and completion of the 60 metric ton station is expected by around 2022.

Tianjin, China

8 FIRST LARGE UAS IN FAA TEST SITE

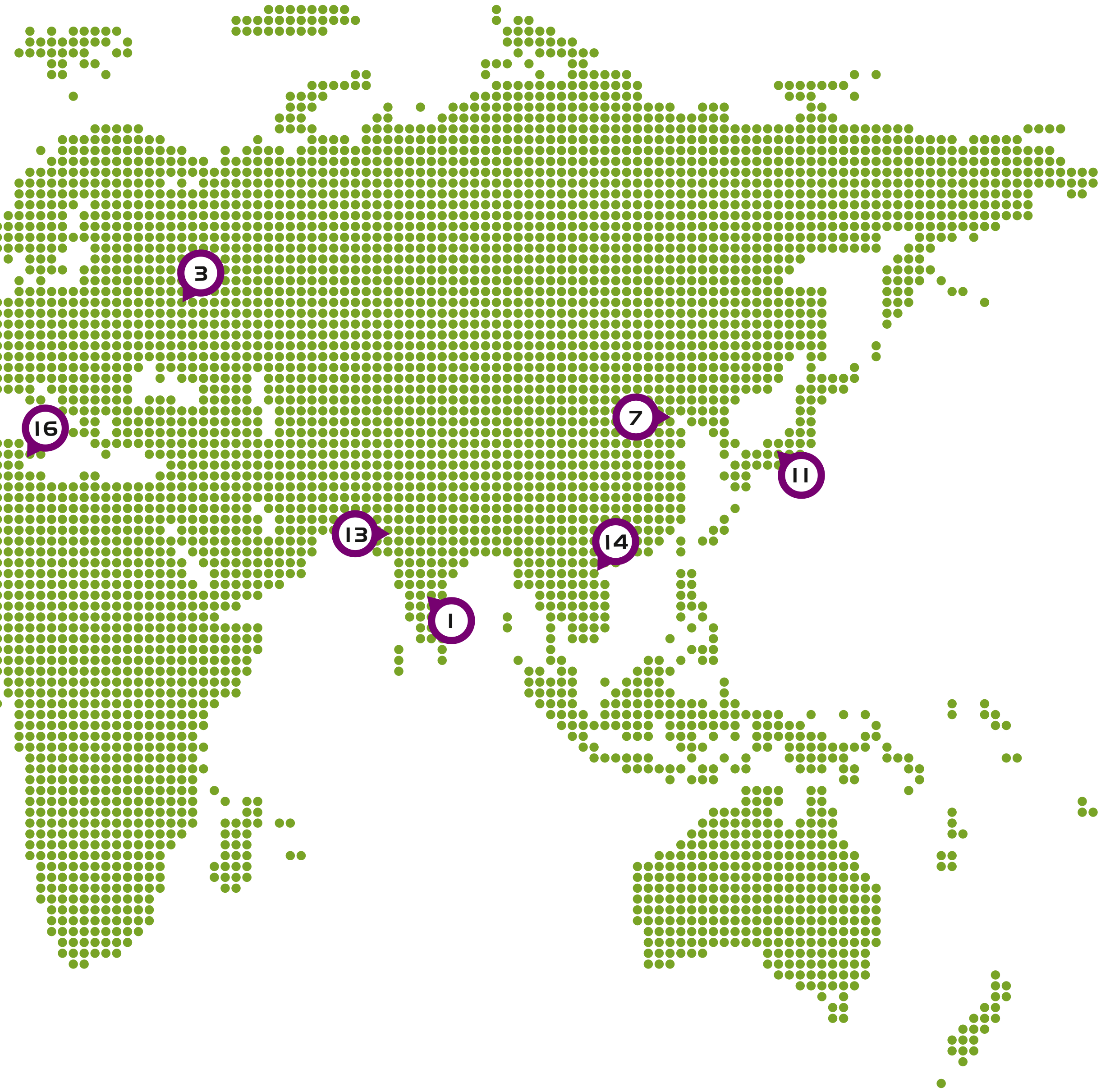
The Centaur optionally piloted aircraft from Aurora Flight Sciences has flown multiple unmanned flights from Griffiss International Airport in Rome, New York. The successful test flights were conducted in full collaboration and compliance with Oneida County's Griffiss UAS Test Site, which is managed by Northeast UAS Airspace Integration Research Alliance. The flights marked the first time any large-scale, fixed-wing aircraft has flown at either of six FAA-designated unmanned aircraft test sites in the USA.

Rome, New York

9 NASA LDSD MAKES SECOND FLIGHT

Engineers are poring over the data following the second experimental landing technology test of NASA's Low-density Supersonic Decelerator (LDSD) project. The saucer-shaped LDSD craft splashed down in the Pacific Ocean off the west coast of the Hawaiian island of Kauai. During this flight, the project team tested two decelerator technologies that could enable larger payloads to land safely on the surface of Mars, and allow access to more of the planet's surface by assisting landings at higher-altitude sites.

Kauai, Hawaii



15 E-2D PROGRAM MOVES HAWKEYE CLOSER TO AERIAL REFUELING

Advanced Hawkeye is closer to reality after the US Navy successfully conducted a critical design review of its AR capability. The review paves the way for installing AR capabilities aboard the E-2D AHE for flight testing; it is expected to reach initial operational capability in FY2020. This key review brings the program closer to manufacturing the AR system for installation on new E-2D AHEs on the production line and for retrofit of E-2D AHEs already in operational use.

Patuxent River, Maryland, USA

16 AIRBUS MAINTENANCE TRAINING PARTNERSHIP

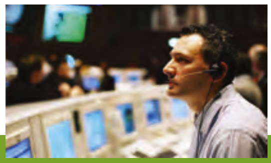
An A320 and A330 maintenance training services partnership has been established in Tunisia. Tunisair Group will acquire Airbus training tools and teaching techniques standards to provide OEM-backed maintenance training capabilities for its personnel and for other A320 and A330 operators in the region. The collaboration will offer unequaled technology training media and courseware in accordance with EASA/Part-147 requirements – the Airbus Competence Training.

Tunis, Tunisia

17 EMBRAER AND BOEING ANNOUNCE ECO-PARTNERSHIP

A collaboration to test environment-focused technologies through the ecoDemonstrator Program in a joint effort to improve aviation's environmental performance has been announced between Embraer and Boeing. This expands ongoing cooperation between two of the world's largest airplane manufacturers. Through their collaboration, Boeing and Embraer are planning to conduct ecoDemonstrator tests with an Embraer airplane in 2016.

São Paulo, Brazil



10 NEXT-GEN MISSION CONTROL SOFTWARE

Together with national space agencies and industry, ESA is working to develop next-gen software for spacecraft control and monitoring. The initiative will see most space organizations in Europe adopting a common infrastructure, which will improve efficiency, lower technical risk, and boost industrial competitiveness in Europe. Space agencies, spacecraft operators and manufacturers in Europe have agreed to adopt a common software infrastructure to control satellites during all phases of their missions, including pre-launch testing.

Paris, France

11 MRJ STARTS LOW-SPEED TAXIING TESTS

Mitsubishi Aircraft Corporation undertook low-speed taxiing tests with the first flight test aircraft of the MRJ (Mitsubishi Regional Jet), their next-generation regional jet, at Nagoya Airport in June. The taxiing tests were performed to confirm braking at low speeds and direction control steering. The MRJ is a family of 70- to 90-seat next-generation regional jets, which has received over 400 orders (223 firm). The first flight is scheduled for September or October of this year.

Nagoya, Japan

12 FIRST F-35B SKI-JUMP LAUNCH SUCCESS

UK'S BAE Systems test Pilot Pete 'Wizzer' Wilson became the first pilot to launch the F-35B short take-off and vertical landing variant from a ski jump. The launch took place at Naval Air Station Patuxent River in Maryland, USA, from a land-based ski jump and marks the start of an initial testing phase expected to last two weeks. The trials demonstrate the aircraft's ability to take off safely and effectively from a ski jump ramp similar to that which will be used on the UK's latest aircraft carrier.

Patuxent River, Maryland

13 COMBAT HELICOPTER IN HOT WEATHER TRIAL

The light combat helicopter (LCH) developed by Hindustan Aeronautics has attained a milestone by successfully completing hot weather flight trials. Test flights were carried out in the temperature range of 39-42°C. The flight testing covered: temperature survey of engine bay and hydraulic system, assessment of performance, handling qualities and loads at different 'all up weights', low-speed handling, and height-velocity diagram establishment.

Jodhpur, India

14 LATEST A350 XWB GOES TO VIETNAM

Vietnam Airlines has become the second airline in the world to operate the A350 XWB. The A350-900 aircraft was delivered to global lessor AerCap on lease to the airline for operation on long-haul routes. Altogether, Vietnam Airlines is set to acquire 14 A350 XWBs, including 10 ordered from Airbus and four from lessors. Vietnam Airlines' new A350 XWB will join an existing Airbus fleet of 59 aircraft, comprising 49 A321s and 10 A330s.

Hanoi, Vietnam

F-35B WEAPONS TESTING MAKES AVIATION HISTORY

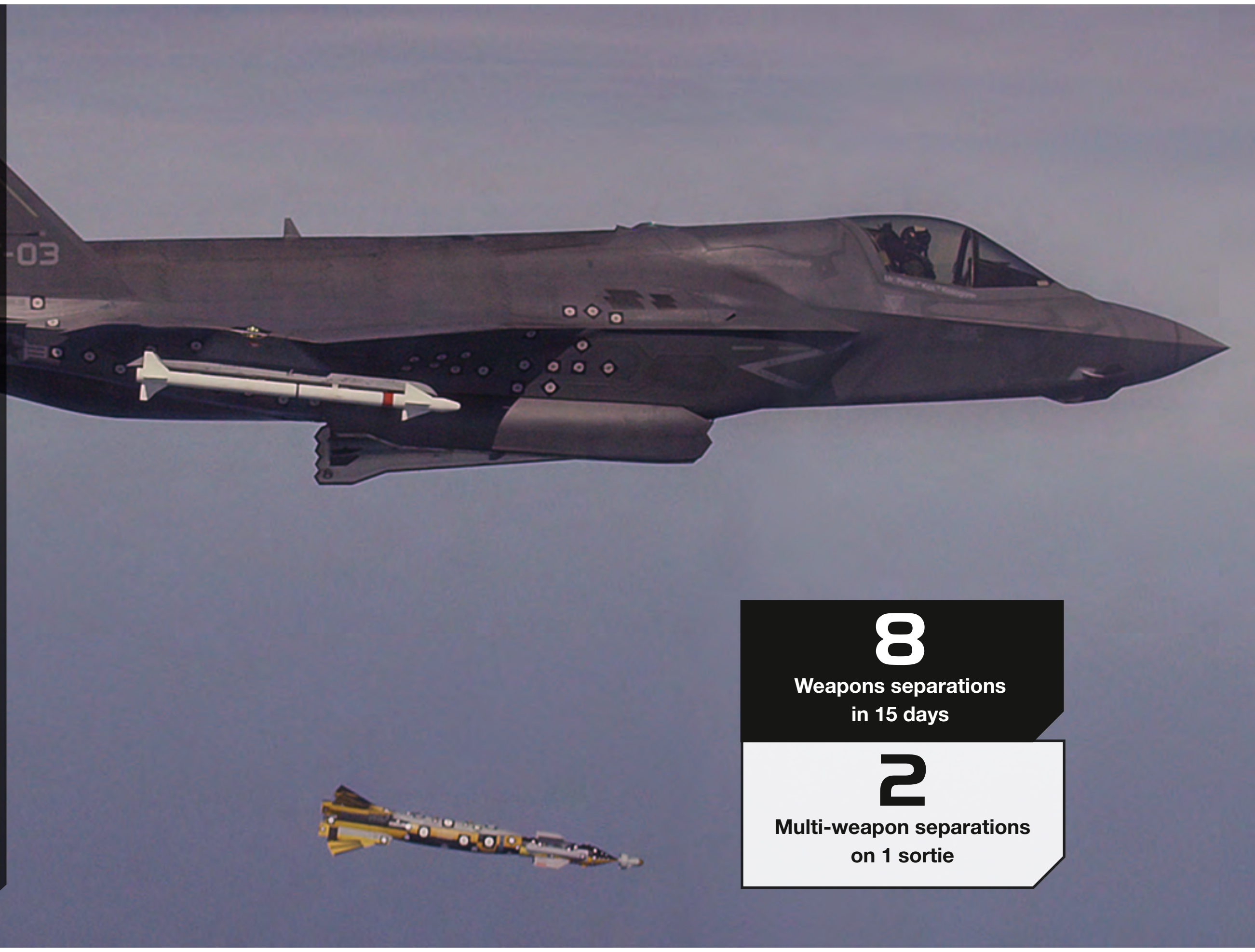
The F-35 Lightning II Patuxent River Integrated Test Force (ITF), based at Naval Air Station Patuxent River in Maryland, USA, is currently executing a series of F-35B weapons separation events over the Atlantic Test Ranges in order to expand the number of stations supporting employment of the dual-mode Paveway IV precision-guided bomb, AMRAAM/AIM-120, GBU-12 and GBU-32 JDAM. These tests verify that the weapons separate from the aircraft without interfering with any structure or demonstrating undesirable characteristics when they enter the airstream.

Initial 2B testing cleared AMRAAM/AIM-120 carriage on two internal stations and now the F-35B multirole short take-off and vertical landing (STOVL) variant is proceeding into the 3F phase of testing to clear carriage and employment of AMRAAM on all four of the internal stations. On June 8, aircraft BF-03 launched the first AMRAAM/AIM-120 from station 4. The separation resulted in a safe separation and motor fire of the missile.

The F-35 Lightning II program also made aviation history on June 12 as Royal Air Force (RAF) Test Pilot Squadron Leader Andy Edgell released two inert 500 lb dual-mode Paveway IV precision-guided bombs from aircraft BF-03. The two individual separations of the Paveway IV – conducted during a single sortie – represent the first UK weapons separations for the F-35 program and begin the process of clearing the employment of the Paveway IV for use by the UK's armed forces. During the test, the inert Paveway IV bombs safely separated from an internal weapons bay, thereby maintaining the stealth characteristics of the aircraft and furthering the collaborative approach of the USA and the UK

F-35B SPECIFICATIONS

- Primary function: Air dominance, multi-role fighter
- Fuel capacity (internal): 18,250 lb (8,278kg)
- Contractor: Lockheed Martin
- Weapons payload: 15,000 lb (6,800kg)
- Wingspan: 35ft (10.7m)
- Length: 51.2ft (15.6m)
- Speed: Mach 1.6 (~1,200mph)
- Height: 14.3ft (4.36m)
- Range: 900 nautical miles (1,667km)
- Weight (empty): 32,300 lb (14,651kg)



8
Weapons separations in 15 days

2
Multi-weapon separations on 1 sortie

in the development of the F-35 Lightning II.

This inaugural weapons separation test of the Paveway IV was a major milestone for the UK Royal Navy and RAF F-35 program. The test brought together the STOVL variant of the F-35 fifth-generation stealth fighter and the Paveway IV – an advanced weapon that equips the Royal Navy and the RAF with a state-of-the-art, all-weather laser-guided and inertial navigation/GPS-guided bombing capability, the first dual-mode bomb operational on the F-35 Lightning II.

On June 13, aircraft BF-03 executed a separation of an AMRAAM/AIM-120 instrumented mass simulation vehicle (IMSV) from station 4 during a pushover (a less than 1.0*g* maneuver). The team successfully executed the release and the separation continues to expand the AMRAAM/AIM-120 employment envelope for the F-35B.

Additional weapons separation testing during the third week of June featured three AMRAAM/AIM-120 separations, a GBU-12 laser-guided separation and a GBU-32 JDAM separation. The team executed one of the AMRAAM/AIM-120 separations and both the GBU-12 and GBU-32 separations with the F-35B external gun pod installed. These events will complete the planned F-35B separation testing of the GBU-12 and GBU-32 JDAM.

By June 23, the F-35 Lightning II Pax River ITF joint team, assigned to the Air Test and Evaluation Squadron (VX) 23 aboard Naval Air Station Patuxent River, had conducted eight weapons separations in 15 days. The team twice conducted multi-weapons separations during one sortie. By the last week in June, the team had conducted nine weapons separations.

The F-35 Lightning II is a single-seat, single-engine, stealthy strike fighter that incorporates low-observable (stealth) technologies, defensive avionics, advanced sensor fusion, internal and external weapons, and an advanced prognostic maintenance capability to deliver optimum international security via integrated coalition operations. Partner nations include the UK, Italy, the Netherlands, Turkey, Canada, Australia, Denmark and Norway. There are also three foreign military sales countries – Japan, Israel and South Korea.

The primary role of the F-35B STOVL aircraft is ground attack, with a secondary air-to-air role. The aircraft is powered by a single main engine with a vertically mounted, shaft-driven lift fan propulsion system.

The F-35A conventional take-off and landing (CTOL) variant will be a multi-role, stealthy strike aircraft replacement for the US Air Force's F-16 Falcon and the A-10 Thunderbolt II aircraft, complementing the F-22A Raptor. The F-35B STOVL variant will be a multi-role stealthy strike aircraft to replace the US Marine Corps' F/A-18C/D Hornet and AV-8B Harrier aircraft. The carrier-suitable variant, the F-35C, will provide the US Department of the Navy with a multi-role, stealthy strike aircraft to complement the F/A-18 E/F Super Hornet. Lockheed Martin is the aircraft contractor and Pratt & Whitney is the engine contractor.

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ENSTROM'S DERIVATIVE TH180 TRAINER

Enstrom Helicopter Corporation, located on the Michigan Upper Peninsula, USA, flew its TH180 reciprocating engine training helicopter for the first time in February and expects to add a second aircraft to the test program this summer. Bill Taylor, Enstrom experimental test pilot, senior technical fellow, and TH180 co-program manager, explained, "One is primarily for ground and endurance tests of the engine and drive system. The other is for flight test, performance handling, etc."

The TH180 is to be Type Certificated in 2016 by the FAA, EASA and Transport Canada simultaneously, and the flight test envelope will be a subset of established Enstrom Model 280FX performance. "It's a trainer, so we're more concerned about handling qualities and taking abuse than making cruise airspeed and hover points… That means autorotation characteristics, the way it responds to power changes and turbulence, the way it responds to unanticipated control inputs."

The two-seat TH180 uses the proven rotor system and drivetrain of the three-seat turbocharged 280FX Type Certificated in 1985. The new helicopter combines a smaller, lighter airframe with a 210hp, normally aspirated Lycoming HIO-390 engine and heavy-duty landing gear for the training role. "We're trying to make a more economical aircraft, so we've reduced the power and eliminated the turbocharger," said Taylor. "One of the systems we're adding to this is a governor – we want it to maintain rotor and engine RPM so it will reduce the workload on the student." Significantly for training operations, the governor can be disengaged to make the pilot maintain RPM manually.

Orlando Alaniz, Enstrom director of sales and the TH180 co-program manager, added, "It's a derivative of the 280. We've got a known baseline of what it costs to run the 280… We're comfortable that we're going to have a low DOC [direct operating cost] aircraft. We know what the rotor system is. We know what the cabin is. The unknowns are relatively small." The new trainer will be certificated with electromechanical flight instruments, a JPI engine display, and a simple Garmin avionics suite, soon to be upgraded to a full 'glass cockpit' with integrated flight, navigation and communications displays. "We're talking to training schools," said Alaniz. "We're getting customer input to define a configuration that will be of benefit to them."

100

Enstrom's revamped production plant in Menominee, Michigan, will be able to build 100 TH180s per year

1,021

TH180 maximum gross weight is targeted at 1,021kg (2,250 lb), about 227kg (500 lb) less than the F280FX

400,000

Although no official price has been set yet, it is expected that the TH180 will sell for less than US$400,000

The first TH180 underwent tie-down trials before first flight. "We're modifying a fairly established airframe," noted Taylor. "That was to ensure we can pull power and things will hold together. We're relying on the strain data from the F28F model, so any strain data we take for this program will be limited. If we see something structural that we want to look at more closely, we'll develop ground fixtures at that time. We don't anticipate that, but it's always an option." The first test vehicle will continue to serve as a ground endurance engine test article for certification.

TH180 exterior changes, meanwhile, demand that all handling qualities tests done for the 280FX be repeated. The flight test vehicle will have a full instrumentation suite including a National Instruments CompactRIO data acquisition system. Taylor observed, "It's a pretty standard package, all of the controls, all the engine parameters including temperatures, airspeed and altitude, aircraft attitudes and pitch, roll and yaw rates. We do not have telemetry capability, so it all gets recorded and reduced after the flight. We have all that capability right here. We do the flying near the plant. One of the nice things about Menominee, Michigan, is it's fairly sparsely populated, so flight testing is not a problem."

Current plans call for a second test pilot to join the TH180 program. Taylor is an FAA designated engineering representative (DER). "We don't need that a DER pilot for the development," he explained. "I'm an engineering test pilot." The first TH180 was flown briefly without its aft fuselage covering and is currently in the hangar for modifications. "We're adding some parts and putting the aircraft into conformed configuration status," said Alaniz. "It's in our plant. Right now we've had to continue using our existing facility in our experimental hangar. We plan to expand our facilities for future product development programs."

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GARNET RIDGWAY

RECOVERY POSITION

The aerospace testing community has recently experienced a number of catastrophic, loss-of-platform accidents. Naturally, the short-term response is to seek answers in support of safe return-to-flight. What do such incidents mean for the long-term success of the program?

SOPHIE ROBINSON

When analyzing historical examples of aerospace testing/early-service disasters, there is certainly no shortage of data. Perhaps the most famous example is that of the de Havilland Comet, the world's first operational jet airliner. Despite being a product of some of the finest engineering minds of the time, five aircraft were lost within its first four years of service, resulting in 110 fatalities.

Clearly, a catastrophic event will cause a delay in the program while answers are sought and rectifying action taken. However, it should be noted that competitors, while not necessarily consciously seeking to benefit from the misfortune of others, may well gain an advantage that would otherwise not have existed. Indeed, Boeing's ability to learn from the Comet incidents is widely credited as being a key factor in the success of the 707. For programs of national importance, this can have massive political implications, as understood by Winston Churchill when commenting, "The cost of solving the Comet mystery must be reckoned neither in money nor in manpower." Indeed, the cost was ultimately to be the decline of the UK's position as an independent producer of large civil aircraft, and a corresponding shift to the USA.

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

A catastrophic incident during the development of an aircraft can also have a long-term impact on the technical direction of a program. There can be a tendency to shy away from the more innovative aspects of the design, even if it transpires that they were not related to the incident. For example, the main contributory factor to the 'Comet mystery' was the square cabin windows – a design feature inherited from pre-jet, unpressurized airliners. In spite of this, 60 unrelated modifications were made during the redesign process, many of which reverted novel features to more conservative designs. This was often done at the cost of additional mass, resulting in a reduction in performance and capability to compound the previously discussed loss of competitive advantage. In the case of the Comet, by the time the lost capability was unlocked in the much-improved Mk4, Boeing had already gained an unassailable advantage with the 707. The aircraft that should have ushered in the jet age instead became a footnote in history.

This column has focused on a single example, but it is evident that such events can be found throughout history. To those who say that catastrophic incidents in testing are irrelevant in the long term, a question: How do you measure the success of your product – against its competitors at the time, or against its rightful place in aviation history?

While aircraft like the Comet suffered, and ultimately failed, as a result of a catastrophic accident, other platforms have fared better. It is possible to overcome, and even to prosper, after disaster strikes.

Prior to entering UK military service in 1999, the Merlin helicopter suffered three serious accidents, two of which resulted in complete loss of aircraft and loss of life. At the time of the first accident, the high cost of the program, and questions about the rationale behind the procurement of a multirole aircraft, prompted politicians to press the UK government into holding a public inquiry into the program. The Merlin risked being ousted by a competitor, such as the Sikorsky Seahawk, or being replaced by an upgrade program for the existing fleet of aging Sea Kings. Luckily, things had changed since the time of the Comet, and with nothing able to compete with the capability offered by the new Merlin helicopter, the program survived. The aircraft has gone on to become an important asset for the air forces and navies of 11 countries around the world.

While capability is often the savior in the military world, perceived safety is always the priority in the civilian world.

So how do aircraft manufacturers and airline operators recover when they encounter incidents during testing or, perhaps more devastatingly, during operations? Some don't recover; Malaysia Airlines reportedly suffered losses of US$140m after the loss of Flight MH370 and the shooting down of Flight MH17 over the Ukraine in 2014, and it seems it will take more than a tweak of the company logo or a redesigned livery to save the brand. Yet others, like Virgin Galactic, seem to survive, not totally unscathed, but still with heads above water.

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

In the immediate aftermath of the Virgin Galactic crash in October 2014, founder Richard Branson was incredibly vocal in his response to the disaster. He was widely praised for responding quickly to the crash, setting a tone that indicated he was serious about finding the cause by traveling to the crash site and discussing the progress of the investigation openly with the media. This helped to limit speculation surrounding the cause of the crash, and limit reputational damage to the company.

While not all aircraft can, or indeed should, recover from catastrophes in testing, with careful management of the media and demonstrable superior capability, it is not an insurmountable task.

André Borschberg completes a yoga routine in the cockpit of Solar Impulse 2 during tests in 2014 (Photo: Solar Impulse/ Pizzolante)

Close quarters

Raymond Clerc, mission flight director for Solar Impulse 2, speaks exclusively to *Aerospace Testing International* about the work that went into proving the human factors critical to the success of this groundbreaking project

BY THOMAS NEWDICK

As reported in the April issue of *Aerospace Testing International*, pilots Bertrand Piccard and André Borschberg are currently embarked on an attempt at the first around-the-world flight under solar power in the Solar Impulse 2 aircraft. For the project team, Solar Impulse 2 (Si2) is a 'flying laboratory' intended to use a series of state-of-the-art technologies provided by and developed in cooperation with industrial partners. At the heart of the Si2 project is the effort to provide an aircraft with capabilities far in advance of the earlier Solar Impulse 1 (Si1), first flown in 2010. Mission flight director, Raymond Clerc identifies three key areas in which Si2 aims to build upon its predecessor: an increased onboard energy resource; improved robustness to cope with extended periods in the air; and a cockpit environment that is more comfortable for its pilot (Piccard and Borschberg are flying alternate legs of the 12-stage, around-the-world flight).

Clerc expands upon the areas of improvement involved in developing Si2: "Firstly, we improved performance – that is to say, we reduced our energy consumption and have more reserves," he says. "Then, we modified the cockpit to improve ergonomics. In addition, we have a more reliable aircraft with redundant safety systems and leak-proof electrical circuits in order to fly in humid conditions. Finally, we have a form of autopilot called the stability augmentation system (SAS), which will maintain flight attitude and a directional heading so that the pilot is able to rest."

But it is the factor of pilot comfort that Clerc sees as the biggest challenge of the test work involved in the program. Theoretically, Si2 can fly forever. The question becomes one of how best to sustain the pilot across the long legs involved in a transglobal flight. "There will be no sleep over populated areas," Clerc confirms, "and we have developed techniques to relax the body while remaining awake." Piccard has elected to use techniques of self-hypnosis, while Borschberg uses yoga techniques.

VIRTUAL FLIGHT TESTING

The build-up to the around-the-world attempt included several thousand flights conducted in simulators, into which various different meteorological parameters were introduced – weather being the other primary constraint of the Solar Impulse project. The simulations extended to the physical aspects of the cockpit, to ensure the crew would be able to cope with the conditions on mission stages that would last for up to five days.

Virtual flight occurred well in advance of the first prototype taking to the air. In May 2008, a flight simulator developed in collaboration with Dassault enabled both pilots to 'fly' Si1 for the first time, for 25-hour periods. These flights saw the pilot provided with a helmet, safety harness,

LEFT: **Bertrand Piccard's first flight in Solar Impulse 2, at Payerne, Switzerland in 2014** (Photo: Solar Impulse/Revillard/rezo.ch)

BELOW: **Bertrand Piccard prepares for his third training flight in Solar Impulse 2, Payerne, Switzerland in 2014** (Photo: Solar Impulse/Pizzolante)

"THROUGHOUT THE PILOTS' TIME IN THE FLIGHT SIMULATOR, RESEARCHERS MONITORED PHYSIOLOGICAL DATA USING TECHNOLOGY USUALLY RESTRICTED TO LABORATORIES"

parachute, oxygen mask, food and other accessories. The simulator also used five projection screens arranged to provide a 210° view around the cockpit. Even at this early stage, the Hirslanden group of clinics was on hand to provide medical advisors and develop a concept to monitor the pilot's physiology.

In early 2012, André Borschberg undertook a simulated 72-hour transatlantic flight in a new flight simulator, a near-exact reconstruction of Si2's cockpit, to study how the pilot interacts in this environment at altitudes between 3,000ft and 27,000ft. During the test phase, the team made use of the flight simulator, which essentially replicates a cockpit, as well as a separate mission simulator that serves as a routing tool to plan the mission based on weather and air traffic control factors.

Speaking at the time, Borschberg noted: "The simulation demonstrated that our concept of flying single-handed for several days in a row is viable. The techniques of relaxation and multiphase sleep worked very well, exceeding my expectations by far. Thanks to careful management of the rest periods, I was able to maintain optimum vigilance throughout the flight. We learned a great deal about the practical management of life on board."

In summer 2012, the proving phase continued with a first 'live' intercontinental flight, which took Si1 from Payerne in Switzerland, via Madrid, to Rabat in Morocco. This was also the first occasion that the two pilots relayed each other at each stage. By the end of the year, the 'live' test phase had accumulated almost 182 flight hours in the course of 17 flights.

It was Piccard's turn in the Si2 cockpit mock-up for another three-day period in December 2013. Among the test points studied were energy management and coping with fatigue, nutrition, and understanding bodily functions – all in a space with dimensions smaller than 9 x 5 x 3ft. The degree of realism in the simulation was heightened by involving the entire mission team, as well as logistics, ground and communication nodes.

94
The % overall efficiency of the solar power system

525
The maximum speed of Si2's 4m-diameter propellers in RPM

17,428
The number of solar cells on Si2's wing

Throughout the pilots' time in the flight simulator, researchers monitored physiological data using technology usually restricted to laboratories. This included miniature electronics to measure heart and brain functions in real time. Resulting data was then compared with results from vigilance and response time tests and subjected to analysis. The result was a tailor-made rest strategy for the circumnavigation flight, originally planned for 2013, and later pushed back to early 2015 as a result of a wing spar failure.

After proving their capacity to operate in the cockpit for 72 hours, the next step was to prepare the two pilots for the around-the-world flight, with a new series of virtual missions in the flight simulator. Compared with Si1, the cockpit of Si2 benefits from an

RIGHT: **André Borschberg conducts stretching exercises during the 72-hour virtual flight in 2012** (Photo: Solar Impulse/ Revillard/Rezo.ch)

LEFT: **Bertrand Piccard and André Borschberg during virtual flight training, Switzerland 2008** (Photo: Solar Impulse/ Stéphane Gros)

advanced seat developed by Lantal, the Swiss seating specialist. The seat uses inflatable pneumatic technology and can be set for flying, relaxation and resting positions. It also includes an integrated toilet.

Borschberg took to the prototype cockpit to trial a series of stretching exercises and yoga positions developed by doctors and osteopaths as the team investigated the best ways to remain healthy and mobile during long-distance flights. The pilots called upon Borschberg's personal expertise with yoga to develop an anti-thrombosis program and during their mission they are able to consult with a yoga teacher via an iPad.

During Piccard's 72-hour test mission, he rested for 20-minute periods on 35 occasions. The simulation also saw the trialling of two different rest strategies. For shorter flights (24 to 36 hours) over inhabited areas, sleep is not an option, and the solution is the use of the aforementioned relaxation techniques.

Above the ocean, sleep is permitted in the form of short naps of up to 20 minutes, 10-12 times a day. During these micro-sleeps, the aircraft relies on its SAS autopilot. Should, for example, turbulence destabilize the aircraft, vibrating sleeves incorporated in the pilot's flight suit will alert him immediately and indicate the direction of inclination in order to correct the aircraft.

As well as the duration of the flights, another challenge was the lack of heating in the unpressurized cockpit – a heating system would consume too much of the limited available energy and add weight to the aircraft. Instead, Solar Impulse worked with Bayer MaterialScience to develop a high-density flight suit, providing a temperature ranging between -20°C and +35°C.

FOOD FACTOR

Another factor that had to be addressed was food to sustain the pilot. The team worked with Nestlé to develop an appropriate diet for the aircrew, delivering the required water and nutrition in the form of 11 daily meals and snacks. For example, during the Pacific Ocean crossing, the pilot's daily intake is 2.4kg (5.2 lb) of food, 2.5 liters (84.5oz) of water, and 1 liter (33.8oz) of sports drinks per day, plus snacks.

According to the Nestlé Research Center in Lausanne, five years and more than 6,000 hours went into research and development of the Solar

SEAT FOR ALL SEASONS

The pilot's multipurpose seat features a survival kit consisting of a parachute and life raft for use in case of emergency, built into the back of the seat. The seat can recline, enabling the pilot to perform physical exercises. It offers more legroom and has an ergonomic inflatable cushion; however, the pilot cannot move freely in the cockpit because he is not allowed to disengage the safety harness. The pilot's seat can be converted into a bed and even a toilet – concealed under the front part of the seat is an opening that serves as a toilet, protected by a sealed bag. Once used, the bag is sealed again and stored until the next landing.

ABOVE: **Detail of the Solar Impulse 2's multipurpose seat, including toilet facility** (Photo: Solar Impulse/Pizzolante)

Impulse pilot diet. The team opted for 'high altitude' and 'low altitude' food, the former consisting of small portions of high-energy, high-carbohydrate and fatty food items; the latter comprising higher-protein foods in larger portions. Different foods were developed to take into account the two pilots' individual nutritional profiles and the 11 meals were tested during the flight simulations in 2012 and 2013.

Heating food on board is problematic as adding water to dry food was not possible due to the risk of water spilling on the electronic instruments in the cockpit. However, the pilot can use a self-heating pouch in which an exothermic reaction subsequently heats the food inside the bag. Nestlé was responsible for testing not only the food itself, but also the new food packaging. After the food itself had been proven during the 72-hour 'transatlantic' simulator rides, the packaging had to be developed to meet the demands of the mission. In particular, this had to be able to withstand the fluctuations in temperature that come with flight at different altitude regimes. Hence all the food is kept in a special food box, to preserve it from temperatures ranging from -20°C to +30°C inside the aircraft.

On June 29 Borschberg took off from Nagoya, Japan for the seventh leg – by far the longest by Si2 to date. Testing the experience gathered in a programme that all began with a tentative 'hop' by Si1 back in December 2009, the flight concluded in Hawaii on July 3, after covering a distance of 7,212km in a time of just under 118 hours. The team's dream of perpetual flight thus took a major step towards becoming reality.

MISSION CONTROL

In permanent contact via satellite with the airplane, the Mission Control Center (MCC) is the pilot's 'guardian angel'. Twenty specialists anticipate every possible scenario and transmit information enabling the pilot to follow the optimum flight plan and complete his mission successfully.

In search of the most suitable patterns for the around-the-world route, several thousand flights have been simulated since 2005, taking account of varying meteorological conditions.

When flights are in progress, the flight parameters are recalculated twice a day, taking into consideration the prevailing weather situation and amount of sunshine. Flight altitudes and track are optimized to ensure enough onboard stored energy is available to fly through the night.

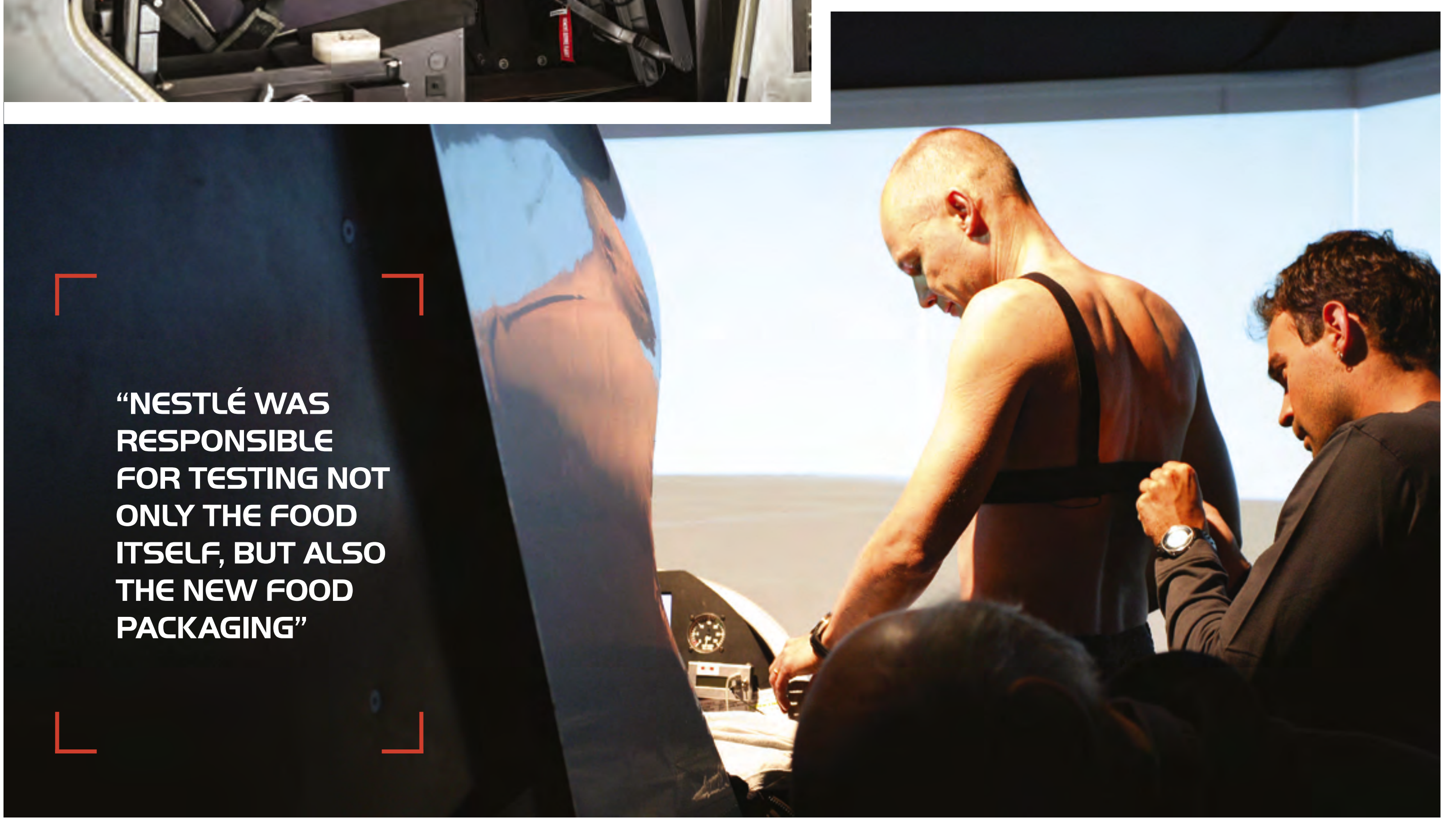
LEFT: **Solar Impulse 2 detail view: cockpit and control panel** (Photo: Solar Impulse/Pizzolante)

BELOW: **Medical examinations on Bertrand Piccard, Switzerland 2008** (Photo: Solar Impulse/Stéphane Gros)

"What André has achieved is extraordinary from the perspective of a pilot. He has also led the technical team during the construction of this revolutionary prototype. It is not only a historic first in aviation it is also a historic first for renewable energies," says Bertrand Piccard.

Piccard will fly to Phoenix, Arizona for the next leg of the round-the-world attempt before the mission continues to New York, Europe and Abu Dhabi.

Thomas Newdick is an aviation and defense writer based in Berlin



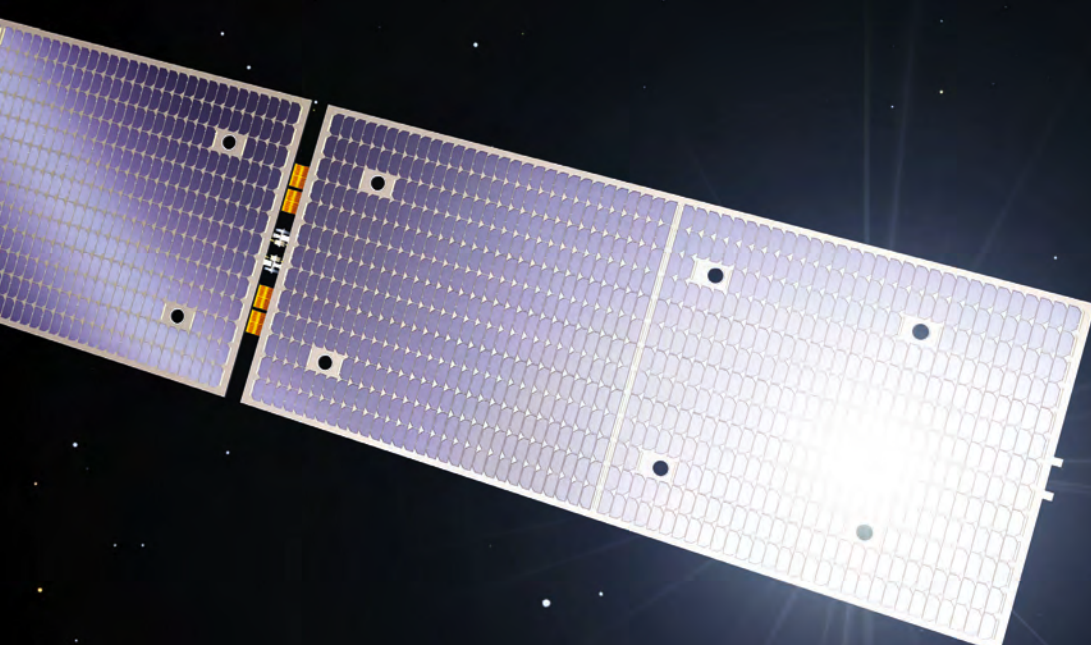
"NESTLÉ WAS RESPONSIBLE FOR TESTING NOT ONLY THE FOOD ITSELF, BUT ALSO THE NEW FOOD PACKAGING"

A Galileo full operational capability (FOC) satellite in orbit

Grilling Galileo

Testing the satellites that form the space segment of Europe's Galileo navigation system must replicate both the sound and fury of a rocket launch, as well as the extreme temperatures of life in orbit

BY BERNARD FITZSIMONS



Galileo, the European Union's global navigation satellite system, has been a long time coming. Wrangles over funding and other issues have led to repeated schedule revisions. But the European Space Agency, which manages the project on behalf of the European Commission, hopes the resumption of launches in March is a sign that the program is back on track.

Another two satellites should be ready for launch in September, followed by two more late this year or early next, and the agency is confident of having all the satellites that have been ordered so far in orbit by 2017. The final constellation is due to have 30 satellites, six of them spares. They include the four in-orbit validation (IOV) satellites launched in 2011 and 2012 and the 22 full operational capability (FOC) satellites ESA ordered in 2010 and 2012.

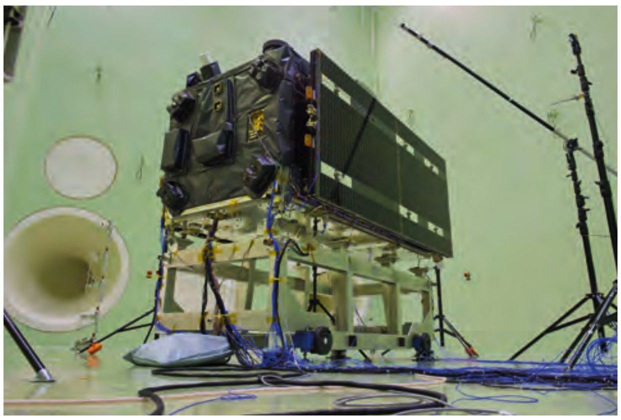
The agency will need to buy more platforms to achieve the target number, but expects to complete the constellation by 2020. Astrium (now Airbus Defence and Space) built the IOV satellites, but the FOCs are being constructed by OHB in Bremen, Germany, with navigation payloads from Airbus Defence and Space subsidiary Surrey Satellite Technology in the UK and propulsion modules from Moog-ISP in Niagara Falls, New York.

Before they leave the factory, the satellites are functionally tested at unit, subsystem and satellite level in ambient conditions. All units and subsystems are tested after integration. The system-level tests that complete the testing in Bremen before the satellites are mechanically completed and sent to ESTEC are particularly important, the manufacturer says: as well as proving the functionality, the functional performance tests serve as a footprint for the tests done at ESTEC after the environmental tests.

The first FOC satellite completed integration and functional testing at OHB's Bremen factory in May 2013. It then traveled by road, enclosed in an air-conditioned and environmentally controlled container, to the European Space Research and Technology Centre (ESTEC) in Noordwijk, Netherlands, for environmental and systems testing. The sixth FOC satellite arrived at ESTEC in December 2014.

Testing at ESTEC starts with a mass property test to check that each satellite's center of gravity and mass are aligned within design specifications. The more precisely these are known, the more efficiently the satellite's orientation can be controlled with

> “UP-AND-DOWN VIBRATION ON THE QUAD SHAKER IS FOLLOWED BY SIDE-TO-SIDE SHAKING ON THE HORIZONTAL SHAKER, WITH DATA GATHERED ACROSS HUNDREDS OF CHANNELS”



LEFT: The second Galileo FOC satellite in the Large European Acoustic Facility for acoustic testing – microphones monitor sound levels while the blue-insulated lines harness data from accelerometers inside the satellite to check on internal vibration

IN-ORBIT VALIDATION

The Galileo satellites are designed to provide four levels of service, the most accurate and secure being the public regulated service (PRS). Transmitted on two frequency bands with enhanced protection, the PRS offers a highly accurate positioning and timing service, with access strictly restricted to authorized users.

EU member states started independent PRS testing in 2013, using the four IOV satellites. Belgium, France and the UK used test receivers from the ESA, which carried out fixed and mobile validation in the Netherlands and Italy; Italy developed its own PRS receiver. The tests showed an autonomous positioning accuracy below 10m when the satellites were in the right geometry.

The first determination of a ground location was made at ESA’s navigation laboratory at the ESTEC technical center. By the time the IOV phase was complete in early 2014, test vehicles had driven more than 10,000km and the system had demonstrated dual-frequency positioning accuracy averaging 8m horizontally and 9m vertically, 95% of the time. Average timing accuracy is 10 billionths of a second, and performance should improve as more satellites are launched and additional ground stations become operational.

ABOVE: The ESA-built Svalbard medium-Earth orbit local user terminal (MEOLUT) on Spitsbergen Island was used to test the Galileo satellites’ search and rescue function

10^{-8}
Average timing accuracy in seconds demonstrated during Galileo in-orbit validation tests

5
Number of weeks the first two Galileo full operational capability satellites spent in the Phenix thermal vacuum chamber

>10,000
Number of kilometers driven by vehicles carrying test receivers during Galileo in-orbit validation phase

thruster firings in orbit. The resulting savings in propellant expenditure can help extend their working lives.

The Galileo FOC satellites provide the same capabilities as the IOV satellites, but transmit at higher power and feature other performance improvements. Since they represent a new design, the first two units were required to go through a full test program, but subsequent platforms will require less rigorous functional testing. The tests on the first two qualified the design, so no further qualification tests are required and mechanical tests can be significantly reduced. Several functional tests were also for qualification only and do not need to be repeated.

SOUNDS ALARMING

Acoustic testing is carried out in the Large European Acoustic Facility (LEAF), claimed to be effectively the largest sound system in Europe. The acoustic chamber, 11m wide, 9m deep and 16.4m high, has four noise horns embedded in one wall. Nitrogen gas passed through the horns generates noise that exceeds 140dB, while accelerometers placed within the satellite check for potentially hazardous internal vibration.

The four horns have cut-off frequencies of 25Hz, 35Hz, 80Hz and 160Hz. Along with three high-frequency generators, they allow acoustic excitation in the frequency range from 25Hz to 10kHz and an overall noise level of 155dBL. The noise pressures generated are comparable to those generated by the launcher engine and airflow along the launcher fairing.

That is followed by vibration tests on electrodynamic shaker tables to simulate the violent forces of a rocket launch. Up-and-down vibration on the QUAD shaker is followed by side-to-side shaking on the horizontal shaker, with data gathered across hundreds of channels.

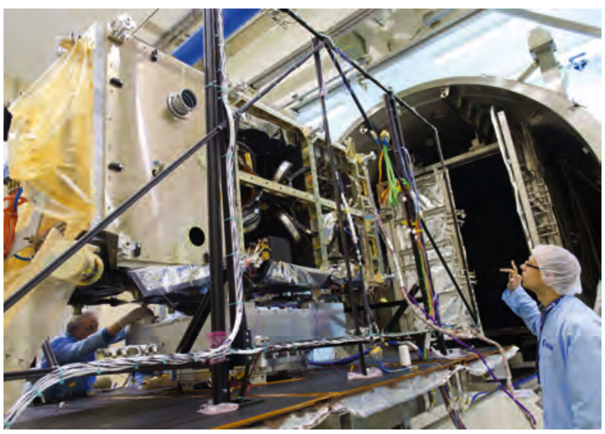
The QUAD system uses four 160kN shakers for a total thrust of 640kN and can safely test payloads with a mass of up to 10,000kg in the vertical direction. A magnesium alloy head expander connected to the four shakers creates a 3.3 x 3.3m interface for payload installation. The QUAD shaker is used for sine, random or transient testing in the frequency range from 3Hz to 2,000Hz with acceleration levels from 0.05g up to 20g.

The control system provides up to 40 channels for vibration input control and automatic test article response limiting. More acceleration measurement channels can be recorded by a mobile data handling system with up to 512 measurement channels.

Radio frequency testing of the navigation payload and antennas is carried out in the Maxwell electromagnetic compatibility facility, a shielded enclosure measuring 17 x 12.5 x 12m with continuously conducting metal walls, floor and ceiling to block external electrical signals. Anechoic absorbers on the walls and ceiling attenuate the reflected electromagnetic energy and the floor is lined with ferrite tiles, coated with a special epoxy to avoid electrostatic discharge. Once isolated within the chamber, the satellite can be switched on to check that all its systems can operate together without interference.

The most demanding of the environmental tests takes place in the Phenix thermal vacuum facility, a 10m-long stainless-steel cylinder with a diameter of 4.5m. Each of the first two satellites spent five weeks in the chamber. An inner box, called the thermal tent, has sides that are heated to simulate the sun's radiation or cooled down by liquid nitrogen to create the chill of sunless space. The first FOC satellite completed thermal vacuum testing on November 29, 2013.

BELOW: The first Galileo FOC satellite beside the Phenix test chamber at ESTEC in October 2013, being readied for its five-week-long thermal vacuum test. The thermal tent visible inside the chamber is used to reproduce the temperature extremes of Earth orbit



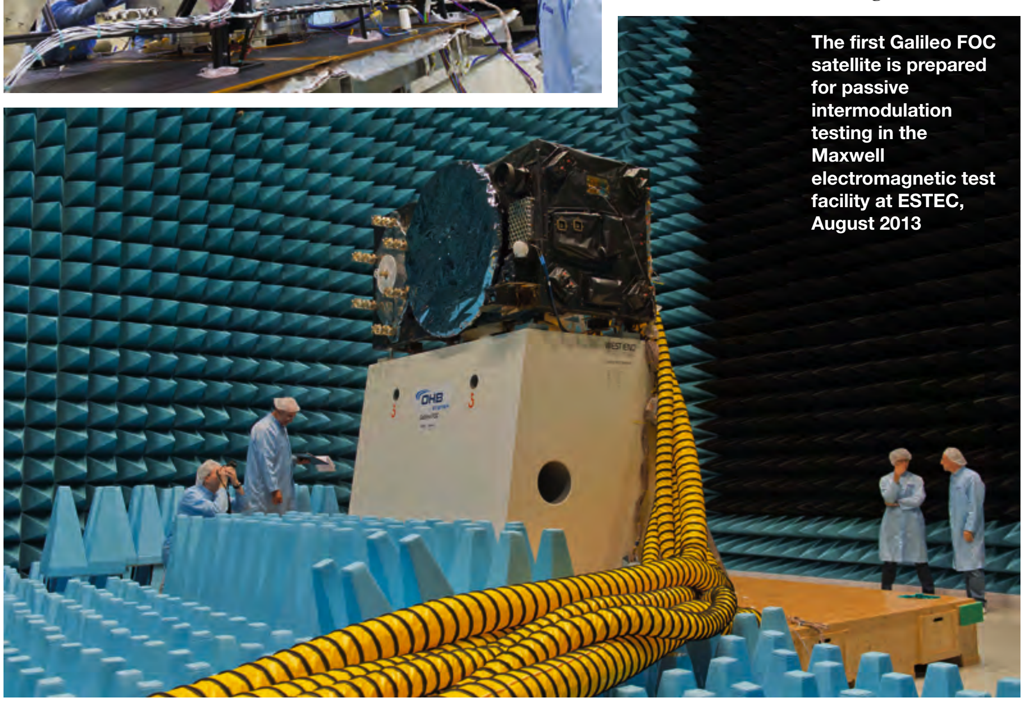
SEARCH AND RESCUE CAPABILITY

Galileo satellites also carry transponders to relay UHF distress signals from emergency beacons as part of the Cospas-Sarsat search and rescue (SAR) system. Tests started in 2013 using the second pair of IOV satellites and two new medium-Earth orbit local user terminals (MEOLUTs) at Maspalomas in the Canary Islands and Svalbard on Spitsbergen in the Norwegian Arctic. There is a third MEOLUT at Larnaca in Cyprus.

The three ground stations are each equipped with four antennas to track four satellites. Monitored and controlled from the SAR ground segment data service provider site at Toulouse, France, the stations are networked to share raw data, effectively acting as a single huge 12-antenna station. The result is unprecedented detection time and localization accuracy in relaying search and rescue signals to local authorities.

The Galileo IOVs were tested in combination with similar search and rescue payloads on Russian Glonass satellites and compatible repeaters on a pair of US GPS satellites. The tests found that 77% of simulated distress locations could be pinpointed within 2km, and 95% within 5km, while all alerts reached the mission control center within 90 seconds.

Despite all the testing, the first two Galileo satellites ended up in the wrong orbit when a frozen hydrazine fuel line to the attitude thrusters in the launcher's Fregat upper stage resulted in loss of inertial reference and erroneous orientation of the main engine. They were subsequently restored to an orbit that enabled their Earth sensors to keep the main antenna pointed toward Earth and their navigation payloads to be switched on in late November 2014. ESA's Redu center in Belgium then started the in-orbit test campaign, using a 20m-diameter antenna that can study the strength and shape of the navigation signals at high resolution.



The first Galileo FOC satellite is prepared for passive intermodulation testing in the Maxwell electromagnetic test facility at ESTEC, August 2013

PRODUCTION FEEDBACK

A production run of 22 is small by aircraft standards, but a lot for a satellite design. Test results will not be used to modify satellite design, OHB says, since any change would require additional testing, making the design changes uneconomic and – even worse – endangering the completion of the full operational capability of Galileo. So there is no intention to implement any change for the satellites currently under production. Even the software for the second pair of satellites launched did not differ from that of the first pair.

Changes in the production process are a different matter. The manufacturer says it was planned from the outset to feed back lessons learned from the early phase into the production in order to achieve the production targets. This is done continuously wherever possible. OHB also plans to check at certain subsequent stages in the program whether larger changes are meaningful and can be implemented, in particular regarding the test program.

The situation is different for additional satellites whose production has not started yet. Given enough lead time, OHB says, it may be possible to implement design changes in order to improve the production or the performance of the systems. ∎

Bernard Fitzsimons is an aviation journalist specializing in air transport business, technology and operations

Rapid response

Bell Helicopter draws on proven dynamics and a proven test organization to bring its new light single-engine JetRanger X to market more quickly

BY FRANK COLUCCI

Bell Helicopter Textron is developing three aircraft simultaneously. With the company's Texas engineering and test resources committed to the Model 525 'super medium' civil helicopter and Model V280 military tilt rotor, Bell Canada in Mirabel, Quebec takes responsibility for development and civil certification testing of the Model 505 light single-turbine helicopter.

"This is our commercial certification testing center," explains JetRanger X program director David Smith. "That's one of the reasons the 505 is here. We've got history here, all the tools, the people." The Mirabel experimental test organization has earned type certificates for all new Bell civil helicopters since 1991, including the successful Models 407 and 429. "The experimental team here is continuously doing testing on the production aircraft," says Smith. "There are kits they need to certify and modifications. They use the same facilities on the production aircraft." The busy Bell Canada plant 30 miles west of Montreal is also home to a dedicated production acceptance testing organization.

The JetRanger X first flew in November 2014 (see sidebar, overleaf) and is scheduled for certification by Transport Canada with first production deliveries in 2016. US FAA and EASA certifications are expected soon after. By early April 2015, Model 505 testers had logged around 17,000 test points in about 150 flight hours on two instrumented aircraft. A third Bell 505 was near completion and earmarked for certification testing to begin in May.

Test director and Bell Helicopter senior technical fellow Ed Lambert notes, "Until now we've pretty well conducted all the envelope expansion testing on the 505. There are some final fine tweaks, but we've got it to the point where it's flying very, very nicely. The pilots are enjoying it."

Bell Canada uses test pilots with other-than-military experience to provide commercial customer perspectives. "The pilots come from a pretty diverse set of backgrounds," says Smith. "I think it gives a whole different level to the feedback they provide." The Mirabel experimental test organization has three test pilots, five test engineers, three instrumentation engineers, one data reduction engineer, and 12 flight technology engineers. They and 22 technicians support tests of the new helicopter and modifications to production aircraft. Pilots routinely step out of the Bell 505 and fly off in the bigger twin-engined Model 429. "We always have walk-in testing to support," observes Thierry Hingray, chief of Mirabel Test and Evaluation. "We do manage to put 25 hours in a day."

TRIED AND TESTED

The JetRanger X uses the long-proven drivetrain and two-bladed metal main rotor of the current production Bell Model 206L-4 LongRanger. Legacy dynamics are a JetRanger X marketing advantage – common part numbers, tools and maintenance training promise to smooth the introduction of new operators to the Model 505. They nevertheless save no flight test hours.

"We have to go out and repeat all the certification testing as though this was a brand-new rotor and drive system on the aircraft. There's no shortcut there," says Smith. The accelerated helicopter program can leverage load data from original LongRanger development in the 1970s. "That will reduce the amount of static and fatigue testing on those items we

Flight test instrumentation inside the wide-open cabin of the new Bell 505 – Garmin has provided a standalone Garmin Test System for the flight test vehicles (All photos: Bell Helicopter)

do down on the ground. Component and ground testing is the real benefit for us." Mirabel testers will perform a 100-hour endurance ground run late in the program to verify power cycles and performance of the rotor brake.

The new five-seat Model 505 is about the same size as the Model 206B-3 JetRanger last produced by Bell in 2010, and will carry a similar 1,500 lb (680kg) useful load in a new, wide-open fuselage with a flat cabin floor, clamshell doors and enhanced cockpit visibility. By the later stages of envelope expansion, Bell engineers were nearly settled on final gross weight and center of gravity figures.

Most Model 505 load-bearing structures are conventional aluminum – large composite parts make the new airframe just 5% composite by part count but 70% by exterior area. Model 505 engineers performed static testing on pieces of the main rotor pylon, tailboom, landing gear and select dynamic components to gain initial safety of flight clearance. "We don't do a full aircraft static article as you might on a military platform," observes Smith.

Mirabel engineers also drew on familiar Bell test practices to plan the Model 505 flight test hours. "We try and look at previous programs when we scope these things out," explains Lambert. "You put a block in your schedule for development testing, but until you start flying you don't know. The development is very tricky in terms of the testing estimate. Once you're done, certification testing is more of a known quantity." Bell engineers typically allocate 500 to 700 flight hours for certification testing.

Testing practices in Mirabel are shared by Bell's Arlington, Texas facilities. "We follow the same set of procedures, policies, the same framework," says Lambert. "We're very well integrated when it comes to overall management of test programs. Members of the team come from both locations to oversee the flight test program."

FIRST FLIGHT COMPLETE

The successful first flight of the Bell 505 JetRanger X helicopter took place on November 10, 2014 at Bell Helicopter's manufacturing facility in Mirabel, Quebec. "The Bell 505 performed exactly as anticipated," said Yann Lavalle, senior flight test pilot at Bell Helicopter, immediately after the maiden flight. "I am excited to be a part of the history of the Jet Ranger, an aircraft that defined the market nearly 50 years ago."

"We hovered in the Bell 505, performed a low-speed controllability assessment and flew two laps in the local traffic pattern. Our top speed today was 60 knots, and the entire flight lasted 30 minutes," added Eric Emblin, senior flight test pilot at Bell Helicopter.

Most Bell 505 flight testing is conducted around the Mirabel plant. The Textron Zone northeast of the plant provides ready access to testing airspace

"AIRCRAFT NO. 3 WILL HAVE ONLY LIMITED INSTRUMENTATION TO RECORD FLIGHT CONTROL POSITIONS IN ADDITION TO BUS DATA"

COLLECTED AND TELEMETERED

Bell 505 instrumentation expertise likewise comes from Canada and Texas. "We have a lot of contact," explains Hingray. "We do try to keep our equipment common that so we can share equipment as needs vary. It's collaborative work." Model 505 static test structures require only basic instrumentation. "There are some instances where we add instrumentation for redundancy or added fidelity, but that's the exception." The first two flight test aircraft have comprehensive suites of strain gauges, accelerometers and engine sensors to supplement data drawn from the aircraft avionics bus. Test instrumentation and bus inputs measure around 600 parameters on the first two aircraft. "Pretty much anything you can think of, we can measure," notes Hingray. Aircraft No. 3 will have only limited instrumentation to record flight control positions in addition to bus data.

The Bell 505 also leverages the proven Garmin G1000HTM avionics used in the Bell 407GX, Agusta Westland AW119 and Enstrom 480 helicopters. Fixed-wing versions of the same suite have been tested and certified on a range of single- and twin-engine airplanes.

"If you look at the entire installed base, it's around 12,500 platforms," notes Garmin senior business development manager Bill Stone at the company's headquarters in Olathe, Kansas. "Collectively we work with the airframer to come up with requirements for what it has to interface with on the aircraft. Then we collectively work to put together hot benches for the system. Ideally we like to have a hot bench here for engineering and a replica hot bench at the OEM's facility."

The Model 505 program has hot benches at Garmin in Kansas and Bell

Like the first Bell 505 test aircraft, Flight Test Vehicle No. 2 is fully instrumented for development testing. The No. 3 aircraft, with a less elaborate instrument suite, will be dedicated to certification testing

in Fort Worth, Texas. Each bench has a representative 'glass cockpit' centered on two 10.4in multifunction displays to show flight and systems data, digital maps, flight planning tools and a power situation indicator. "It is the entire avionics system," explains Stone. "Then we will provide stimulus to that system. Some things are simple, like switches on the collective – we don't need aircraft hardware. Some systems are more complex like a FADEC [full authority digital electronic control]. We will either get a simulator from the manufacturer of that equipment or an actual piece of hardware. That's evaluated on a system-by-system basis. The intent is to get a complete end-to-end test prior to it being installed in the first test article."

Individual Garmin avionics boxes carry their own environmental qualifications, which are transferrable from one aircraft to another," explains Stone. "There are aircraft-specific environments that have to be validated for certification. HERF [high-energy radiated field] and lighting requirements, for example, are very aircraft specific. Wire routing and wire length have a major influence, and we have to provide a wide range of signals and power to ensure there are no adverse effects on the avionics."

Garmin engineers use representative wire harnesses to connect systems on the hot bench. Electromagnetic compatibility chambers provide a representative test environment. "There are laboratories that will conduct this testing, but there's actually precious few of these laboratories," continues Stone. "To have control of schedule and throughput, we've made a pretty large investment to construct these in our own facility."

The Bell 505 is powered by a 504shp (376kW) Turbomeca Arrius 2R turboshaft with dual-channel FADEC. The engine manufacturer performs initial FADEC software testing in France, and Bell engineers set up an engine testbed in Fort Worth with the real FADEC for subsequent tests. The Garmin hot bench uses a FADEC simulator. "To get faithful data from it, you need an actual engine running," explains Stone. "Companies like Turbomeca provide a high-fidelity simulator for integration and verification."

150

The number of flight hours logged on two instrumented test aircraft by early April 2015

600

The number of test parameters measured on the first two test aircraft

17,000

The number of test points logged on the two test aircraft by early April 2015

Model 505 flight test data is recorded on board the development aircraft as well as telemetered to the ground. Stone explains: "In the certification environment, we have a massive recording capability we developed – the Garmin System Test. It's basically a computing and recording system that listens to the network in the avionics and records massive amounts of data. During certification testing, an entire test flight can be played back, capturing every parameter in the avionics." While the standalone GST has a high-capacity hard drive, production avionics typically retain only localized recording capability for maintenance troubleshooting.

The Bell Canada facility can collect real-time data from three flight tests simultaneously. "We have two telemetry rooms permanently based here in Mirabel," notes Hingray. "We can fly out to 30 nautical miles radius, Sometimes up to 45 nautical miles in certain conditions. We also have a mobile unit we can use. When we do high altitude testing or cold weather testing, we use the van – it's basically a replica of everything we have here."

The flight test area northeast of Mirabel is considered a Textron Zone. "It allow us to go pretty much to 20,000ft [6,000m] if we need," notes Hingray. "When we do special-conditions testing, hot or cold weather, we go to Leadville, Colorado." The Model 429 flew its high-altitude certification tests from the 10,000ft high Leadville Airport and underwent high-temperature certification test at Lake Havasu City, Arizona. Cold-weather testing is typically performed at Thompson Yellow Knife, near Resolute Bay, Canada. "We take the cold seriously up here," quips Lambert. Surprise snow testing was performed at Mirabel in March. "It was fortunate to have the right snow in our flight test environment. We call it MIL Spec snow and only get it three or four times a year."

Lambert concludes: "Basically, we've pretty well competed all the testing we can in the environmental conditions we can do here in Mirabel. We're already planning our hot-weather and high-altitude testing. Apart from those extreme environment conditions, I think we've nailed down what the final configuration needs to be." ∎

"DURING CERTIFICATION TESTING, AN ENTIRE TEST FLIGHT CAN BE PLAYED BACK, CAPTURING EVERY PARAMETER IN THE AVIONICS"

Frank Colucci is a specialist in rotorcraft design, civil and military operations, test and avionic programs

Military precision

Fuel system trials pose very specific safety challenges, in the trial process itself and to subsequent aircraft operation. *Aerospace Testing International* talked to RAF and QinetiQ engineers at the UK's MoD Boscombe Down test facility to find out more about military fuel system trials

BY PAUL E EDEN

Members of the test team connect the Airbus Defence & Space Voyager KC3 to a Tornado

The risks in fuel system testing are obvious – few engineers would choose a flammable liquid as the medium for any investigation, but in this case there is seldom any other fluid that will do. Even in the test rig, seals and other components rely on fuel interaction to function correctly, while filling an aircraft's tanks with anything other than fuel risks contamination and potentially disastrous consequences. Safety, in system operation and test procedures, is therefore perhaps the greatest concern, on the rig, in ground testing and in the air.

Fuel systems typically go some way beyond supplying fuel for the engines to burn. In larger aircraft, pumps move considerable volumes of fuel between multiple tanks, supplying the engines and fulfilling vital trimming and center of gravity control functions. In fast jets, fuel is required for multiple purposes, including hydraulics and cooling. Where any aircraft is required to accept fuel in flight, the test burden is considerably expanded.

HEAVY AIRCRAFT TEST

Based at MoD Boscombe Down in Wiltshire, UK, 206 (Reserve) Squadron is the Royal Air Force's Heavy Aircraft Test and Evaluation Squadron. Its small establishment includes test pilots and flight test engineers, and evaluator aircrew, often working alongside their co-located QinetiQ civilian colleagues under the Aircraft Test and Evaluation Centre (ATEC) construct. Their remit extends from tests on individual modifications or upgrades, including clearances for particular capabilities, up to full system testing on new aircraft.

Fuel system work is an important aspect of the squadron's test load, especially as the RAF introduces a new tanker – the Airbus Defence & Space Voyager KC.Mk 2/3 – into service. The aircraft's own fuel system is already proven, but 206(R) Sqn and QinetiQ are working hard to clear it against various receivers.

Air-to-air refueling (AAR) introduces additional challenges, not least through flying two potentially large aircraft close together, but also through the high fuel pressures and flow rates generated. Receiver pilot fatigue is carefully managed, as flying repeated contacts can be mentally and physically exhausting. Extensive ground testing de-risks subsequent airborne trials, with fuel pumped between the aircraft to reveal leaks, pressure spikes and other issues.

Squadron Leader Gareth Thomas, a 206(R) Squadron flight test engineer, has worked alongside QinetiQ flight

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VOYAGER

The Royal Air Force operates a core fleet of nine A330-based Voyager multirole tanker transports under a private finance initiative through AirTanker. Five more aircraft are being procured to provide a surge fleet and AirTanker is able to lease them to other operators when they are not required for RAF use.

Voyager is heavily committed to ongoing RAF operational activity. The aircraft are based at RAF Brize Norton, Oxfordshire.

QUICK QUESTIONS

- **Aside from AAR, can you give an example of the challenges of military fuel system testing?**
  Emma Bradley: "On rotary wing and fast jets, we might have to clear fuel tanks for safe carriage alongside forward-firing weapons."
- **Is all your fuel system test work directly related to the host aircraft?**
  Squadron Leader Gareth Thomas: "No. We've tested fuel cells for airborne delivery, cabin fuel tanks for refueling other aircraft on the ground, even fuel systems on air-droppable boats."
- **How many sorties does an AAR trial typically need?**
  Becky Walsh: "It depends on the particular trial, but generally at least five."
- **Do you test for failure cases during AAR?**
  Squadron Leader Gareth Thomas: "Where we can we'll simulate emergency scenarios, including receiver or tanker engine issues."
- **Do you fly AAR tests at night?**
  Squadron Leader Gareth Thomas: "Yes, a full range, but test points are flown by day before being conducted at night."

TOP: The view from a C-130J behind the Voyager KC3 fuselage refueling unit

ABOVE: The C-130J behind Voyager KC3

systems engineers Emma Bradley and Becky Walsh on a series of fuel systems trials, including proving compatibility between Voyager and various large aircraft receivers including the Sentry airborne early warning platform and C-130J Hercules. He explains the value of having military personnel working with QinetiQ's subject matter experts (SMEs): "Safety in role is often the primary concern of the QinetiQ SMEs, but as operators we're always interested in whether it's fit for purpose. The combination of these two viewpoints is the reason we work together as an ATEC. Essentially, we want to be sure that it's safe, but also that it will do what we need it to do on exercise or operations."

For their trials, ATEC personnel rely on the availability of operational assets and regularly travel to reach them, but for AAR ground tests, says Walsh, "We prefer to get them here if we can, because the site's set up for testing, we have a dedicated fire crew and the other facilities we need." Thomas adds, "With fuel trials in particular, the provision of fuel run-offs and spill management plans is particularly important. Trials safety is a top priority and a detailed risk assessment is conducted before any trials work starts, where risks to personnel, equipment and the environment are identified and actively mitigated."

Typically, an area is set aside on the pan for aircraft fuel system testing, with dedicated fire cover in attendance in case of leaks or spills. Personnel are briefed on using spill kits, a NOTAM is issued covering the use of radios in the vicinity to minimize ignition risks, and tasks are deconflicted with other Boscombe activities, especially work in the Radio Frequency Environment Generator.

INSTRUMENTED RECEIVER

An AAR ground test begins with basic compatibility trials. The tanker is parked ahead of the receiver, trailing a hose that is connected to the receiver's probe. With the basics of the coupling proven, fuel is transferred at progressively higher rates and pressures. Walsh explains, "You're testing to see if pressures go over system limits. We increase pressures progressively, but there's still an outside risk of a pipe rupture. The transfer rate in AAR is high and safety is critical."

Test receiver airframes are typically instrumented to assess the aerodynamic effects of trailing close behind the tanker, while fuel pressure transducers installed in fuel pipes measure steady state pressure during fuel transfer and the effects of changes in the receiver's fuel system through valve operation and other procedures, which cause pressure spikes. "We need to make sure that pressures remain within limits through any combination of fuel from the tanker and valve operations on the receiver," says Walsh.

The instrumentation requirements for the receiver and tanker on each trial will be considered individually based on the evidence required to meet the objectives and to ensure safe conduct of the trial. In the case of proven tankers, this evidence may be sourced from elsewhere, negating the need for specific instrumentation. Trials with large receivers are simplified by their ability to carry flight test personnel for real-time onboard data monitoring and direct interaction with the flight crew.

ABOVE: The Tornado refueling probe

TOP RIGHT: The C-130J and Voyager KC3

Pilots are restricted to two hours of AAR test points to manage fatigue, but multiple crews can be accommodated for extended sessions – as much as seven hours for Sentry.

Walsh reports that processing data live makes for a more efficient program: "We proceed through pressures, valve combinations and other test points in small steps and see the results there and then, knowing if it's safe to proceed to the next step." Bradley emphasizes the significance of recording data alongside real-time analysis. "If there's an anomaly, we have it recorded. We can go back and study it, then see if it's repeatable and assess what caused it." Such issues can also be addressed in the air, but require a careful judgement call. "We might see something unexpected happening and want to repeat it, but the test crew will need to decide if it's safe and appropriate."

"It's a combination of test observations and general airmanship," Thomas says. "We take a considered approach, depending how far something was outside expected parameters. We might decide to stop and go home, or repeat the test point, but perhaps with additional safety mitigations in place or using smaller incremental steps. We could also introduce additional test points to help pinpoint the issue, provided we stay within the bounds of the approved testing."

Bradley has worked on fuel gauging test work, where there can be significant differences between ground and air test. "We can see how gauges react to bowser pressure, for example, but that gives little indication how they'll behave in the dynamic environment of flight, although we can still glean valuable ground test data, such as accuracy, that de-risks the flight trial."

PROBE AND DROGUE

Two primary methods of AAR have evolved: flying boom, and probe and drogue. The US Air Force uses the former method, as do operators of aircraft originally designed for that service, while probe and drogue is favored by the RAF, US Marine Corps and US Navy, among others.

In flying boom contacts, the receiver concentrates on flying an accurate formation with the tanker, the 'boomer' taking responsibility for placing the boom's nozzle into the receiver's receptacle; in probe and drogue refueling, responsibility for a successful contact lies with the receiver.

The tanker trails a hose with a stabilizing basket, or drogue, at its end, surrounding the nozzle. The receiver is equipped with a probe, pushed into the basket as the pilot 'overtakes' the tanker at something approaching walking pace. Fuel flow is activated when the probe makes positive contact with the fuel nozzle, at which point the receiver maintains steady formation until refueling is complete.

"THERE'S TYPICALLY A DEBRIEF DISCUSSING EACH OF THE TEST POINTS IMMEDIATELY AFTER THE SORTIE"

DATA COLLECTION

The data gathered from an AAR trial is vast and varied. Bradley reports, "There'll generally be numerical data and pilot comments on aspects like handling qualities and HMI [human machine interface], from several sources. As well as data recorded by the instrumentation, and perhaps video, much of it will be on pen and paper." With large aircraft AAR trials producing seven- or eight-hour sorties, flying is typically scheduled for every other day, such is the volume of data collected and time required to process it.

"There's typically a debrief discussing each of the test points immediately after the sortie, during which we usually confirm whether we're happy to go on to the next flight," says Thomas. Then the multiple gigabytes of data gathered in flight are analyzed to ensure they agree with the information viewed in real time on the instrumentation and recorded on test cards during the sortie.

FAST JET FUEL SYSTEMS

Pete Jackson, principal engineer, flight systems and Keith Douglas, principal engineer, air division, at QinetiQ, explain that fast jets pose additional challenges, particularly through their compact size, which limits crew capacity and leads to fuel systems having multiple functions. Fuel finds uses beyond the trimming typical of larger aircraft and is frequently employed as a hydraulic fluid and as a cooling medium. AAR is often a critical fast jet capability, while external fuel tanks are a common fit.

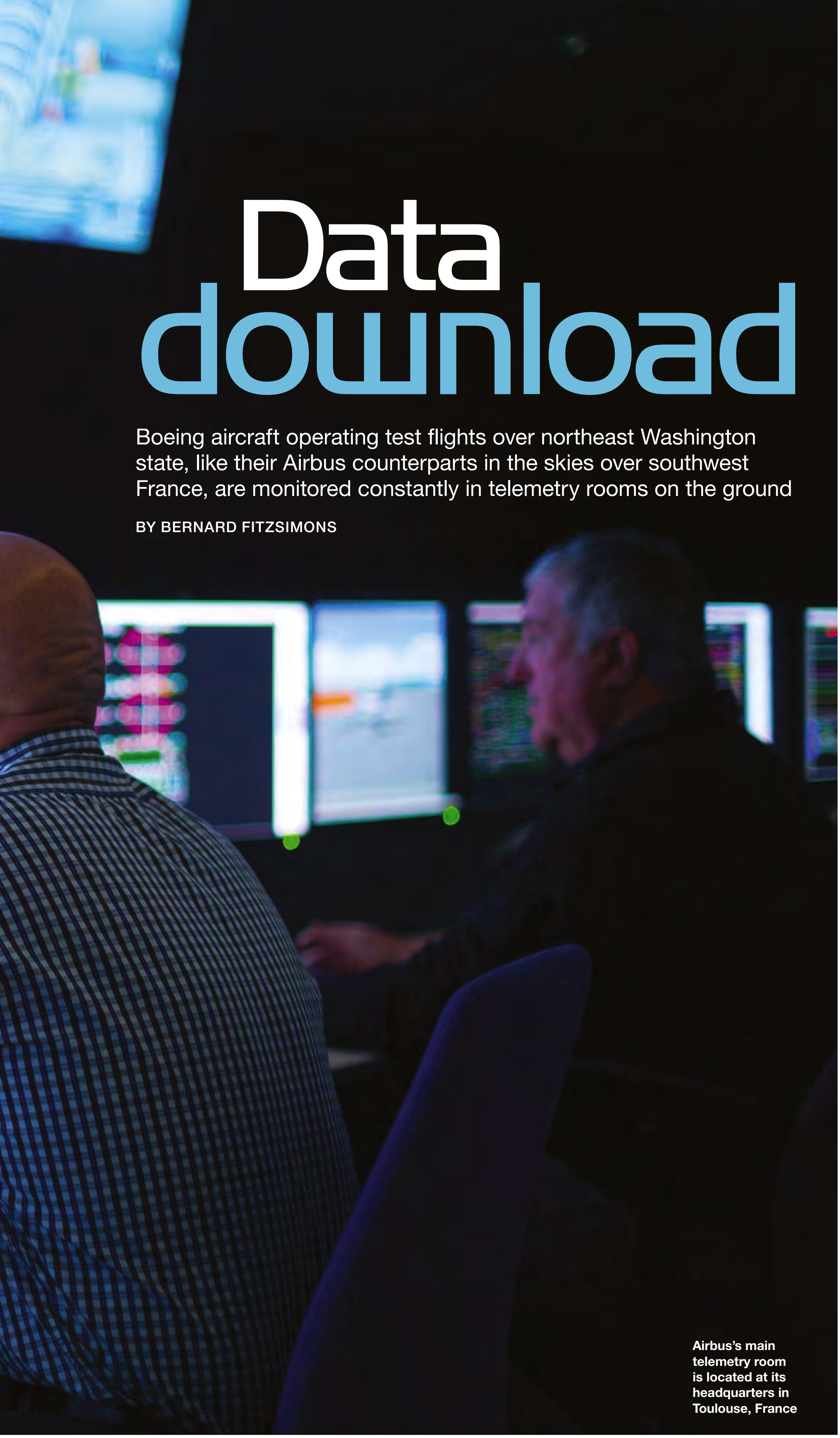
Thus a fast jet fuel system presents many more aspects to test, while AAR trials are complicated by the restricted seating capacity. Even in a two-seat jet, it is rare for a flight test engineer to occupy the rear cockpit; a navigator or weapons systems officer adds an increased level of safety should an issue arise. Test data gathered from aircraft instrumentation is therefore telemetered to the ground, and sorties may be limited to two hours around the tanker before pilot fatigue becomes an issue. ■

Paul E Eden is an aviation writer based in the UK

Data download

Boeing aircraft operating test flights over northeast Washington state, like their Airbus counterparts in the skies over southwest France, are monitored constantly in telemetry rooms on the ground

BY BERNARD FITZSIMONS



Airbus's main telemetry room is located at its headquarters in Toulouse, France

When the Airbus A350 took off for the first time just over two years ago, there were two test pilots and four flight test engineers on board. But on the ground in Toulouse, France, another 70 specialists were monitoring the flight in real time via voice, video and datalinks relayed to the airframer's telemetry center.

"We're the eyes of the airplane on the ground," comments telemetry center leader Jean François Meryet. "We're not on the airplane, but we feel like we are. We have the same information as them, we have the dataflow that permits us to know what's going on, and we have the flight crew dialog. We really feel like we're with them."

The additional experts on the ground are there to help the flight crew carry out the test flight and achieve its specific goals. And as well as answering specific questions and verifying that the test condition has been achieved, or asking for it to be repeated, the occupants of the telemetry room monitor the aircraft's structure and systems in real time so they can warn the flight crew of any unsafe condition. The benefit for the engineers on the ground is the immediacy of the readings and the fact that they can better understand the context of each test and the effect of factors such as local weather.

THE SETUP IN SEATTLE

The telemetry (TM) room at Boeing Field in Seattle uses hardware identical to that installed on the aircraft to drive the displays and show the data to the engineers. "We want the same look and feel in the TM room as what they would experience if they were on the airplane," says Tom Smidt, instrumentation and data systems manager at Boeing Test & Evaluation. "When our analysis engineers fly with the airplane, they can look at data in real time. So the TM room is just an extension of the airplane."

Engineering values are shown on paper output from strip chart recorders as well as computer screens, all driven by the Airborne Data Analysis and Monitor System (ADAMS). "It's essentially just an Ethernet network of hardware that runs the TM room," explains Smidt.

Each of the eight tables in the room is allocated to a different discipline such as structures, flight controls or systems. "They each are looking at

RIGHT: **Boeing's main telemetry room is located in Seattle, Washington**

LEFT: **Boeing test engineers analyze the data transmitted live from a test flight**

their particular things during the test," he says. And there are more people in the TM room than there would ever be on the aircraft: "On a typical flight on the airplane you might have 10 or 12 people. In the TM room you could have 30. We'll have more people in the TM room than on a flight because we need to view critical data in real time."

Nobody is there without a good reason, though. "They have a pretty strict policy that if you're needed for the test you can be in the room; if you're not needed for the test you can't be in the room, however senior you are," Smidt says. And the test director is the sole point of contact with the aircraft: "There may be a lot of activity going on in the room, but there's only one person that talks to the airplane."

Boeing does its test flying in the eastern part of Washington state, about 300 miles to the east of Seattle. "Our TM system operates in the S-band region (2.3GHz)," explains Smidt. Data and VHF voice communications from the aircraft used to be received by a ground station at Moses Lake and was relayed by satellite to Seattle but that has changed in the last three years with the installation of new hardware at a company site at Moses Lake. "Now we're using the internet to bring both the data and the radio channels back.

Only a limited subset of the data generated on board can be sent to the ground, even with a 15Mbps bandwidth datalink. "On some airplanes that might be everything, but on most airplanes that's maybe a quarter of what's available," Smidt says. The data to be downlinked is selectable and can be changed on the ground between test flights: "If they see an area of interest and they want more information, they can change that. Not on the fly, but before the next flight."

Data is stored initially on solid state drives with a capacity of around 700GB. In the course of a test flight lasting four to six hours, Smidt says, a 787 might fill up a couple of drives, "but on a 737 you wouldn't fill up one." In the ground station, an online RAID server system retains the data for about 30 days before transferring it to tapes, which are held in a Hewlett-Packard tape library. Duplicate copies are stored off-site.

"We have a 12-year retention policy, although we are asked to keep some things longer," says Smidt. "We can recover data from everything that we did within the last 12 years. If you wanted to request something that you did last year, it might take an hour for the system to locate and download that tape."

The same system that was used for 787 testing is currently being used for flight tests of the US Air Force's new KC-46 Pegasus tanker. The next program on the schedule is the 737 MAX, expected to fly next year, and for that there will be changes, Smidt explains – a Crystal server will provide the basic computing power and the current paper strip charts will give way to flat panel displays that should improve reliability.

"The strip chart recorders are mechanical devices, so they need a little more care and feeding," he

"THERE MAY BE A LOT OF ACTIVITY GOING ON IN THE ROOM, BUT THERE'S ONLY ONE PERSON THAT TALKS TO THE AIRPLANE"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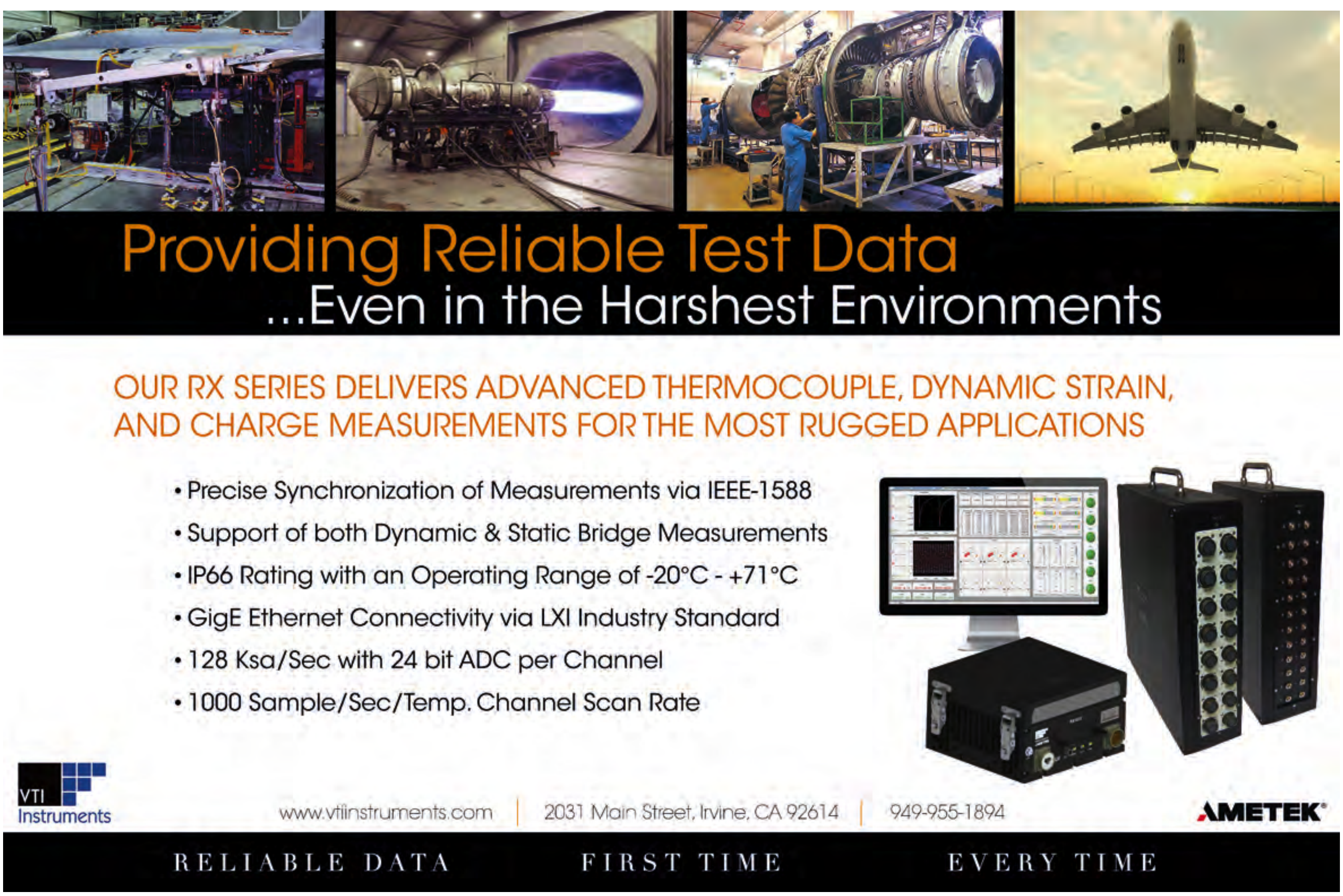
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LEFT: Airbus flight test engineers Manfred Birnfeld and Sandra Bour Schaeffer on board the A320neo prior to its maiden flight

ABOVE: Members of the A350 XWB first flight crew prepare for the milestone trip on June 14, 2013 – there were only six crew on board, but a record 70 people monitored the flight in the telemetry room in Toulouse

comments. They should also show the airframe oscillations induced during flutter testing more immediately, for example: "I think we're going to see the results more quickly on the screen because the paper has to travel from wherever the print head is. Some of the engineers are attached to the strip charts – but they'll get over that." None of the equipment is hard-wired, he adds: "All of this is programmable, so you can have any piece of information on any channel."

"I think of the TM system as a tool," Smidt sums up. "It provides an efficient and safe way of testing the airplane before it is deemed airworthy. The alternative would be to do a test and land, and then look at the data, so it certainly beats that."

1
Number of people in telemetry room allowed to communicate with test aircraft

5.091-5.250
Frequencies in gigahertz used to download Airbus telemetry data

≤ 600,000
Number of parameters available on the Airbus A350

AIRBUS APPROACH

Airbus installed the first TM room at its Toulouse, France headquarters in 1987 for flight tests of the A320. A second room was added in 1990 and a third in 2006, while the military transport aircraft flight test center in Seville gained its own TM room in 2004. The three rooms enable the Airbus master telemetry center in Toulouse to follow three different flight tests simultaneously, and are networked with both Seville and annex telemetry rooms installed in 2009 at Hamburg and Bremen in Germany and at Filton in the UK. Current flight test activity is focused on the re-engined A320neo family.

With its soundproofed, matt black walls, the Toulouse center was designed to minimize the stress of work that demands intense concentration over extended periods of time. Instead of windows, each of the TM rooms has large screens showing high-definition video, including live video transmitted from the cockpit and external cameras on the flight test aircraft. The screens are managed via a video-matrix-driven touchscreen from AMX, while a Bouyer public address system relays audio to the telemetry rooms and the corridor outside.

For the specialists monitoring specific aspects of the tests being flown, there are PCs with twin displays showing the output from Airbus software running on a Linux mainframe server via Oracle Secure Global Desktop (SGD). According to Oracle, the SGD network enables Airbus staff and suppliers to access test data from server-hosted environments via a web browser using a standard corporate PC, allowing experts in the various disciplines to provide nearly instant feedback from their off-site locations, rather than having to travel to Toulouse.

Test flights are carried out in six overlapping zones, each roughly circular and approximately 500km in diameter, that extend from Brittany and the Bay of Biscay on France's west coast, to its Mediterranean coastal waters in the southeast. There is a dedicated antenna on the ground for each area: line-of-sight range from antenna to aircraft is more than 350km at 40,000ft. The antennas are controlled from the telemetry center in Toulouse, and an Ethernet/IP network relays data from the antenna stations at up to 10Mbps.

Originally, the telemetry signals were transmitted in L-band (1-2GHz). In 1992, the medium was changed to S-band (2-4GHz) and last year there was another switch to C-band (4-8GHz) using the 5.091-5.250GHz frequencies allocated by the International Telecommunications Union to airborne mobile telemetry in 2007. The airborne telemetry equipment consists of a data

RIGHT: A quiet-looking Airbus telemetry room – however, during a major test it can house up to 50 engineers

ABOVE: Telemetry room at Airbus' Filton, UK facility, monitoring an early A350 test flight

concentrator, a multiplexer to mix the audio, video and data, a transmitter and the antennas.

One objective of the telemetry center is to enhance the safety of test flights by minimizing the number of crew on board the aircraft, while maximizing the number of analysts on the ground. The other is to make the flight test campaign more efficient by providing real-time analysis support from the ground, which enables the contents of the flight to be optimized and the number of flights to be reduced.

Depending on the criticality of the test, there can be anywhere from three to 50 people following a flight test. The highest number ever was 70 for the first flight of the A350 in June 2013.

> **"THESE TELEMETRY TOOLS ALSO PROPOSE REAL-TIME AUTOMATIC MONITORING, WHICH CAN WARN THE SPECIALIST IN CASE OF AN UNEXPECTED EVENT"**

There are 12 flight test groups covering performance, aerodynamics, engine, handling qualities, flight control, braking, electricity, cabin, flutter, load, autopilot and fuel.

When the A340-600 entered flight test in 2001, a data transmission rate of 0.8Mbps limited the maximum data flow to 2,400 parameters. By the time the A380 flew for the first time in April 2005, the bandwidth had increased to 5.3Mbps and the number of accessible parameters had grown to a maximum of 8,000.

Those figures are still small fractions of the number of parameters that can be accessed – 600,000 in the case of the A350, nearly twice as many as on the A380. These figures are a function of an increase in the number of computer tasks on the newer aircraft and a parallel increase in the number of computers.

During each test maneuver, the telemetry team assesses the incoming data and advises whether it has been completed satisfactorily so that the crew can move to the next step in the test flight plan. The on-board flight test engineer has the final say in all decisions.

The central telemetry room continually analyses essential data such as fuel consumption, loads experienced by different parts of the aircraft structure, and the response of key flight control systems. Two graphic recorders can make instant printouts for closer analysis of any part of the data. Requests can also be sent from the computers in the telemetry room to the aircraft's test flight computers for more information about the performance of specific systems.

The team of specialist analysts study real-time transmissions from the aircraft on generic or ATA chapter-specific screens. Telemetry equipment is pre-configured based on the results of functional integrated benches and simulators (mainly for systems parts), but also on input derived from computations – finite element stress analysis for loads, computational fluid dynamics for aerodynamics, and so on.

The equipment then interprets flight test behavior and is able to send a warning to the aircraft when the situation becomes critical or dangerous. These telemetry tools also propose real-time automatic monitoring, which can warn the specialist in case of an unexpected event.

The telemetry center can also analyze data received from the aircraft in slightly deferred time. Deferred computation allows for a more detailed analysis, which is then compared with previous models and sent to the design office, aircraft program, other crew and test specialists after the flight test to obtain a global overview of the results. ■

Bernard Fitzsimons is an aviation journalist specializing in air transport business, technology and operations

Twilight years

Current commercial aircraft can reasonably be expected to remain active and earning revenue for 50 years, if not longer, prompting Airbus to offer operators the option of extending their service life

BY IAN GOOLD

Experience is "as to intensity, not to duration", according to automotive engineer Lawrence Pomeroy (himself quoting the author, Thomas Hardy). In other words, a career might comprise 40 years of different experiences – or no more than one year's experience 40 times over. For aircraft, that is the difference between flying many sectors a day providing short-distance shuttle flights; and operating single daily flights over long distances connecting continents and accruing myriad flying hours but many fewer landings.

Post World War II piston-engined 'propliner' designs might have come and gone in just a decade or two – and the initial turbine-powered models didn't last much longer – but jetliners dating from the 1970s and 1980s are proving altogether more robust and durable. Meanwhile, competition has seen successful manufacturers reduced to just a handful, with a great number of 'wannabes' having failed to stay aloft or even take off.

Indeed, as airliner structures and systems have been maintained to higher standards and become more reliable, the aerospace industry has reached the point now where current production models will not be replaced on final-assembly lines by completely new clean-sheet projects any time soon.

Rather, the present designs will be enhanced and improved, fitted with the latest technology systems and equipment and powered by more-efficient, new-generation engines that propel machines that otherwise look superficially unchanged apart from evident aerodynamic tweaks such as winglets. This development has been led by European manufacturer Airbus, which in the early 1970s took on the established US industry (consequently rationalized into a single entity, Boeing Commercial Airplanes) as it developed a complete family of aircraft and captured a half-share of the market (for jetliners with more than 100 seats).

In late 2010, recognizing the increasing cost of developing new designs and the diminishing performance gains from such

Image Shutterstock © tratong

investment, Airbus began offering the single-aisle A320neo (new engine option) to provide a "minimum change with maximum benefit" variant of its very successful A320. Boeing soon followed suit with the proposed MAX variant of its much longer-established model 737, its fourth iteration in more than 40 years.

The US manufacturer has applied the philosophy further with its bigger 777 twin-aisle twinjet, which is offered in 777X form with both new engines and a new wing. Competing against the 777X with its new 'xtra wide-body' A350XWB, Airbus has opted to also update its current A330 design into a similar NEO variant. At the very top of the market, Airbus is considering the merits of re-engining the mighty double-deck A380 behemoth – a development for which one (but, for the moment, only one) current operator is pleading very publicly.

HOW LONG?

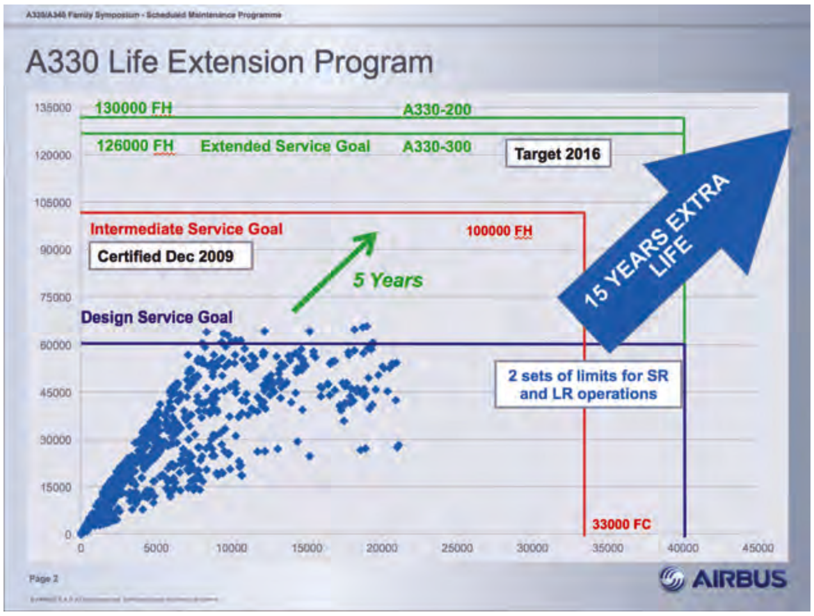
These developments offer the prospect of aircraft having working lives as long as those of people; already it is possible for a Boeing employee to have been on the 737 assembly line for 48 years. But the question of just how long thousands of jetliners produced in the past 30 or 40 years can continue to earn an honest living is one to which the aircraft makers might respond: "How long is a piece of wing?".

Manufacturers have worked with national airworthiness authorities to establish means of extending airliners' operational usefulness, and there is little evidence of planned obsolescence in major airliner designs.

Airbus agrees with Pomeroy, noting that aircraft are designed for service in terms of a limited intensity of operations, which it dubs their 'design service goal' (DSG). The phrase refers to maximum allowable numbers of flight hours (FH) or flight cycles (FC), whichever come first, that may be achieved "without reference to aircraft age".

Competitor Boeing prefers the term 'design service objective' (DSO), which is "an internal target not used as a basis for certification". The US manufacturer says aircraft may fly well beyond their DSO, so long as "there is a certified maintenance program and all required modifications are accomplished". (Boeing claims aircraft are retired more on economic factors and that economic service life is "much larger than the DSO" – see *Generation gap*, overleaf.

Aircraft FCs may be defined as completed flights (that is, landings), but can perhaps more properly be understood as the number of pressure cycles – how often the aircraft interior has been depressurized while climbing to altitude, and subsequently repressurized to local atmospheric conditions before landing.



LEFT: Airbus is planning A330-200 and A330-300 extended service goal (ESG) targets of 130,000 FH and 126,000 FH, respectively, and 40,000 FC for both variants of the twin-aisle twinjet, equivalent to 15 years' additional operational life beyond the initial design service goal (DSG) – an intermediate increase to 100,000 FH was certified in 2009 and Airbus hopes the new ESG can be approved next year

Although the term is used generically within the industry, unqualified references to an aircraft's 'life' can be mistakenly inferred to represent actual (or prospective) calendar age. Nevertheless, Airbus acknowledges that generally DSG is "aligned with a 20-year utilization" at average flight times, which for the Airbus family vary between 1.3 hours for the A320 short-/medium-range jet and 7.4 hours for the A380 long-hauler.

In fact, there is some flexibility in application of FC and FH limits, so that operators with atypical FH:FC ratios – most usually, those flying very long sectors – may trade one for the other, since fewer airframe pressure cycles/landings tax the structure less and permit increased exposure to less-demanding cruise flight. As an example, the A330's initial DSG was defined as 60,000 FH and 33,000 FC for short-range operation; and 45,000 FC for long-range services.

To allow operators to increase operational boundaries imposed by FC and FH limits, manufacturers typically develop extended service goal (ESG) – or 'life extension' – packages that can provide many more years of additional revenue service above initial objectives. Airbus suggests, for example, that ESGs that it expects to establish in 2016 for the A330 will permit an extra 15 years' life.

What does this mean for operators? "The ESG will enable our customers to earn additional revenue by flying their aircraft longer, as well as benefiting from the increased residual value of their fleets," says John Grant, head of upgrade services marketing in Airbus Customer Services. "In addition, operators will have the opportunity to upgrade their fleets to keep aircraft at the highest level of efficiency."

Airbus encourages forward fleet planning by its customers in order to introduce the ESG in the most cost-efficient manner, by including necessary modifications or upgrades in work packages to be completed while aircraft are 'down' for a heavy-maintenance visit (HMV).

When an aircraft approaches the DSG limits, owners have a simple choice to make, according to Grant: "They may withdraw it from service, or they may invest in the ESG program. Most decisions will be based on the business case."

In the case of the A320 fleet, about 600 examples face such consideration in the coming five years. Up to the beginning of June, Airbus had received firm ESG upgrade orders covering 110 machines, with about 230 more in the "acceptance process", and around a further 100 aircraft "under discussion".

Grant points out that it is in the airline's interest to consider the impact of the ESG ahead of programmed HMVs. "Such planning can save costs and ensure the timely embodiment of the work. Structural reinforcements may need to be embodied in a calculated timeframe and this allows some flexibility."

How is an ESG package defined? To permit operations beyond initial DSG thresholds, airworthiness authorities demand that manufacturers demonstrate that the basic aircraft design is physically capable of further service to the degree proposed.

PROVEN PERFORMANCE PLAN

"This is a task performed and coordinated by Airbus for our aircraft," says Grant. "A number of actions – including stringent analysis, full-scale fatigue tests, systems reviews, and consideration of operational feedback analysis – are carried out. Once complete, the necessary actions enabling the aircraft to fly longer are agreed and the required service bulletins (SBs), inspections and maintenance practices are formulated and certified."

Aircraft testing to certify the ESG is performed and paid for by Airbus, with equipment and systems suppliers and engine manufacturers conducting their own related similar exercises, ahead of airworthiness approval. Airbus also provides certified SBs and conducts a review of concessions (basically, permitted deviations from build standard, such as those that arise with in-service repairs and which are specific to individual aircraft). For its part, the operator buys Airbus SBs and kits and arranges inspections and embodiment by an approved maintenance, repair and overhaul (MRO) provider, which could be its own in-house engineering department.

Several requirements are to be satisfied when developing an ESG limit

GENERATION GAP

With early-build Boeing 737NGs only now reaching mid-career, the US company said last year that it had no short-term plans to develop a life-extension package. "The oldest 737NG is 17 years old and the high flight time is getting close to 60,000 FH, and 42,000 FC," said Boeing maintenance-economics director Khwaja (KM) Ali.

The 737NG began life in the late 1990s with a DSO of 20 years, 75,000 FH or 51,000 FC. "The DSO is an internal target not used as a basis for certification. Airplanes may fly well beyond DSO so long as there is a certified maintenance program and that all required modifications are accomplished," Ali asserts of DSO implications.

The company expects the 737NG to have a 100,000 FC/125,000 FH certification limit of validity (LOV), essentially meaning that operations would then cease unless new fatigue testing and/or modifications justified DSO extension.

The US Federal Aviation Administration requires manufacturers to offer any service actions needed "to preclude the onset of widespread fatigue damage, and to establish an operational LOV that effectively defines an airplane's usable life," which is based on fleet data and fatigue testing, according to Boeing.

It has estimated that the first 737NGs to reach the LOVs will be about 36 years old, but that this will not occur until after the year 2030.

ABOVE: **With the structures of commercial aircraft sufficiently robust to fly for decades, manufacturers have taken to modifying them with new more-efficient engines, a trend led by the Airbus A320neo, seen here on its first flight in Toulouse, France, in September 2014**

to permit aircraft to be flown for longer periods than initially intended. An overall 'top cover' SB is issued, functioning essentially "almost as a validation, or entry ticket, from Airbus to the ESG program" for a specific aircraft, Grant explains.

Any relevant "repair design-approval sheets" are reviewed to confirm that repairs previously performed on that machine remain applicable up to the ESG limit. In addition, a small number of components covered by systems SBs may need to be replaced, while airframe structural reinforcements and kits may also be required.

Following approval of requisite documented actions and analysis, ESG programs are now available from Airbus covering the first three aircraft families in its product range: the A300/A310, A320, and A330/A340. Embodiment of the new life-extension limits depends not only on the Airbus model (or type), but also on its configuration, according to Grant. "Once the needs for individual aircraft are identified and the required actions taken, flight operations can continue past the original DSG objectives in line with the airworthiness authority certified maintenance program."

Since required work to embody an approved ESG may be specific both to an operator and an individual aircraft, as many as 900 man-hours might be required to install all structural SBs, warns Grant. This is why Airbus counsels airlines to consider well ahead of time any such ESG work, which then "could be spread over a number of years, dependent on the specific aircraft".

The Airbus executive confirms that ESG embodiment does not generate any step-change in the frequency of routine maintenance checks. Rather, the ESG is "required to enable the aircraft maintenance program to be continued past the DSG".

What about airlines whose long-range operations mean they "clock up" flying time relatively quickly, while not logging lots of landings? For A320 and A330/A340 aircraft, Airbus has introduced an interim service goal (ISG) to permit operators with a higher than average FH:FC ratio to achieve a 'stepping stone' extension before full implementation of the ESG provisions.

As Grant explains, "The ISG was defined by trading cycles for additional hours for the A320 and A330 only, without the need for extensive testing – but, of course, meeting certification requirements." He also confirms that new production A320s, for example, cannot be delivered with an ESG as standard. "The original DSG of an A320 is delivered with the aircraft, and the extension will be reviewed in a 20-year timeframe, as for existing aircraft in service." ∎

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AIRBUS FAMILY LIFE EXTENSION (CERTIFIED SERVICE GOALS)

MODEL	DESIGN SERVICE GOAL			INTERIM SERVICE GOAL****			EXTENDED SERVICE GOAL		
	FC*	FH**	AFT***	FC	FH	AFT	FC	FH	AFT
TWIN-AISLE (EARLY MODELS)									
A310	26000	40000	1.5				48000	75000	1.6
A300-600	26000	40000	1.5				40000	85000	2.1
A310	26000	40000	1.5				42500	75000	1.8
SINGLE-AISLE									
A319	*48000*	*60000*	*2.0*				*60000*	*120000*	*2.0*
A320	48000	60000	1.3	37500	80000	2.1	60000	120000	2.0
A321	*48000*	*60000*	*1.3*				*60000*	*120000*	*2.0*
TWIN-AISLE (LONG RANGE)									
A330-200 (WV 000 and 020 series)	*40000*	*60000*	*1.5*	*33000*	*100000*	*3.0*	*40000*	*130000*	*3.3*
A330-300 (WV 000 and 020 series)	*40000*	*60000*	*1.5*	*33000*	*100000*	*3.0*	*40000*	*126000*	*3.2*
A330 (WV 050 series)	33000	100000	3.0	N/A	N/A	N/A	TBD	TBD	TBD
A340-200	20000	80000	4.0	20000	100000	5.0	25000	134000	5.4
A340-300 (WV 000 and 020 series)	20000	80000	4.0	20000	100000	5.0	31000	156000	5.0
A340-300 (WV 050 series)	20000	100000	5.0	N/A	N/A	N/A	TBD	TBD	TBD
A340-500/-600	16600	100000	6.0	TBD	TBD	TBD	TBD	TBD	TBD
A380	19000	140000	7.4				TBD	TBD	TBD
A350XWB	28800	120000	4.2				TBD	TBD	TBD

*Flight cycles; **flight hours; ***average flight time (hours); ****ISG applies to a limited number of aircraft. Italic figures represent values not yet certificated. WV = weight variant. *Source: Airbus (2014)*

Q&A

TESTING TALK

Meet Randy Neville, chief model pilot for the Boeing 787 Dreamliner, and the man responsible for engineering flight-test activities related to all Boeing 787 airplane models

BY CHRISTOPHER HOUNSFIELD

HOW DID YOU BECOME A TEST PILOT AND HOW DID YOU MAKE THE JUMP FROM F-22 TO 787 TEST PILOT?

I loved airplanes from a young age, and I loved understanding the technology that made them work. I studied engineering in college, and then flew fighters in the USAF. That experience and academic background gave me the opportunity to attend the USAF Test Pilot School at Edwards AFB, California – an intense year equivalent to full-time pilot training, while working on a technical Masters degree. The timing worked great for me, and upon retirement from the USAF, I was hired by Boeing to be a part of the test team for the new F-22 program – an amazing airplane. As the airplane became operational and the testing slowed down, I looked for other opportunities in the company, and the future looked bright in the commercial area. I had helped periodically in Boeing's commercial flight test office during my stint on the F-22, so the transition went smoothly.

As different as the F-22 and the Boeing 787 Dreamliner are, I found a strong similarity in the test pilot's role in working through the engineering challenges, and the test planning involved with new, technologically advanced airplanes.

WHAT PROGRAMS HAVE YOU WORKED ON PRIOR TO 787, OTHER THAN THE F-22?

Many years ago, in my military days, I conducted testing for the USAF on the F-4 and the F-16. With Boeing, during and after my stint on the F-22, I participated in numerous test programs for new derivatives of several Boeing transports, including the next-generation 737, 757-300, 767-400, 777-200LR, and the 747-8. One of the advantages of a large, busy office like ours that does Boeing's transport aircraft testing is that we have a chance to participate in a variety of test programs, whether assigned full-time, or as a guest helper.

WHAT IS THE DIFFERENCE BETWEEN A CHIEF MODEL PILOT AND CHIEF TEST PILOT?

The difference is mostly semantic in the way we identify responsibilities in our organization. We have a chief test pilot for our flight test organization that manages all flight operations. Each of the chief model pilots reports to that chief test pilot. A chief model pilot is responsible for overseeing all of the activity related to a specific airplane type. As the 787 chief test pilot, I oversee activities related to the fleet. I also oversee any active, ongoing test activity, such as the recent high-tempo 787-9 test program. I am also responsible for pilot participation in the early development and test planning for the 787-10, now ongoing.

WITH SO MUCH COMPUTER DATA WITHIN A TEST PROGRAM, IS A TEST PILOT STILL RELEVANT?

The test pilot continues to play a crucial role in the development of today's airplanes. In fact, in a sense, it is more important than ever. In today's high-tech world, it is ever more common to incorporate technology and automation. The pilot must remain focused on understanding how that technology and the potential failure of that technology would impact the aircraft operation, safety, crew workload, training, etc.

HOW ARE YOU ABLE TO INFLUENCE TECHNICAL CHANGES AFTER FIRST FLIGHT?

A big part of a test pilot's job involves close work with the engineering design team. We are part of a large team that ensures the design meets our objectives in terms of how the aircraft will be operated. The test pilot is a key member of the team that evaluates changes to the aircraft throughout the life of the airplane. For instance, we have test pilots assigned to the 737, 767, 747 and 777, even

RIGHT: **Randy Neville in the cockpit of a Boeing 787 Dreamliner**

"ONE OF THE ADVANTAGES OF A LARGE, BUSY OFFICE LIKE OURS THAT DOES BOEING'S TRANSPORT AIRCRAFT TESTING IS THAT WE HAVE A CHANCE TO PARTICIPATE IN A VARIETY OF TEST PROGRAMS"

ABOVE: Randy Neville pictured in front of an F-22

“HUNDREDS OF WHAT-IF SCENARIOS MUST BE CONSIDERED AND METHODS DETERMINED TO MINIMIZE ANY RISK THAT MIGHT OCCUR”

though those airplanes have been in service for decades. The test pilot must ensure that any changes to the airplane will function as they are intended, and do not impact the normal operation of the airplane, such as changing the handling qualities, flight deck indications, crew procedures, or training requirements.

DO YOU HAVE ANY INVOLVEMENT PRE-FIRST FLIGHT?

The test pilot can be involved for years prior to the first flight of a new aircraft. During the engineering development, each technical aspect of the aircraft must be evaluated for safety, reliability, ease of operation, and severity of the impact if a particular system fails. That development work starts years before there is an airplane to fly. The pilot spends many, many hours in simulators and mock-ups evaluating various features. For the actual flight, the pilot is critically involved in planning each maneuver to be conducted on the first flight. Much of the planning is spent preparing for the ‘what ifs’. That is, what if: the weather is bad, the radio quits, the flaps don’t work, the telemetry link drops out, etc? Hundreds of what-if scenarios must be considered and methods determined to minimize any risk that might occur.

CAN YOU DESCRIBE YOUR AVERAGE WORKING DAY WHEN YOU FLY?

Many days include meetings with engineers, or perhaps flying the simulator to evaluate potential changes to the flight controls or other systems. The best days are the ones that include test flying. There is a main preflight briefing for all test participants that typically lasts an hour or more. While certain high-risk tests, such as first flights and flutter, have only two pilots as the only people on board the airplane, most of our test flights have a contingent of engineers on board monitoring the data in real time. There could be 10-15 engineers along on a flight, depending on how many technical disciplines are being evaluated during that day’s testing. Specialists represent such areas as flight controls, propulsion, systems, avionics, structural loads, etc. All participants board the airplane, and the testing begins. Flights might be only a couple of hours, or they could be 6-8 hours long, depending on the testing. They could be even longer, such as navigation testing over the North Pole. Much of our testing occurs around Washington state and the northwest regions. However, there are numerous locations around the USA and abroad where we might deploy for specific types of testing. That could include such things as high-altitude airport testing in La Paz, Bolivia; crosswind testing in Keflavik, Iceland; hot weather testing in Australia; cold weather testing in Canada; or complicated runway testing at Edwards AFB, California.

WHAT WERE THE VARIOUS STAGES OF INFLIGHT TESTING THAT YOU UNDERWENT WITH THE 787?

First flight and initial airworthiness – minimum crew of just the two pilots, with the data telemetered to engineers in a control room. These initial flights confirm the basic safety of the airplane prior to putting others on board. We then began envelope expansion – flying very slow and very fast, including testing to evaluate flutter, stalls, and handling qualities. Further stages involve testing the flight controls, including failures, autopilot operation and crosswind landings. We then underwent propulsion testing, to evaluate the engine operation throughout all foreseeable flight regimes, including shutting them down and relighting.

Systems operation testing was also conducted on the electrical, hydraulics, pressurization, and air-conditioning systems. Finally cold weather, hot weather, high altitude airports, and humid environments complete the testing roster.

IN YOUR VIEW, WHAT MAKES THE 787 STAND OUT AS AN AIRCRAFT?

The 787 is a pleasure to fly, even in scenarios that are typically a high workload for the pilot, such as during turbulence or in the uncommon event of engine failure. We achieved that goal with some highly sophisticated flight controls. In testing, we ensured that all of that magic in the flight control computers blended smoothly and predictably for the pilot. Other unique technologies that have huge benefits include the carbon fiber composite structure and the new-generation bleedless engines – i.e. engines that take no bleed air to be used for wing anti-ice and pressurization. Those technologies, among others, reduce airplane weight and significantly increase efficiency. They also enable a better passenger experience with higher cabin humidity, a lower cabin altitude, and the largest windows of any commercial airplane today.

AND WHAT IS THE BEST AIRCRAFT YOU HAVE FLOWN AND WHY?

It’s tough to identify the very best…

I would have to go with at least two, which are also the most recent. The F-22 and the 787 – I feel they are both the most advanced airplanes in the world in their respective areas. Evaluating the technologies that went into making those airplanes the best was a fascinating experience.

The F22, a single-seat fifth-generation fighter aircraft, has composite material – very stealthy and highly maneuverable, with flight controls and vectored thrust so the pilot can maneuver the aircraft aggressively and confidently throughout its flight envelope, from very slow speeds to very fast speeds. Furthermore, it has a suite of avionics that gives the pilot an unprecedented view of the airspace around the aircraft. Testing such technology is challenging, but gratifying to see such advanced capabilities being fielded in the USAF.

The 787 is a great airplane with smart new technology, making it a new benchmark in efficiency, environmental performance and passenger experience. But it is actually an easy airplane to fly, and many of the complex systems are automatically controlled. The challenge in flight test was to ensure that all of the magic in the systems and flight controls works properly, and that it helped the flight crew, rather than complicating their job. And it does.

GREEN WITH ENVY

Away from his flight test responsibilities, Randy Neville also played a part in the making of the Hollywood blockbuster movie, *Hulk*. "I was initially hired by the director, Ang Lee (pictured with Neville, right), to be a consultant on the movie," he explains, "as a segment of the film featured the F-22."

However, at the time of filming (mid-2002), the only F-22s that existed were the test airplanes at Edwards AFB. A military coordinator at Universal Studios was able to find an F-22 test pilot through the Society of Experimental Test Pilots, of which Neville is a Fellow.

"As a consultant for the film, I initially provided some input to Mr Lee and the set designers on the way the F-22 was being used in the film," continues Neville. "I also provided feedback on the technical accuracy of the mock-up being used in the movie. As the time to do the actual filming approached, Lee asked me to take the role of the pilot. That was an unexpected surprise, and I was happy to oblige. It was a fascinating experience. It took 2.5 long days in one of the sound stages at Universal Studios to do the filming for a segment that only lasts about two minutes in the final movie. It was a fun ride."

WHAT HAS BEEN THE BIGGEST ADVANCE IN TESTING AIRCRAFT?

In my view, there are probably two significant technological advances that enable safer, more robust, efficient testing. The advances are not the actual testing, but rather in the tools that we use: data collection and simulation.

The ability to capture and analyze ever increasing amounts of data has been enabled by technology advances. In flight test, we still have to demonstrate that the airplane flies nicely and the systems work properly, and that the engines keep running regardless of weather or extreme corners of the flight envelope. Yet onboard sensors, networks, and processing power allow huge amounts of data to be collected. That can be a double-edged sword, so we need to be careful in defining just what we need to measure to prevent getting bogged down by all the data.

New tools for simulating and analyzing the airplane yield an incredible capability to predict how the airplane will fly and how various systems will interact. Computing power gives us a great advantage to evaluate and fine-tune designs long before we actually take flight.

> "COMPUTING POWER GIVES US A GREAT ADVANTAGE TO EVALUATE AND FINE-TUNE DESIGNS LONG BEFORE WE ACTUALLY TAKE FLIGHT"

WHAT DOES THE FUTURE HOLD?

For Boeing's commercial flight test organization, there is a lot of upcoming work on our near-term horizon. The 767 Tanker (KC-46) program had its first flight in December 2014 and is now in flight test. Soon we will start the 737 Max testing. After that comes the 787-10, then the 777X. So the future looks bright.

For me personally, while I will help conduct testing on the other programs as my time allows and the need exists, I will remain primarily focused on planning for the next version of the 787 – the 787-10. That is a further stretch version beyond the 787-9. Even though first flight is in 2017, we are already doing the engineering development work.

Looking further ahead, it is hard to predict what my career will hold, as it has already taken so many paths that I had never foreseen. And each phase has been stimulating, challenging, and fulfilling. So, I will stay immersed in the technical aspects of aviation, continue to learn, and hopefully be prepared for whatever new opportunities arise.

ANY SCARY MOMENTS?

Through the years, I have encountered some situations that certainly grab your attention during a flight. However, a big part of the job of the test pilot, and indeed the entire test team, is identifying potential risks and then figuring out how to minimize those risks.

WHAT ARE THE BEST AND WORST ELEMENTS OF WHAT YOU DO?

I love my job, and I love this career field. It is a constantly stimulating environment where I never stop learning. And I am surrounded by many like-minded colleagues. Having the opportunity to get in at the ground floor of developing a new airplane, and then seeing the development through to final completion when our airline customers begin using it, is extremely gratifying. It is actually quite difficult to identify worst elements, since my entire career has been so exhilarating.

WHERE DO YOU SEE CIVIL AIRCRAFT 20 YEARS FROM NOW?

Automation will continue, and our challenge will be to ensure it helps the pilot, rather than complicating the job. Also, in many areas around the world, there are not enough experienced pilots to meet the demand, so new approaches to training flight crew in the complex airplanes have been developed. From an airplane design perspective, that means we must acknowledge that there will continue to be an increased reliance on automation, and it will be more challenging for new pilots to hone their basic 'stick and rudder' skills.

Same difference

The US Navy has begun flight testing Australia's Boeing EA-18G Growler fleet, paying particular attention to its unique software configuration and weapons platform

BY NIGEL PITTAWAY

In late July the first Boeing EA-18G Growler for the Royal Australian Air Force (RAAF) will leave the final assembly line in St. Louis, Missouri, USA, and enter a period of test and evaluation to verify its unique hardware and software configuration.

Although Australia's policy is to keep its Growlers as close to the standard US Navy configuration as possible for reasons of ease of support and interoperability, there are nevertheless some minor differences that will require a period of developmental test and evaluation.

This work is to be carried out by the US Navy on Australia's behalf, primarily at NAWS China Lake, CA, by Air Test and Evaluation Squadron VX-31 and the F/A-18 Advanced Weapons Laboratory (AWL), but some testing will also be undertaken at Patuxent River, MD, USA, by VX-23.

To be undertaken between mid-2015 and the end of 2016, the work will culminate in RAAF Airworthiness Board certification, in time to allow Australian crews to begin ferrying the first aircraft home early in 2017.

Australia ordered 24 F/A-18F strike fighters in 2007 as a 'bridging' air combat capability between the withdrawal of the General Dynamics F-111C in 2010 and the delivery of the first Lockheed Martin F-35A later in the decade.

The possibility of the RAAF also acquiring an airborne electronic capability was first made public when the Super Hornet deal was signed in March 2007 and it was revealed that the final 12 aircraft would be pre-wired on the assembly line for future conversion to EA-18G if required.

These aircraft were given the unofficial F/A-18F+ designation and in August 2012 the Australian government announced that it would acquire equipment to enable the conversion of an unspecified number of Super Hornets to Growler configuration.

In the event, however, a decision to acquire 12 new-build aircraft instead was taken in late February 2013 and initial operational capability is expected in mid-2018. Once operational, the RAAF will become the only air force other than the US Navy and US Marine Corps to field a tactical airborne electronic attack capability.

GROWLER FLIGHT TESTING

The EA-18G is replacing the Grumman EA-6B Prowler in the US Navy. The EA-18G's networked capability and high level of systems integration results in a flight test regime that is more complex than that for aircraft of previous generations.

This complexity, in particular when compared with the testing previously carried out on the Prowler, is explained by Lieutenant Commander Matthew Menza, the lead test pilot for VX-31: "There is a huge difference between testing the EA-6B and the EA-18G. The EA-18G is a complex, software-intense system of systems that integrates an AESA radar, datalinks and air-to-air weapons into a modern fighter.

"The F/A-18 architecture then integrates into a unique mission computer for the airborne electronic attack systems we call the EAU, or Electronic Attack Unit. The EA-6B is not nearly as complex and the software

MAIN: A US Navy Growler and an RAAF F/A-18A Hornet take fuel during a recent exercise. Growlers have already been tested with the RAAF's Airbus KC-30A Multi Role Tanker Transports and are cleared for operational use

ABOVE: **An artist's impression of a Growler in Australian colors. The 12 aircraft on order for the RAAF will be operated by No.6 Squadron at RAAF Base Amberley, located southwest of Brisbane**

GROWLER'S GROWING ROLE

A variant of the F/A-18F Super Hornet, the EA-18G Growler provides tactical jamming and electronic protection to US military forces and allies around the world. By jamming enemy radar, the EA-18G Growler helps aircrews reach their targets without being detected. Electronic Attack Squadron 139 (VAQ-139) – the Cougars – is a US Navy squadron currently deployed aboard the aircraft carrier USS Carl Vinson (CVN-70) in the Persian Gulf. With five EA-18G Growlers flying from the ship, the capabilities of the aircraft are critical to operations.

"We are the only airborne electronic attack platform that provides support for the joint warfighter and do it across the entire electromagnetic spectrum," explains Commander Chris Hunter, executive officer of the Gauntlets of VAQ 136. "Because of that we are a central figure in how that joint fight is brought to our adversaries," he continues.

The Growler's inherent flexibility allows it to address threats of vastly different magnitudes, whether interrupting command and control networks for enemy communications on the ground, or creating a sanctuary for allied operations in a sophisticated Integrated Air Defense System (IADS).

is more modular than in the EA-18G. The consequences of making a subsystem change in the Prowler is totally different from the EA-18G. The mission systems testing in the EA-18G requires a very thorough process that considers how each subsystem behaves and interacts with the others since they are so interrelated."

TESTING FOR AUSTRALIA

Because Australia's EA-18Gs will differ slightly from the US Navy standard configuration, there is an amount of testing to be carried out on behalf of the RAAF.

The RAAF Growlers will feature the Raytheon ATFLIR targeting pod used on RAAF Super Hornets, and they will also be integrated with more air-to-air weapons than their US Navy counterparts and there is some Australia-unique software added to the aircraft.

"The testing is being carried out to ensure that whatever changes have been made, the Australian jets will retain the same level of capability and interoperability as the US Navy's Growlers," notes Wing Commander Paul Jarvis, acting director of the RAAF Growler Transition Office. "VX-31 will be conducting the majority of that testing on our behalf but we will have exposure to the outcomes."

From a US Navy standpoint, Menza says that the RAAF configuration software will be tested by the F/A-18 Advanced Weapons Laboratory at China Lake and the ongoing test work by VX-23 and VX-31 will ensure that the ATFLIR targeting pod and other RAAF-unique requirements are properly integrated into the Australian aircraft.

"The developmental flight test of the Royal Australian Air Force EA-18G will mimic what we currently do with the US Navy Growlers. Since the RAAF funded some extra software features or improvements that are not in the current US Navy configuration, we are test flying and regression testing the minor differences," Menza says.

"It is not uncommon to change a few lines of code and impact the system as a whole. Therefore we will flight test the RAAF Growler configuration in a series of flight tests that will thoroughly check out every corner of the airborne electronic attack capabilities and regular common F/A-18E/F and EA-18G capabilities to make sure it works perfectly before turning it over to the RAAF."

Because the Australian aircraft are almost identical to the US Navy EA-18G configuration, the ranges and support required to test the aircraft do not require any modifications, and this is the same for the methods already in use in the US Navy test community.

"The aircraft is essentially the same as a US Navy Growler, with the exception of a few software features that the RAAF paid for that the Navy did not include," explains Menza.

"The RAAF has added the ATFLIR targeting pod and will expand the type and number of air-to-air weapons on its Growlers, and while this will be new flight testing for the Growler it is no different from what we do in Naval Air Systems Command with other F/A-18 aircraft. The agreement is that VX-31 and the AWL will flight test the first RAAF Growler software configuration from start to finish, and at completion will generate a certification letter to the Australians that will allow them to begin their operational test period."

AUSTRALIAN OPERATIONAL TEST & EVALUATION

RAAF OT&E will begin in the USA after the aircraft are accepted at NAS Whidbey Island, Washington, in January 2017. It will consist of about six months of operations alongside a US Navy Growler squadron, testing the end-to-end Australian system, including mission planning computers, Australian-developed tasking and mapping, maintenance procedures and logistics as well as interoperability with US and other Australian aircraft.

This will include both Australian-only and combined activities and will make use of several training ranges in the USA for this purpose. "To that end, we have Squadron Leader Matt Kitchin, a flight test systems specialist here in the Growler Transition Office, as our flight test manager," explains Jarvis. "Right now he is putting together the test and evaluation plan, looking at the measures we need to test against as well as developing the individual test plans."

From an operational perspective, the Growler will require the development of new ranges in Australia and the upgrade of others to ensure that the electronic attack capability can be tested and exercised to the maximum potential possible.

To this end, a new range will be developed close to the Growler's home base at RAAF Base Amberley in southeast Queensland. "It will be used for day-to-day geolocation and identification training, which forms the largest element of [the] Growler's role – the 'find and fix' part of the operation," explains Jarvis. "We won't be doing too much active jamming around there due to the population density and the amount of the electromagnetic spectrum that's already in use."

"A NEW RANGE WILL BE DEVELOPED CLOSE TO THE GROWLER'S HOME BASE AT RAAF AMBERLEY IN SOUTHEAST QUEENSLAND"

BELOW: US Navy test and evaluation squadron VX-31 will carry out the bulk of the Growler testing on behalf of Australia from NAWS China Lake on the west coast of the USA

BOTTOM: An EA-18G from VAQ-135 is pictured with an RAAF F/A-18A Hornet from No. 3 Squadron during Exercise Cope North Guam 15

6
Number of months of operations in the USA before aircraft are ferried to Australia during 2017

12
The number of Growlers on order for the RAAF

1.5bn
The cost of Australia's Growler program in A$

This range will be similar to one currently under construction near Whidbey Island in the USA. The existing Delamere Weapons Range in Australia's sparsely populated Northern Territory will receive an upgrade similar to a range near NAS Fallon in Nevada, USA, used for high-end exercising. "The range at Delamere won't have as many emitters as the range at Fallon, but it will be the same conceptually," adds Jarvis.

"The emitters and emulators are all joined with command and control linkages, so as to look and smell like an Integrated Air Defense System (IADS). That will also have a second-order benefit for other aircraft self-defense training. The range is designed so that we can conduct large force employment exercises. Growler never flies solely for Growler purposes, other than in initial training. The majority of our flying will be training in support of either land or maritime force elements or other aircraft. For us it's always about the protected entities."

It is worth noting that while the US Navy has a wealth of Prowler (and further back in time, USAF EF-111A) experience to use in Growler development, Australia has never before had an airborne electronic attack capability. Jarvis, however, has paid tribute to the assistance received by his team, both from Australian defense agencies and services and from those in the USA.

"The PMA-265 (F/A-18 and EA-18G) and PMA-234 (Airborne Electronic Attack Systems and EA-6B) Program Offices, the Airborne Electronic Attack Integrated Project Team, and Commander, Electronic Attack Wing, Pacific have been most gracious partners," concludes Jarvis.

"They have really welcomed us into the airborne electronic attack community." ∎

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

Crack team

Finland and Australia collaborate on Hornet fatigue testing

BY NIGEL PITTAWAY

With a shared interest in the structural fatigue life of the 'legacy' F/A-18 Hornet strike fighter, Finland is collaborating with Australia in a comprehensive test program to validate a Finnish Air Force (FINAF) modification designed to prevent cracking in one of the more highly stressed locations in the aircraft.

Finland's Patria Aviation, in conjunction with the FINAF, has developed a boron doubler, which is currently being applied to the FINAF Hornet's center fuselage structure, also known as the center barrel section, with access via the main landing gear bay.

Australia's Defence Science and Technology Organization (DSTO) in Melbourne has an extensive history of both Hornet fatigue testing and international cooperation, having performed a full-scale test on a Hornet aft fuselage section in collaboration with Canada, and is currently involved in ongoing work on center barrel fatigue testing for the Royal Australian Air Force (RAAF) and other clients. DSTO has conducted fatigue tests on 18 retired center barrels, provided by the RAAF, US Navy and Royal Canadian Air Force, courtesy of a major structural modification program to extend the operating life of the aircraft, which involves a new-for-old replacement of the center barrel.

With full-scale center barrel test articles and structural test expertise available at DSTO, an agreement between Australia and Finland has resulted in the recent application of a boron doubler to one test article and subsequent fatigue testing to assess its performance. At the time of writing, the results of this work were being analyzed, with a paper on the subject to be presented to the International Committee on Aeronautical Fatigue and Structural Integrity (ICAF) biennial conference in Helsinki in early June by Geoff Swanton, DSTO's F/A-18 center barrel test manager from DSTO's aerospace division.

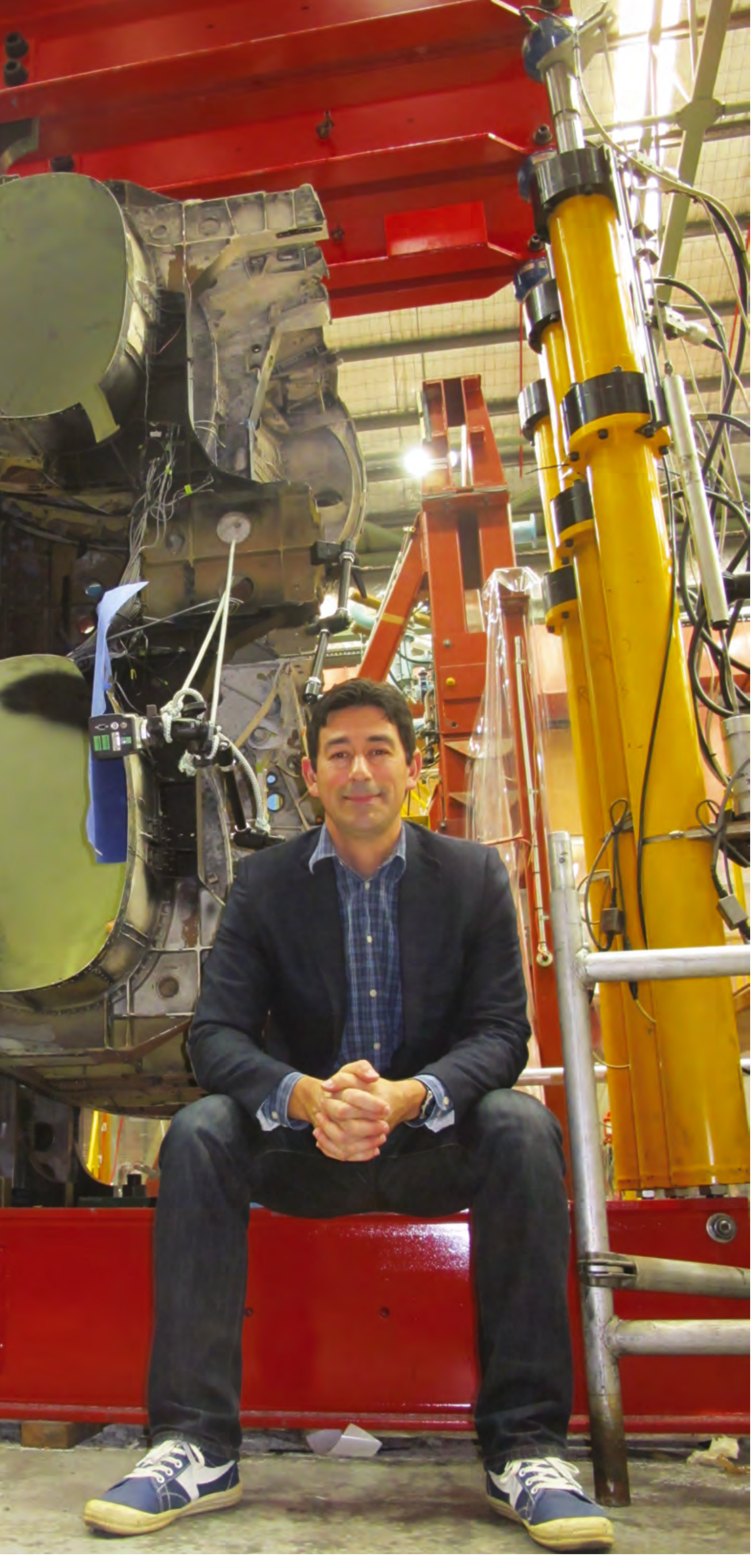
RICH HISTORY

DSTO can trace its aeronautical research history back to the 1940s, when structural test work was performed on Commonwealth Aircraft Corporation (CAC) Boomerang and De Havilland Australia Mosquito wings.

Its location at Fishermans Bend in Melbourne was no accident, being located close to Australia's two major aircraft manufacturing facilities at the time – CAC and the Commonwealth Department of Aircraft Production (DAP, later Government Aircraft Factories).

In 1947 DSTO's Arthur Wills pioneered research into aircraft structural fatigue and two years later presented a paper titled *The Life of Aircraft Structures*, which was regarded as a seminal work on the subject. Today, a specially constructed fatigue test facility at DSTO bears his name.

In 1950 what ultimately became a 12-year program into the fatigue behavior of aircraft structures began. This program involved the testing of 222 Mustang wings under a complex series of repeated loads and was the most extensive series of fatigue testing of a single type of aircraft structure ever undertaken.



During the 1970s full-scale fatigue test programs included work performed on Nomad and Mirage IIIO aircraft, as well as research into the improvement of the wing carry-through structure of the General Dynamics F-111C, prior to its introduction into service with the RAAF. During this time DSTO also pioneered fatigue life extension by the application of boron patch repairs to aircraft structures, local applications for which included RAAF Lockheed C-130E Hercules, Mirages and F-111C wings, and this technology was also used by the US Air Force in its Lockheed C-141 Starlifter life-extension program.

Discussions regarding international collaboration on Hornet fatigue testing between Australia and Canada began in 1988, which resulted in the International Follow On Structural Test Project (IFOSTP).

TESTING THE HORNET

Initial structural testing of the legacy Hornet by McDonnell Douglas, the OEM, was predicated on the operational profile and configuration of its major customer, the US Navy.

The flight profiles of land-based customers of the aircraft, such as Australia and Canada, were not the same, however, as well as there being some structural configuration differences, so as a result it soon became understood that further testing would be required.

Under the IFOSTP agreement, Canada would be responsible for the testing of the Hornet center and forward fuselage and wings, while Australia assumed responsibility for aft fuselage and empennage testing, using a representative flight spectrum common to both countries.

However, during certain flight regimes the Hornet is subject to high-frequency dynamic buffet loading, including to the tail surfaces, which until the IFOSTP testing began, could not be applied to the test article at the same time as the typical maneuver loads.

Conventional test rigs use 'whiffle trees' – a series of large beams that apply distributed loads over a wing or fuselage of a full-scale test specimen – however the mass and stiffness associated with this system has historically precluded the application of simultaneous vibratory loads.

In response DSTO developed a unique system using airbags to apply maneuver loads and electromagnetic shakers to apply buffet loads. The

MAIN: DSTO's F/A-18 center barrel test manager, Geoff Swanton

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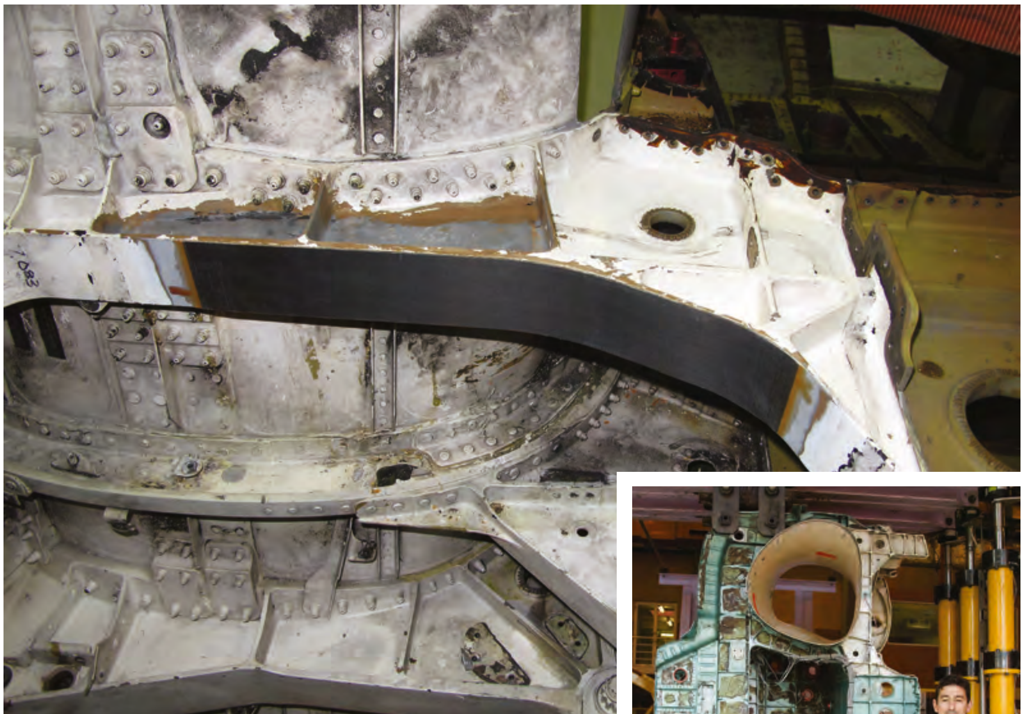
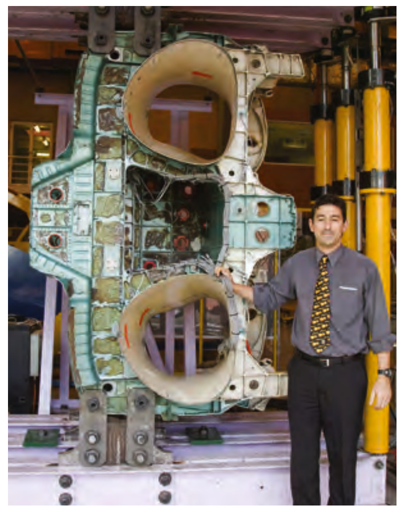


MAIN: **Finnish Air Force boron doubler modification installed on one of the lower bulkheads of a centre barrel test article, prior to testing at DSTO**



INSET: **Geoff Swanton with a center barrel in one of DSTO's test rigs**

3,909
The highest strain (unit: microstrain) recorded by a doubler gauge

15,328
The number of load points in a single block of the fatigue load spectrum applied to the test article

airbags didn't add a significant amount of structural stiffness to the test article, permitting the simultaneous application of dynamic loading via the shakers.

These tests formed the basis of the structural certification and set the life limits for the Hornet structure under RAAF operating conditions, and the work won the prestigious International Council of Aeronautical Sciences von Karman award in 2002, recognizing "outstanding examples of international cooperation in the field of aeronautics".

Since then delays to the introduction into service of the Lockheed Martin F-35A, the successor to the Hornet in RAAF service, has resulted in further DSTO analysis of the center barrel structure beyond the IFOSTP to support life-extension activities.

CENTER BARREL CRACKING

The Hornet center barrel structure comprises three major bulkheads, each of which has two large lugs at its upper corner, to which the wings are attached. Flight loads are transferred from the wings to the center barrel structure via these lugs, and the bulkheads also have cut-outs to accommodate the engine air inlet ducts, a bladder fuel tank, fuel and hydraulic lines, etc.

Geoff Swanton explains the nature of the center barrel bulkhead failures experienced during testing: "One of the locations that initially failed in the OEM fatigue test was addressed by retrofitting a metallic doubler to fleet aircraft to reduce the stress in that location," he says. "This doubler was subsequently fitted to the IFOSTP Canadian center fuselage test, and this also failed, but at the end of the doubler instead. While the OEM doubler successfully addressed the initial cracking, a by-product was that it shifted the stress concentration and potential for cracking to the end of the doubler," he explains.

The RAAF Hornet fleet has two configurations of center fuselage bulkhead: the early configuration that included the metallic doubler retrofit, and a later production version that featured a thicker section in lieu of the doubler where the OEM failure occurred.

"The bulkheads are optimized structures designed to withstand high loads without compromising weight and strength, and this means that there are numerous regions that also experience high stresses," continues Swanton. "Over the past 10 years our center barrel testing program has demonstrated that those other areas do fail as well."

"THE DOUBLER TESTING AT DSTO WHILE THE FINAF IS MODIFYING ITS FLEET IS A GREAT EXAMPLE OF CONCURRENT ENGINEERING"

It is important to note, however, that scatter factors and conservative assumptions are applied to the demonstrated test lives to reduce the risk of these failures ever occurring during the nominal lifetime of the aircraft. "The FINAF boron doubler is considerably longer than the original OEM doubler and was designed to address several of these areas, not just the original one that failed in the OEM's test," says Swanton.

THE FINNISH SOLUTION

The boron doubler developed by Patria in collaboration with the FINAF is applied to the bulkhead through the Hornet's main landing gear wheel wells of the aircraft. This easy access means that installation can be accomplished during programmed maintenance. The only disassembly required is the temporary removal of some hydraulic tubing in the wheel well.

"The FINAF is concerned that, under its own operating conditions, the fatigue life of its F/A-18C/D Hornets might not be adequate to get the aircraft out to their retirement date," explains Swanton. "The doubler testing at DSTO while the FINAF is modifying its fleet is a great example of concurrent engineering. The opportunity to take advantage of DSTO's accelerated test program means that any potential issues would become apparent years before they ever manifested in the fleet."

As a result of the collaborative agreement, four Patria technicians traveled to Fishermans Bend during 2013 and over a four-day period installed the boron doubler on an ex-US center barrel test article, before handing it back over to DSTO for fatigue testing and analysis.

8
The number of strain gauges applied to the boron doubler test article

62
The number of Finnish Air Force Hornets being modified with the doubler

ABOVE: Center barrels from RAAF F/A-18 aircraft, in their 'as-received' condition, prior to any testing

TESTING THE BORON SOLUTION

The center barrels are cycled in a purpose built test rig, which require the barrels to be rotated 90° before connecting them to the loading beams via the wing attachment lugs on each bulkhead, which are in turn connected to opposing pairs of hydraulic jacks. The rig is operated by a bespoke closed-loop control system designed by DSTO.

The jacks impart a load to the beams, which is transferred to the center barrel structure as a wing root bending moment. The cycling of the jacks simulate representative flight loads, which during flight would otherwise be fed into the center barrel via the wings.

The FINAF boron doubler and surrounding bulkhead structure were instrumented with conventional foil strain gauges so that the local strains could be accurately measured and compared. Testing began in late 2013 and continued through to April this year.

"We applied a representative RAAF load spectrum to the test article and cycled until a failure occurred. We didn't know what part of the bulkhead was going to fail or when – the whole point was to find out," explains Swanton.

"The bulkhead failed just outboard of the doubler, in one of the areas known to be susceptible to cracking. Previous DSTO center barrel tests had also failed there, without the presence of the Finnish boron doubler, so it wasn't a surprise in that regard. However, the strain gauges indicated that the stresses were reduced considerably in the areas covered by the doubler, and certainly in the other areas prone to cracking there was no failure."

Because an RAAF spectrum was applied to the test, a correlation exercise will be required to determine what this means in terms of the equivalent FINAF fatigue life, and whether the results will give the FINAF the margin it is seeking to operate its Hornet fleet out to its planned retirement date.

"The correlation activity will close the loop on this program," continues Swanton. "We should be able to estimate the number of flight hours for FINAF operations based on the results of testing under an RAAF spectrum. We've basically got to do a retrospective comparison to see how the test result translates to a FINAF spectrum. Hopefully that will give the fatigue life it's after, but we can't answer that question yet because we haven't done the correlation."

The correlation will be carried out at DSTO via a coupon test program, cycling some coupons with the FINAF spectrum and others with the RAAF spectrum, and comparing the respective crack growth rates as determined by quantitative fractography of the fracture surfaces.

"We could do it analytically and complete the work in a couple of weeks if it were using software simulations alone. However, we prefer to generate real crack growth data from which to perform the analysis," concludes Swanton. "The preferred approach of generating and using real crack growth data could take up to a couple of months to complete, but it is believed that the data will be more robust, ultimately resulting in a more accurate estimate for the management of the FINAF fleet center barrel."

DEVELOPMENTS IN STRUCTURAL FATIGUE

While the basic principles of aircraft structural fatigue testing remain the same today as they were in the 1970s, with the use of whiffle trees, loading beams and hydraulic actuators to apply load to a test article, there have been major developments in the way data is collected.

DSTO, for example, is currently undertaking research into the use of fiber optic strain sensors in lieu of traditional foil strain gauges. Known as fiber Bragg gratings (FBG), the new sensors are being assessed in conjunction with a distributed sensor system that also uses fiber optic technology.

DSTO is also using thermoelastic stress analysis (TSA) scans to support fatigue test programs, using infrared cameras to build a real-time stress map of a piece of structure under cyclical load. While there are COTS systems available, the organization has produced an in-house solution that it says is "an order of magnitude" cheaper in cost, and is continuing research to make the systems smaller and more portable. DSTO has also demonstrated this technology on Lockheed Martin's F-35 Joint Strike Fighter test program.

"We can build a real-time stress map in a matter of minutes and we are using it often now in our testing, to show where the problem areas potentially lie," says Geoff Swanton, F/A-18 center barrel test manager, DSTO.

Robot to the rescue

NRL scientists are able to predict aspects of F/A-18 performance by using a custom-designed robot as a multi-axial loading machine to test composite material samples

BY KYRA WIENS

The US Naval Research Laboratory (NRL) has built a robot to pull, bend and twist samples of the composite materials used to build F/A-18s and other aircraft. Dr John Michopoulos leads the project. With a machine that can, as he says, "measure so much more than anything else", and some very advanced math, he can "create a theory that is consistent with all these experiments that we made, and works for all scales". He predicts how the materials will perform when made into large structures and used over many years.

Sitting in his lab, Michopoulos picks something the size of a luggage tag off his desk. "This is the material that was used for the original versions of the F/A-18, for the skin of the airplane," he says. It's a sample of advanced composite, made of resin reinforced by carbon epoxy fiber. "That little thing that's so light is actually stronger than steel."

The F/A-18 Hornet became the US Navy and Marine Corps' first strike fighter in 1978; the median age of today's active aircraft is 22-23 years old. As F/A-18s continue to age beyond their design lifetime, showing structural stress corrosion cracking and wing panel composite skin abnormalities, engineers have had to do extensive analysis to develop repairs. "So," explains Michopoulos, "the need for certifying a new material comes in and we ask, 'How are we going to compare a new material and, if we start using it, have confidence it's going to behave the same as or better than the old material?'"

With the multi-axial robot, Michopoulos's lab has tested thousands of samples like this one and asked, 'How are you behaving, when you see all possible loads that you may see when you are part of a structure?'

Today, the Department of Defense (DoD) uses a building-block approach from 1999, as set out in the *Composite Materials Handbook-MIL 17*. The approach starts with testing fibers and matrix materials. Then the tests get, as the handbook states, "increasingly more complicated", until reaching the level of structural subcomponent (or higher).

It's easy to see that this is time-consuming and expensive. "I can tell you that qualifying the system for the F/A-18 took about 13,000 specimens and about 18 years," says Michopoulos. "Engineers are forced to conduct tests at multiple scales because they do not have a theory to connect the behavior across multiple scales."

As private companies and the military continue to look to advanced composites for new aerospace and other applications, NRL's robot could help get aircraft from factory to fleet faster.

UP TO 72 LOADING PATHS

Michopoulos realized that, to accurately characterize the behavior of a material, he would have to capture the behavior of the composites in every possible combination of loading – as opposed to traditional approaches, where scientists take only simple loading cases, such as tension or compression. No technology existed to do that.

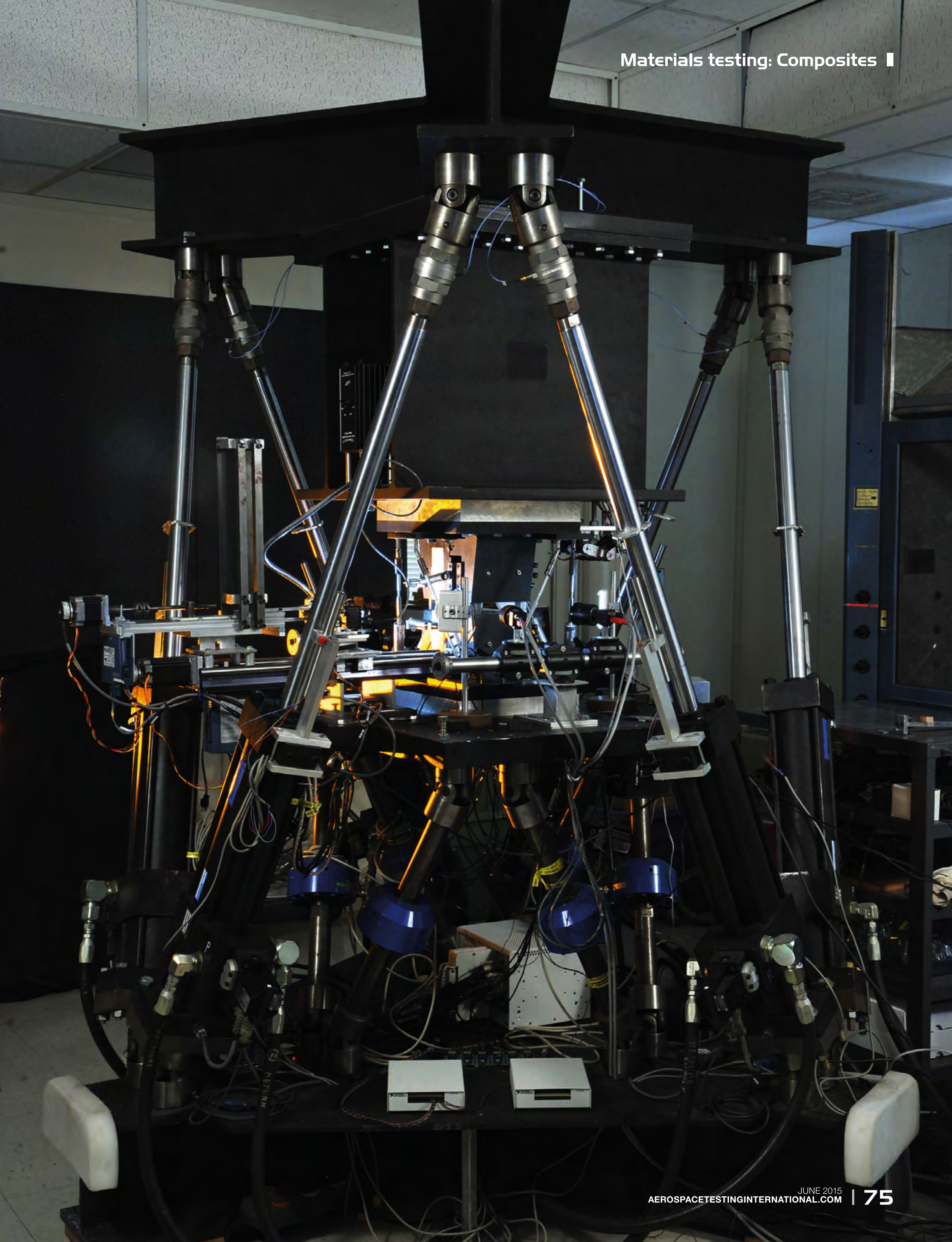
"So we said, to heck with it, let's invent it." Named NRL66.3, the robot is a multi-axial loading machine. It has six devices that apply linear movement, termed actuators, in a hexapod configuration. While a material sample is held by a fixed grip from one end, the actuators move a grip that holds the other end of a material sample, moving it in any combination of up to three translations and three rotations. "This means the robot can apply combinations of tension or compression, bending and torque simultaneously," explains Michopoulos.

Like the old jukeboxes with an arm to load the next record, NRL66.3 is fully automated. Assisted by two other robots, it will take 72 specimens of, for example, the material used in part of an F/A-18, and apply 72 loading paths in that six-dimensional space. The robot loads each specimen until it snaps, then quickly moves onto the next. A custom-developed machine vision system, with four cameras, captures digital images of what's happening in real time.

While the experiment is going on, the scientists use custom-developed full-field measurement algorithms that Michopoulos's group has now patented to take those digital images and analyze them, and convert them to displacement and strain fields.

What the experiments do is to very quickly capture what might happen to an advanced composite in the real world. Advanced composites age in a very particular way. "The resin that's

RIGHT: **The US Naval Research Laboratory (NRL) has built a robot and created sophisticated algorithms to predict, from just a small sample, how advanced composites will perform when made into larger structures**



between the fibers starts developing micro-cracks," says Michopoulos. These micro-cracks can cause the resin to separate from the fibers or the fibers to break. "A continuous accumulation of micro-cracking, which leads to a softening of the material, can be used as a metric for material degradation assessment."

The group has, over the past 20 years, used various robots to test more than 150 material systems, with potential applications for ballistic missiles to rocketry to automobile manufacturing. "So we do have a very rich database," says Michopoulos.

COMPUTATIONAL PREDICTION

A snapped composite specimen is one thing; a theory of how that material will behave when formed into a jet wing is another. But that's what Michopoulos's group has done. "It's highly computationally driven," he says. "You cannot write on a small piece of paper a single equation that encapsulates how composites behave."

From 2008-2012, the Cooperative Research Centre Advanced Composite Structures (CRC-ACS) of Australia provided specimens to NRL to test and characterize, while it did its own tests using more traditional methods. Universities in Australia and the Massachusetts Institute of Technology also participated in the project, with support from the Office of Naval Research (ONR). "We tested 1,152 specimens in 12 days; that has never really happened anywhere anytime before," notes Michopoulos.

Additionally, as Michopoulos explains, "ONR said, 'CRC-ACS is also going to create specimens that you're not going to test, but instead they are going to test. But you will tell us ahead of time, in a blind prediction, how they're going to behave.'"

Michopoulos's group ran predictions on the tests that they would make, which were really bigger specimens with holes or with stiffeners and so on. "We came within a maximum error of 3% on anything they asked us to predict," he says. Without having tested these specimens experimentally at NRL, they were still getting the same results as CRC-ACS because of all the data they'd captured with NRL66.3.

"For me," he says, "it really was kind of fun to see this going on before my eyes, and having all the collaborators experience it."

NRL collected 12TB of data during the testing period. "Just to give you an idea of how much richness there is in

LEFT: An F/A-18E Super Hornet from the Vigilantes of Strike Fighter Squadron (VFA) 151 launches from the flight deck of the aircraft carrier USS John C Stennis (CVN 74)

BELOW: Dr John Michopoulos with NRL66.3 – the robot he and his group built at the US Naval Research Laboratory

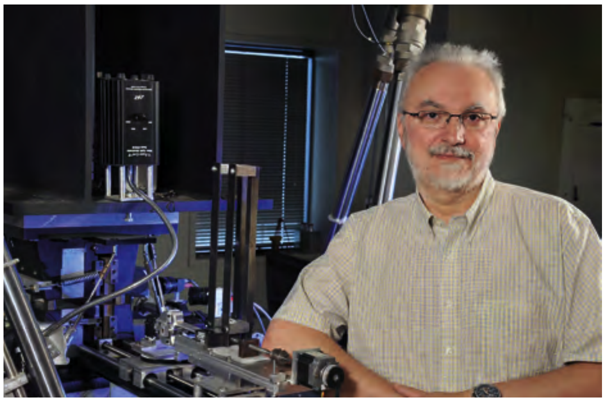
DATA MANAGEMENT

Robots used in the testing of composites are able to capture huge amounts of data, but how is this data best managed and interpreted? Indeed Dr Michopoulos says that NRL66.3, in its first fully autonomous campaign, generated a staggering 12TB of data. "It was therefore critical to use data reduction and mining methodologies to get to what is essential and useful," he explains.

"For example, the largest part of our data comes from the digital images (four per second) captured by the four-camera vision system we designed to feed our displacement and strain measurement methodology, based on NRL's custom-built Meshless Random Grid method, which is orders of magnitude more accurate and more efficient than the Digital Image Correlation method employed by most of the commercially available software," he continues. "This software layer identifies the geometrical centroids of dots painted on the surfaces of the specimens and therefore it no longer needs to carry the bitmap images captured by the cameras. This step alone achieves a 70% reduction of the data needed for the follow-up analysis.

In addition to that, a mesh-free approximation is used to represent the continuous field of the displacement and strain field data, which essentially achieves two goals: it eliminates the need to actually carry the centroid information, and at the same time generates the information needed for all areas of the specimen including the empty space where there were no centroids. So the data is reduced further, but the useful information increases by orders of magnitude.

Then this information, along with the information collected from the load and displacement sensors, is used to define the elements of a design optimization methodology that minimizes a properly constructed objective function. This process yields the values of the design variables that have been selected to be the unknown constitutive parameters of the material. The interpretation of these parameters is the usual interpretation of constitutive properties (anisotropic elastic, and inelastic with damage parameters) that are usually coefficients of a strain energy density functional."



12
During a 12-day testing period, NRL collected 12TB of data

72
Number of loading paths applied by NRL66.3 to each specimen

1,152
In just 12 days, NRL tested 1,152 F/A-18 composite specimens

CHALLENGES AHEAD

Despite the advances made by the US NRL, there are still challenges to be overcome before it can further improve its understanding of certain aspects of the behavior of composites. These challenges can be classified into three categories:

- **The multiphysics testing conditions challenges: For contemporary optimized design under simultaneous exposure of realistic composites under multiple field excitations such as temperature, humidity/water and electromagnetic fields, in addition to traditional mechanical loading, certain test configurations and methodologies need to be created. However the unwanted interaction of some of these fields with the instrumentation involved presents critical isolation and integration challenges.**
- **The *in situ* quantitative micro-tomography (mXCT) characterization of multiscale multi-axial damage: Various teams in the USA and Europe have identified that in order to understand the evolutionary propagation of all species of damage involved with the integrity of composites under various loading conditions, one would have to be able to monitor the *in situ* evolution of the various types of damage in real-time as the relevant materials are tested under relevant loading conditions. While NRL has solved the problem of multi-axial robotic testing, and while various manufacturers of quantitative x-ray tomography and mXCT have solved the problem of identifying and quantifying the material damage in a postmortem *ex situ* fashion, nobody has yet been able to integrate the multi-axial loading capability of NRL and an appropriate mXCT capability to enable the real-time monitoring and quantification of damage evolution, because of the instrumentation challenges imposed by the two technologies that define opposing requirements. Nevertheless, NRL is actively working in collaboration with MIT to address these challenges.**
- **Embedded sensor and actuator testing: When embedded sensor or/and actuator systems are integrated with composites for smart structures or health monitoring applications, the behavior of the resultant aggregate system can no longer be assumed to be the same as that of the original composite when it does not contain the embedded devices. Characterization of the integrated aggregate system now requires special considerations that account for both the hardware and software overhead associated with all the embedded devices in such a manner that they maintain their integrity despite the loading conditions imposed by the characterization tests. The complexity of the issues associated with the property mismatches between embedded devices and material, as well as the reliability and integrity of measurement, remains very high today – from both the testing and the deployment perspectives.**

this data," he says, "out of the 72 loading paths we applied, an MIT student based a dissertation on just one of them."

Michopoulos wants to offer design engineers a simulation environment based on actual data. "Instead of asking the question, 'Is this good or bad in a general sense?' – which again, is never really what they mean – it is better to ask, 'Is it good for a particular use for me at this moment for my current needs?'"

BEST OF TIMES

While Michopoulos is interested in continuing to run experiments on composites, he refers to it as a third-best time activity. "Characterization of composite materials," he says, "is a domain that I'm fortunate to be able to express – as an industrialization process, an application."

BELOW: **An F/A-18 Hornet strike fighter conducts a combat mission from the USS John C Stennis (CVN 74)**

"WE CAN HAVE THE MACHINE DECIDE WHERE IT WANTS TO GO TO GET THE BEST POSSIBLE DATA FOR CHARACTERIZING THE MATERIAL IN REAL TIME"

But, he says, "If done correctly and efficiently, we have some leftover time to reinvest in developing the tools we want in the future." That time he calls second-best time. "If you look at the roots of development of technology, you see that the real revolution and progress has come from the time people spend developing their tools."

What Michopoulos wants to build in the future is a self-configuring, self-organizing machine: "That's the area I want to go. A robot that has a process to optimize its own performance based on how well it collects data for material characterization." Such a robot could give more information, and do it more quickly and with fewer specimens.

The robot he has today can apply one loading path per specimen. Instead, he envisions a robot that could "follow a different path, a zig-zag, or a curvy path" – maybe even have actuators that move around to change the machine's shape. "We have initial analysis that shows that, indeed, we can have the machine decide where it wants to go to get the best possible data for characterizing the material in real time."

But then, he says, "There's first-best time, which is really developing your mind. It's that time that's the most inefficient and the most painful – but also the biggest fun, and therefore the most exciting."

Michopoulos has a PhD in theoretical and applied mechanics and applied mathematics from the National Technical University of Athens and pursued postdoctoral research in multiphysics, fracture mechanics, and applied mathematics at Lehigh University. When he tells how he came to be at NRL in 1986, he describes what his future mentor, Dr Phillip Mast, asked in the interview: "He said 'If you imagine there is a line connecting Socrates with Bertrand Russell, where are you on this line?' Instead of asking me an engineering and mathematics question, he asked me that question. So then I knew I had to stay."

Kyra Wiens is a public affairs specialist at the US Naval Research Laboratory

TESTING ACOUSTIC FATIGUE

High-intensity acoustic fatigue testing in Chinese spacecraft ensures the resilience of key components

Spacecraft, including satellites and launch vehicles, experience high levels of mechanical, thermal and acoustic stress, particularly during launch. High sound pressure levels can cause damage to thin metal plates and electronic printed circuit boards within the spacecraft assembly. Rigorous acoustic fatigue testing is an important part of ensuring the resilience of spacecraft and their components.

Founded in 1956, the Beijing Institute of Strength and Environment Engineering (BISEE) is the main research institute and certification testing organization for aerospace structural reliability engineering in China. It has ISO 9000 certification, ISO/IEC17025 national laboratory accreditation and multiple military qualifications. BISEE is part of the China Academy of Launch Vehicle Technology, one of the largest centers for launch vehicle research, design and manufacture in the world. Its most successful product is the Long March vehicle.

BISEE uses an m+p international system with a total of more than 760 channels to perform environmental and reliability testing, including acoustic fatigue and vibration testing on various types of missile, rocket, satellite, ground equipment and instruments.

ACOUSTIC TEST FACILITIES

To achieve the high noise levels required for realistic acoustic fatigue testing (typically 130-170dB), a reverberant acoustic test facility (RATF) or a progressive wave tube (PWT) is normally used. An RATF uses the internal resonances within a chamber to store energy and deliver diffuse high sound power levels to the test object. A PWT is a tube (usually rectangular) in which the sound energy flows in approximately flat waves, with virtually no reflections, either at right angles to the test object or at grazing incidence. RATF facilities are used to test larger assemblies – for example, a satellite – whereas PWTs are used for smaller components, or flat items, which may be incorporated into one wall of the PWT. The high sound levels required for acoustic fatigue testing are potentially dangerous and it is therefore essential that the system controlling the noise generator(s) is responsive and reliable to ensure that sound levels do not exceed specification.

CONTROLLING PWTs

BISEE uses m+p international's VibRunner hardware and VibControl software to provide fully automatic, repeatable closed-loop control to a reference narrowband spectrum for its PWTs. Eight m+p VibRunner modules, each with 16 analog input channels and two analog output channels, are employed to control and measure up to 12 PWTs simultaneously using a single computer. Separate control profiles can be defined for each PWT. A key benefit of the system is that each drive signal can be stored for later use, avoiding the need for an equalization stage and speeding up test time. Additional safety features include automatic microphone drop-out detection and exclusion and extensive octave band and OASPL (overall sound pressure level) alarm and abort checks.

The institute also uses three more m+p international systems for acoustic control and testing in its RATFs. "Over extensive testing, the high performance and reliability of the m+p system was proven, especially in complex and hostile conditions," a BISEE engineer comments. "The scalability and flexibility of the hardware and software system makes it very easy to adapt our systems to meet new requirements."

ABOVE RIGHT: **China's Long March 5 launch vehicle**

RIGHT: **m+p international's system for automatic, closed-loop PWT control**

FLY THE LIMITS

A professional test platform for developing new flight guidance and envelope protection systems

FIGURE 1: Testing novel flight guidance and envelope protection systems with the unmanned research aircraft ULTRA Dimona (HK36R Super Dimona in the scale of 1:3)

The envelope of an aircraft is restricted by a set of aerodynamic and structural limits, as well as by a wide variety of internal system constraints. To stay within these limits and to not overstrain flight control subsystems, current flight guidance and control systems contain sufficiently large safety margins at each automation level. When automation increases, this leads to a decrease of system performance, creating a high potential for optimization.

Today's protection functions implemented to keep the aircraft within a safe flight envelope are located at the lowest automation level. They have an ultimate feed-through to the final control commands and once they become active, all high automation functions are dropped. Thus, advanced flight guidance functionalities are not available at the envelope limits.

The objective of advanced flight guidance and envelope protection systems, developed at the Institute of Aircraft Systems Engineering of the Hamburg University of Technology (TUHH), is to enhance the overall system performance on higher automation levels while maintaining the current safety level.

The newly developed, model predictive flight guidance system explicitly knows when and where the original protection functions become active and how to prevent their activation by actively maintaining the aircraft in the safe operating envelope.

THE ULTRA PROJECT

To reduce the cost on flight test equipment and to lower regulatory requirements, an unmanned, scaled-down (1:3) research aircraft (HK36R Super Dimona) provides a reliable and cost-effective platform for technology demonstration, increasing the level of acceptance of novel concepts, such as the advanced flight guidance and envelope protection system. The Unmanned Low-cost Testing Research Aircraft (ULTRA) project, founded by the Institute of Aircraft Systems Engineering at TUHH, enables such capabilities within a representative framework for researching and testing the adoption of industry-standard software and hardware components.

The ULTRA project provides not only the ability of flight testing with the research aircraft, but also a laboratory infrastructure enabling software-in-the-loop (SIL) and hardware-in-the-loop (HIL) simulations. A generic, high-fidelity flight simulation environment and corresponding toolchains support the execution and analysis of virtual and real flight tests. The ULTRA test platform is comprised of a distributed, generic hardware and software network, connected via Ethernet and CANbus. Using commercial off-the-shelf (COTS) hardware and software components, the flight test platform enables an aircraft industry's rapid prototyping process on a representative, standardized industrial level. Key enablers are dSPACE real-time systems in conjunction with MATLAB/Simulink from MathWorks, which provide a highly integrated and widely used development and integration environment. This setup enables easy model-based development and implementation processes even for students.

VIRTUAL AND REAL FLIGHT TESTING

The complexity of the test platform and of the actual control algorithms make success in real flight tests unlikely to happen in the first trial. Accordingly, a three-stage virtual flight testing strategy is used to provide adequate preparation. The baseline is the generic flight dynamic simulation that consists of flight dynamic models of the unmanned research aircraft and emulations of respective system and sensor components. Depending on the level of integration of real hardware (flight control computer, sensors, actuators, etc) the virtual flight tests are carried out in model-in-the-loop (MIL), SIL and HIL real-time simulations using dSPACE hardware.

To conduct real flight tests with the research aircraft in a nearby airfield, a mobile infrastructure is required. The ground control station accommodates the on-ground part of the ULTRA test platform. During testing of the advanced flight guidance and envelope protection system, selected data is transmitted between the aircraft and ground control station through a telemetry link that uses a long-range wireless Ethernet bridge. Specifically developed toolchains enable the planning, monitoring, and control of flight tests. Modern display concepts provide situational awareness of the flight conditions for both the safety pilot and the flight test engineer. This includes the indication of the envelope limits and the aircraft's proximity to these.

The simplicity of testing, implementing and operating advanced flight guidance and envelope protection systems is one of the major advantages of using a dSPACE MicroAutoBox on board the research aircraft. Therefore, efforts regarding coding, data handling and performance limitations are reduced to a minimum. All onboard avionics, including sensors to measure aerodynamic flight parameters like airspeed, position, attitude or angle of attack, are connected to the dSPACE MicroAutoBox via CANbus, enabling a reliable and rapid reconfiguration of the hardware architecture such as linking further avionic components and sensors. Simple control of all actuators is provided by the PWM interfaces of the dSPACE MicroAutoBox. ▮

FIGURE 2: **Development, simulation and test infrastructure in the ULTRA laboratory with dSPACE real-time systems**

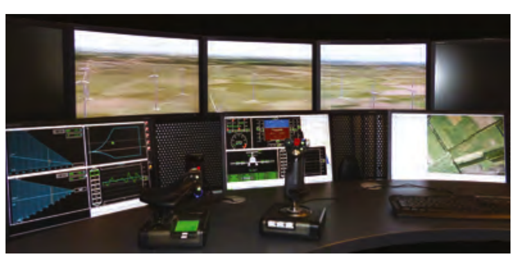


FIGURE 3: **Controlling and monitoring virtual flight tests with the ULTRA laboratory display concept**

FIGURE 4: **Mobile ground control infrastructure at the flight test airfield**

INTEGRATING NAVIGATION

A high-frequency interface for flight simulation allows dynamic integration of navigation systems, further extending TechSAT's test system technology platform

The integration of avionics navigation systems in commercial aircraft is a highly sophisticated engineering task. A broad spectrum of knowledge from navigation to electronics and high frequency technology is required to master the complexity of navigation system integration.

Around the world, several vendors provide measurement and test solutions for navigation aids such as instrument landing systems (ILS), distance measurement equipment (DME), VHF omnidirectional radio range (VOR), or radar altimeter (RA). They focus on dedicated applications at equipment level, such as transceiver testing, high frequency signal analysis, calibration or field tests.

DYNAMIC INTEGRATION

Aircraft integrators use test systems for integration tasks at system or aircraft level as a matter of course. These test systems usually provide interfaces for the aerospace buses such as A664, A429, A825 or MIL1553B, and other discrete and analog I/O. HIL test systems additionally provide suitable aircraft, environment and flight simulations, allowing closed-loop operation of the system under test. An HIL test system for dynamic integration of navigation systems has to provide high-frequency interfaces for the different aeronautical radio navigation signals.

The challenge is to provide a high-frequency interface for flight simulations that does not increase the complexity of the test system with regard to the high-frequency technology and all details of navigation.

The best approach is to build an HF simulator as a black box system for each navigation aid. The different HF simulators encapsulate the technological complexity and only provide the necessary interfaces for the flight simulation and the HF signals to the real navigation equipment. In this way, the HF simulator can be used for navigation subsystems or synchronized to a single simulation environment for the entire navigation system. TechSAT's HF simulators for navigation are available for global navigation satellite systems (GNSS), ILS, DME, VOR, RA, and the automatic direction finder (ADF). The GNSS solution currently supports GPS, GLONASS and the satellite-based augmentation system. BeiDou and Galileo are available on request.

SYSTEM ARCHITECTURE

All of the HF simulators except the ADF simulator are based upon widespread COTS test equipment that forms the high-frequency component. The ADF simulator is the only one that has to transmit modulated and synchronized HF signals on three HF lines. Therefore a new product has been realized for the HF component of this application to keep complexity and cost down.

In the figure below, the principle architecture of all simulators and their integration in the Avionics Development System 2nd Generation (ADS2) test system is shown – in this example, the ADF simulator. The high-frequency component of the ADF simulator is connected to the real ADF antenna input by cable and used to generate the HF signals. It is integrated into the test system by standard Ethernet.

The ADF simulator software component is used to control the HF component and make it dynamic for the closed-loop operation in the HIL test system. The software gets all data of the flight and environment simulation that is relevant for the dedicated application. It also computes all navigation algorithms to command the proper HF generation that is required for a particular flight phase.

All information relative to the actual aircraft situation is generated in the flight and environment simulation and exchanged with the ADF simulator software.

Any 6DOF flight simulation with world scenery data (flight gear, for example) providing a fitting dynamic data interface can be connected to the HF simulators. In a closed-loop scenario, the HF signals received by the ADF are converted and transferred via the ADF data interface to the rest of the navigation system, or directly to the test system.

When comparing the information simulated over the HF signal lines with that received on the data interfaces of the system under test, the dynamic functionality of the entire navigation system is verified.

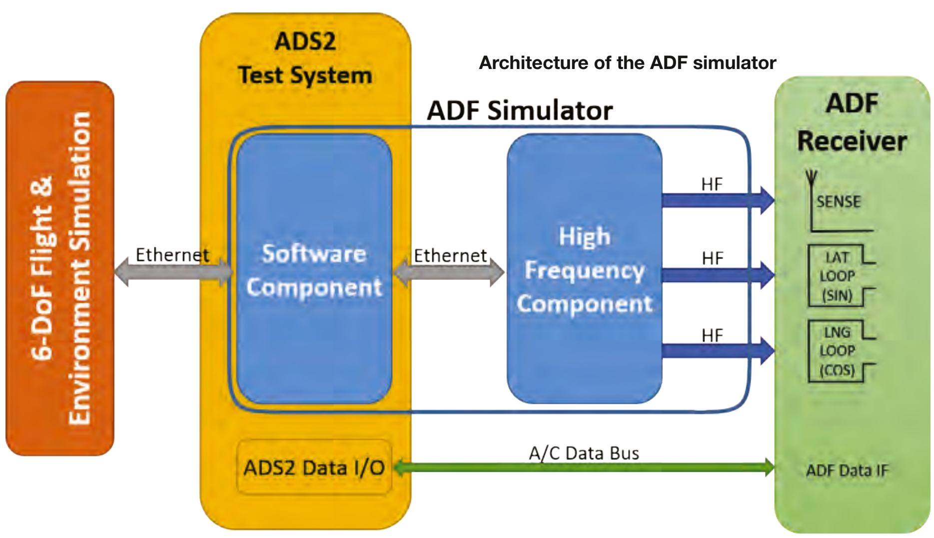
USER BENEFITS

TechSAT's high-frequency simulators for navigation are fully integrated into the ADS2 real-time environment. Once they are connected to the system under test and integrated into the flight and environment simulation, they operate transparently. Using a dedicated graphical user interface, they are controlled in the same way as the entire ADS2 technology platform. Therefore the test team and operational staff require no additional training.

The modular design of the HF simulator allows for the future extension of navigation aids such as ground-based augmentation systems or traffic alert and collision avoidance systems. The design of HF simulators for communication systems (VHF, satcom) will allow integration of future air navigation system features in HIL test systems.

Versions of the existing HF simulator for integration into other test environments are available upon request. ∎

Architecture of the ADF simulator



SOLID SUPPORT

Bonding tester to ensure the electrical and structural integrity of the aircraft

Ground support equipment approved for the Airbus A350XWB

The launch of a new aircraft is always an exciting experience for the aerospace industry. When a brand-new aircraft enters service, new test and ground-support equipment (GSE) is required. For the new Airbus A350XWB, Test-Fuchs has developed a special ground-support package, which consists of a hydraulic ground power unit, a fill and drain device for the supplemental cooling system, a multifunctional bonding tester, and a waste line cleaning trolley. All four devices have received manufacturer certification.

Hydraulic ground power units are needed to supply the hydraulic pressure for functional tests to an aircraft when the engines or APU are not running. This is necessary for the aircraft technicians when they perform certain tests or checks on the aircraft. Apart from supplying the aircraft with hydraulic pressure, the Test-Fuchs Hydraulic Servicing Trolley also performs various other tasks: water removal, filtering or deaeration of the hydraulic medium. This specific ground power unit is already successfully in use in more than 200 locations worldwide. Since the hydraulic system of the Airbus 350XWB is slightly different from other already certified Airbus aircraft, it was necessary to adapt the trolley to the new aircraft, and then undergo a new manufacturer certification process. In accordance with ATA chapter 29, the necessary tests are performed in an easy, quick and reliable way.

Another item of GSE for the Airbus A350XWB is a fill and drain device for the supplemental cooling system of the aircraft. This set consists of a trolley, a fully automatic fill-drain device, plus a manual top-up unit and an adapter kit for the A350XWB. This set is used to drain, fill, bleed and top up the aircraft supplemental cooling system with the appropriate propylene glycol water cooling fluid, in accordance with ATA chapter 21. The whole test set is extremely simple to operate and therefore minimizes service times as much as possible. Driven by a hand pump, the ergonomic top-up unit is completely independent from any electrical supplies. All hoses and adapters are stored on the unit and provide excellent access to the filters and the removable waste fluid reservoirs. Outdoor operation is possible in extreme environmental conditions from -30°C to +50°C.

A Test-Fuchs bonding tester has also been certified for use on the A350XWB. Bonding tests are necessary because the electrics and structure of these very complex aircraft are exposed to lightning, electrostatic charging, high temperature differences and corrosion. To make sure that the electrical and structural integrity of the aircraft has not been damaged, non-destructive bonding tests have to be carried out. The multifunctional bonding tester is equipped with adequate clamps to undertake various tests quickly and reliably. The tester can also be used on all other aircraft types.

Also certified on the Airbus A350XWB is a new and innovative trolley to clean the aircraft's waste line system. Cleaning waste lines in an aircraft is necessary to avoid clogged waste lines or toilets; however no satisfactory method to do this has been invented so far. In the past, the unpleasant task of removing the scale from the tube system was delayed as much as possible by using a large amount of aggressive chemicals. In the end, the complete waste line had to be dismounted and cleaned with aggressive chemicals at every C-check. The Test-Fuchs method is surprisingly simple, cost-effective and time-efficient – and works with citric acid that can be bought in any supermarket, making it more environmentally friendly. It is no longer necessary to dismount the waste line, as the Waliclean trolley does all the work in a couple of hours without monitoring by technicians and even performs leakage tests when it is finished to ensure the waste line does not contaminate other parts of the aircraft.

The first units of the Airbus A350XWB equipment have already been delivered and are working successfully with the operators of the new aircraft.

A Waliclean in use by an operator during a maintenance check

Hand pump for use with the fill-and-drain trolley (right) for the A350XWB's supplemental cooling system

Trolley for the test equipment for the supplemental cooling system

GROUND CONTROL

Leveraging LXI for a distributed PXI Express ground vibration testing system for commercial aircraft

PMX04 portable four-slot PXIe 'tablet'

Ground vibration testing (GVT) plays an important role in the verification process of structures, including aircraft. GVT for aircraft includes the basic dynamic responses needed to update the finite element analysis (FEA), as well as full-scale flutter tests required to validate structural instabilities for safety reasons. Completions of such tests are required before first flight to determine flight worthiness.

As GVT can often be expensive and time consuming, aircraft manufacturers are always looking for quicker and more efficient systems to validate and ensure the safety of their aircraft. When a large aerospace manufacturer was faced with upgrading a legacy test system, VTI Instruments was selected as the provider of a new solution.

The aircraft manufacturer's existing implementation required the test instrumentation to be centralized in a control room in close proximity to the controlling PC to ensure synchronization of measurement data across all channels. The system was quite large and since the control room is located at a substantial distance from the test article, it was constructed using large runs of sensor cabling, which complicated maintenance and part replacement.

While the legacy system used by the manufacturer served its purpose at the time it was initially designed, it was burdened by limitations that added unnecessary cost. When the manufacturer established goals for its next-generation GVT solution, it sought to reduce test system size, enable distribution of instruments while maintaining synchronization, and decrease cabling costs and setup times. The large size of the aircraft and number of sensors meant that the system had to be able to acquire high-speed data from >500 channels. This manufacturer wanted to move away from a centralized system to a distributed architecture with instruments located close to and on the aircraft. Using multiple CMX09 nine-slot rugged PXIe chassis, EMX-4250 digitizers and several EMX-2500 gigabit Ethernet LXI controllers, VTI Instruments was able to break up the test system into several pieces that could be easily distributed around the aircraft. This facilitated easier transportation of the system, quicker setup times, simplified cabling (Cat 5e cables were used) and more efficient maintenance.

SOLUTIONS/BENEFITS

The rugged design of the CMX09 PXI Express chassis meant that the units could be easily distributed in an industrial environment with a minimized risk of unit damage.

By placing the instrumentation closer to the aircraft, the manufacturer was able to reduce the length of sensor cabling, reducing overall cost while improving signal integrity. The smart cooling of the system pulls air in from the sides and circulates throughout the chassis to maintain ideal temperature, allowing for tests to be conducted for long periods of time without overheating, eliminating the need for costly retests and ensuring accurate data.

The chassis also offers health monitoring in the front of the mainframe, giving alerts when issues arise and allowing automatic shutdown in the event of an error. With a loaded weight of 15 lb, the CMX09 is also considerably lighter than the legacy mainframes that were in use, enabling easy transportation around the unit being tested.

The PMX04 portable four-slot PXIe 'tablet', installed with EMX-4250s, further improved ease-of-use and portability, as it provided the test engineers with a mobile test system that they could carry to any point near the aircraft and quickly set up in order to acquire data on the spot.

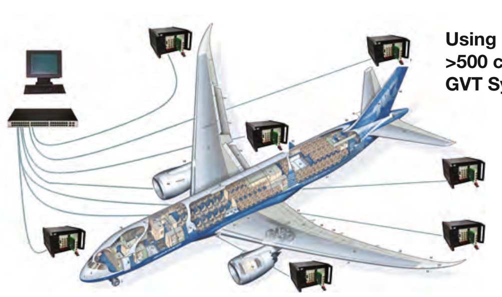
Leveraging the EMX-2500's LXI capabilities, and its integration of the IEEE 1588 protocol that is used to synchronize multiple mainframes to tens of nanoseconds, VTI was able to provide the high-speed digitizing capabilities of the PXI Express platform with precise synchronization. The IEEE 1588 synchronization used in the EMX-2500 provides a common reference from a master clock source over standard Ethernet cabling. This eliminates the need for ancillary cabling and hardware interfaces, greatly reducing total costs.

To increase ease of distribution, VTI also incorporated custom breakout boxes (BOBs) into the final solution. The previous legacy test system being used incorporated BOBs that were rack mounted. The new BOBs could be pulled out from the rack mount and distributed around the testbed.

The EMX-4250 16-channel PXIe digitizer played an essential role in the system, as it provided 204.8k samples/second/channel, ensuring sampling and bandwidth performance that accurately captured all critical frequency domain information.

By upgrading to VTI's latest PXI Express technology for its solution, the manufacturer was able to reduce the cost of the GVT system by nearly US$150,000 over the previous legacy system.

To further reduce costs associated with system maintenance and calibration, VTI was able to provide the manufacturer with a calibration kit, enabling all calibration to be completed in-house. ∎



Using LXI to create a >500 channel distributed GVT System

EMX-4008 and EMX-4016: 8- and 16-channel breakout boxes

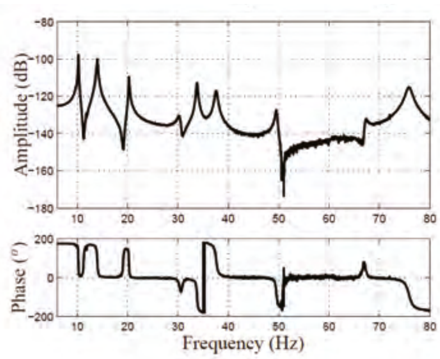
BLADE RUNNER

Increasing engineering insight into modal testing with strain gauges

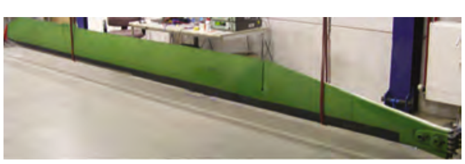
Accelerometers are typically selected to perform experimental modal analysis and calculate the displacement mode shapes. One way of bringing innovation into modal analysis is to use groundbreaking sensor technology. The use of strain sensors for modal testing brings tremendous advantages and important additional engineering insight, in spite of it being less in the industry spotlight. In fact, in very specific cases, such as in the testing of jet engines and complex structures, the use of strain gauges is the only option for gathering information on structural integrity.

Siemens PLM Software is complementing its traditional modal analysis testing solutions with measurement and identification techniques that include strain information. While strains are usually used for lower-frequency (or even static) measurements, modern data acquisition systems such as the LMS SCADAS from Siemens PLM Software permit highly accurate strain measurement up to higher frequencies. This enables the measurement of strain gauges together with the other traditional modal sensors.

Combining traditional and strain sensors in modal tests brings further engineering insight into structural performance such as stress, fatigue and damage, and contributes to creating consistent and accurate data sets.



ABOVE: Helicopter main rotor blade – strain FRF from an arbitrary measurement point



ABOVE: Blade suspended by elastic cords in free-free condition

New strain measurement technologies such as fiber Bragg grating (FBG) open new possibilities to get even more in-depth insight in the dynamic loading of structures such as composite materials.

The application of new strain measurement techniques creates new engineering data to interpret the performance of structures, particularly in inflight flutter tests, wind tunnel tests on aircraft and jet engine tests.

HELICOPTER CASE STUDY

Siemens PLM Software performs extensive studies to support the strain concept and promote the industrial advantages of using strain modal analysis. One such test involves the use of different types of sensors, excitation methods and correlation with a computational model of a composite helicopter blade.

For this particular experiment, the main rotor blade of a PZL SW-3 helicopter was used in strain modal analysis verifications. The blade was suspended with elastic cords to obtain a free boundary condition. Strain sensors were used to measure the dynamic strain on the surface of the blade. Next to traditional electrical strain gauges, 20 FBG strain sensors were instrumented on the surface of the blade, following two straight fiber lines of 10 sensors each.

To carry out dynamic strain measurements, piezoelectric strain sensors (for example PCB 740B02) are an interesting alternative to fiber lines. The advantage of this type of sensor, in comparison with the resistive strain gauges, comes from its better signal-to-noise-ratio, due to the piezoelectric sensing element.

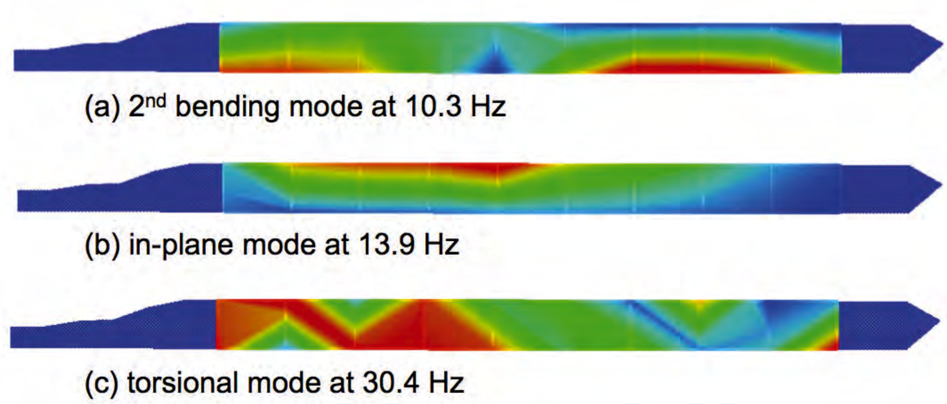
The helicopter's blade was excited using an electrodynamic shaker. The driving point was set close to the tip of the blade, near the trailing edge, with a sine sweep excitation. The measurements were performed using LMS SCADAS data acquisition hardware and LMS Test.Lab structures acquisition and analysis software. The strains can therefore be successfully used to estimate the Eigenfrequencies, damping ratios and strain mode shapes.

These strain mode shapes can be considered either as an alternative or as complementary information compared with the traditional displacement mode shapes obtained by use of accelerometers. They can be correlated with a finite element model. The sensors were able to capture the critical modes (bending, in-plane and torsional) and the strain mode shapes were particularly useful in the visualization of the bending and in-plane modes.

Future studies involving industrial end users will also include investigation of sensor placement for enhanced strain field interpretation, hotspot (high stress and strain) locations, time and modal relations between strain and displacement, and methods of scaling the strain modes.

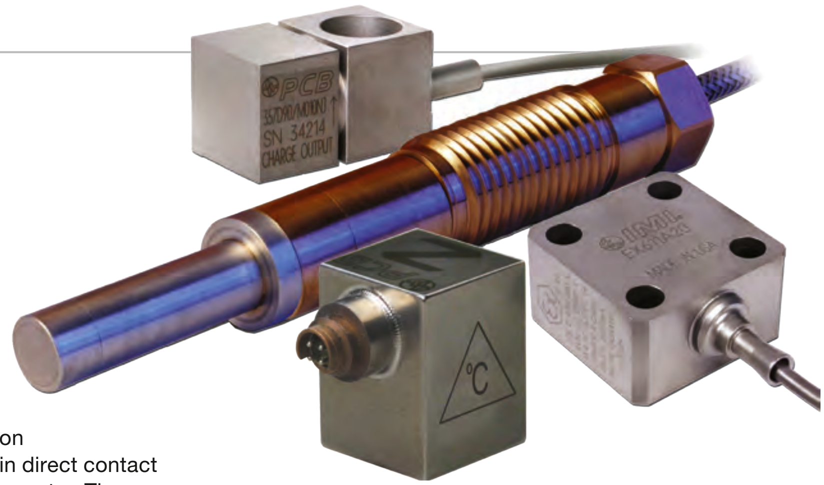
"Our experiment is intended not just to put theory into practice and demonstrate its viability," says Bart Peeters, product line manager, structures at Siemens PLM Software. "It is also a means to position and validate the critical role that the strain sensors have to play in modal testing and its future. This leads to better engineering insight when tuning the dynamic behavior of structures. We are continuously working on ways to make innovative measurement techniques applicable to industry."

BELOW: Helicopter blade mode shapes



CRYSTAL CLEAR

Design and selection criteria of high temperature accelerometers for aerospace propulsion



Piezoelectric accelerometers and pressure sensors for measurement in aerospace propulsion systems require stable performance over wide operating temperatures, for example -420°F to +1,300°F (-251°C to +705°C), while providing highly accurate measurement, stability and reliability. Typical applications for high temperature aerospace propulsion sensors include measurement of gas turbine engines both in flight and in test cells, as well as rocket motors and thruster assemblies. The same sensor might be required to withstand radiation when used to monitor vibration inside a nuclear power plant or space vehicle, or the cryogenic conditions of liquid propellants. Extreme high temperature requires careful selection of the sensing crystal to enhance high temperature performance. This article discusses a new high temperature shear mode accelerometer and the benefits it provides for turbine engine vibration monitoring.

Piezoelectric sensors are made from both naturally piezoelectric crystals and artificially polarized polycrystalline ferroelectric ceramics. Each material has unique features and advantages that characterize its performance in various applications. Naturally occurring crystals tend to provide the highest temperature range and the lowest (or zero) pyroelectric output. Pyroelectric output is not desirable as it creates what appears to be real vibration signals as a result of temperature variations with time. The table below organizes material types by temperature and pyroelectric susceptibility and thus their suitability for use in engine applications where thermal loading is not constant.

EXAMPLES OF PIEZOELECTRIC MATERIAL

One of the more popular high-temperature crystals has been bismuth titanate (BiTi). BiTi was originally selected for its ability to reach high temperatures up to 1,112°F (600°C). But it is only available in compression mode, where the crystal is in direct contact with the base of the accelerometer. There are two distinct disadvantages with BiTi as a sensing crystal: firstly, its compression mode design experiences thermal and bending strain errors; and secondly, the material suffers from pyroelectric output, which appears as giant noise spikes when viewing the resulting vibration waveform on a scope or readout device.

The use of a new commercially available, naturally piezoelectric crystal named UHT-12 (ultra-high temperature – 1,200°F) provides the added benefit of even higher temperature operation, while the crystal does not suffer from pyroelectric output (noise spikes), and permits a shear mode sensing element.

Shear mode means the sensing crystal is isolated from the base (or bottom) of the accelerometer, and provides the benefits of thermal and bending strain isolation. Accelerometers for high-temperature applications clearly benefit from shear mode construction technology, and BiTi crystals are not able to function in a shear configuration.

Several advantages have been gained from the development of UHT-12 shear mode, high-temperature accelerometers, compared with compression mode BiTi designs. These include:
- UHT-12 crystal provides an extended temperature range up to 1,300°F (705°C);
- Employing non-pyroelectric UHT-12 crystal helps to minimize thermal errors associated with changes of temperature during measurement;
- UHT-12 crystals can be made in the shear mode. Shear mode which has less measurement error due to thermal expansion and contraction which takes place during temperature changes;
- The shear mode configuration of UHT-12 crystal minimizes non-linearities in output, especially in a direction 90° to the primary measurement direction. This reduces measurement error associated with sensor resonance in the transverse direction;
- Using UHT-12 for the sensing crystal allows for improved long-term stability so the sensitivity of the accelerometer does not change as much with time; and
- Use of inert gas fill inside a sensor made from UHT-12 minimizes contamination issues and oxidation of internal parts. The sensor can also be made with a hermetic seal, which is ideal for use in dirty environments such as exhaust systems and gas turbines for power generation.

Shear mode accelerometers with UHT-12 crystals are currently in use providing successful vibration measurements of both ground-based, aero derivative turbine engines and flight-worthy jet airplane engines across the world.

Whether they are used in aircraft turbine engines, rocket motors, or power generation stations, these accelerometers provide high levels of accuracy, stability and reliability.

Accelerometers and pressure sensors can be manufactured with UHT-12 crystals and they can benefit the test engineer with: a higher accuracy as a result of the absence of pyroelectric noise spikes; operation in an extended temperature range up to 1,300°F (705°C); sensitivity that remains more consistent over a wide temperature change; and a shear mode design that isolates the crystal from the base strain and transverse measurement errors. ▮

Natural versus Ceramic Crystals

Material	Natural Piezoelectric Single Crystals	Ferroelectric Ceramic, Piezoceramics	Piezoelectric Coefficient pC/N	Maximum Useable Temp °C	Pyroelectric
UHT-12 shear	X		12	650	No
UHT-12 compression	X		6	650	No
Quartz shear	X		4	250	No
Quartz compression	X		2.2	200	No
Tourmaline shear	X		3.5	650	Yes
Tourmaline compression	X		1.8	650	Yes
Bismuth Titanate		X	21	500	Yes
Bismuth Titanate derivates		X	14	600	Yes

ABOVE: **PCB Piezotronics sensors featuring UHT-12 sensing technology**

LEFT: **Examples of piezoelectric material**

FIBER PROVIDER

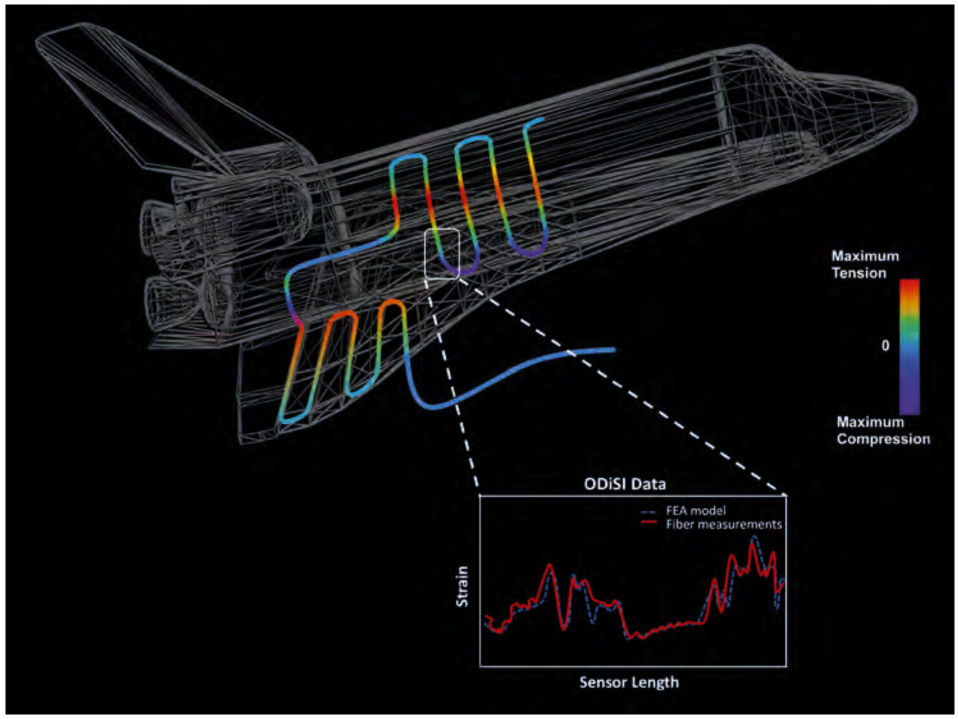
The design of composite structures can be validated with high-resolution distributed fiber sensing

Engineers working on the next generation of aircraft designs are increasingly relying on composite materials to reduce aircraft weight and meet more stringent performance goals for fuel efficiency. These reductions in weight must be balanced with the need to maintain the aircraft's structural integrity under all loading conditions. The use of polymer composites adds a whole new level of complexity to this task given their lack of homogeneity when compared with metals normally used in aircraft design. To meet these new challenges, engineers are increasing the sophistication of modeling tools used to predict an aircraft's stress profile under load. These advances in predictive modeling must be balanced with new technologies for test and model validation that can accurately detect the non-linear strain profiles and large strain gradients associated with the use of composites in complex geometries. Traditional point sensing using strain gauges is inadequate and may fail to accurately reflect the distribution of strain throughout a structure comprising these new composite materials.

Luna Innovations of Roanoke, Virginia, USA, has developed an advanced system that uses fiber-optic cables as a distributed sensor to measure either strain or temperature along a continuous length of fiber-optic cable. Fiber-optic cables, when illuminated, have the equivalent of an optical fingerprint and this fingerprint will change, in a predictable and repeatable way, in response to changes in temperature and in response to fiber elongation when bonded to a structure experiencing strain. This fiber optic cable replicates a virtually continuous line of strain gauges with just millimeter spacing between sensing points. The fiber optic cable functioning as a sensor is immune to EMI, is inherently a dielectric, and can be bonded or embedded within a structure under test. A single cable can be laid out along the structure in a grid pattern to provide a full picture of the distribution of strain. For cylindrical objects the fiber can be wrapped in a helical fashion and can reflect strain resulting from either bending moments or torsion. Strain or temperature data can be displayed by length or individual points can be selected anywhere along the fiber and displayed by time. The location of these measurement points can be changed within minutes compared with the hours it would take to reposition a strain gauge.

The application of the fiber optic distributed sensor is similar to the traditional strain gauge in that the surface is sanded and cleaned prior to the sensor being epoxied in place. The difference, however, is that with a fiber-optic sensor, a virtually continuous line or array of sensors can be installed in one application. Furthermore, this line of sensors is connected to the processing unit through the same fiber optic cable, thus the fiber optic cable functions as both the sensing elements and the signal path for these elements back to the processing unit. This provides an improvement by several orders of magnitude over traditional strain gauges in the simplicity of the wiring and size of the harness connecting the strain sensors to the processing unit. This not only offers advantages during the initial test setup, but will also aid greatly in subsequent test setups to accommodate any design iterations.

High-resolution measurement technology using fiber optics as sensors helps mitigate risk in designs using new polymer composites by providing a full field view of the distribution of strain within structures built with these new materials. Even for design and testing of structures using traditional metallic materials, distributed fiber optic technology offers a quantum leap in setup time and simplification of the wiring and harness. ∎

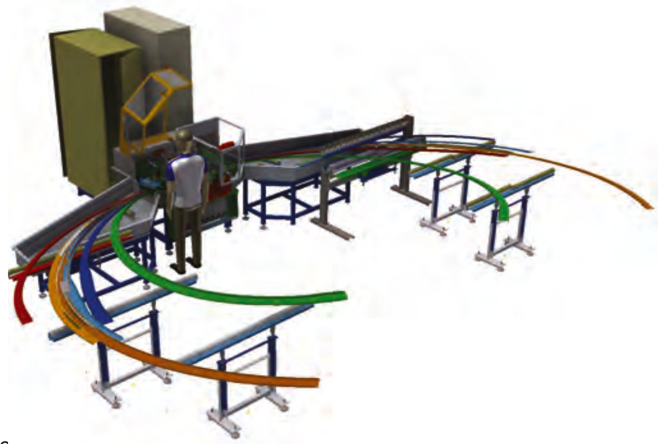


ABOVE: Strain or temperature can be measured along a continuous length of fiber-optic cable

RIGHT: Luna Innovation's ODiSI B fiber optic sensing solution

DO IT YOURSELF

Customized NDT equipment can optimize in-house inspection on aircraft components



Non-destructive testing (NDT) remains a critical stage in the manufacturing process of aircraft components – parts/structures manufacturers may therefore decide to have their own NDT process to remain competitive. Many competencies are required in such cases: engineering, design of NDT facilities, manufacturing, development of the NDT system, qualification and certification of personnel, audits, customers and aeronautical authority approvals, NADCAP, etc.

The management of these disciplines is the main problem faced by companies when developing NDT processes: managing many providers without internal strong NDT experience drastically complicates the task and can jeopardize the success of the project.

To help manufacturers optimize the efficiency of their process development, Testia Group offers a solution based on the conjunction of two concepts: a turnkey solution and adaptive design of equipment.

NDT TURNKEY SOLUTIONS

The turnkey solution concept means that the whole NDT process is taken in charge, from the basic customer requirements to the final validation of the line, going through the writing of specifications, the engineering, design and manufacturing of the equipment, the operators training and qualification, the writing of procedures, technical instructions, etc.

The customer is then free to focus only on the core activity, which is to produce components. The strength of Testia is to be able to offer all the capabilities and competencies internally concerning all the NDT tasks. This avoids usual concerns like multiprovider management, long delivery times, time-schedule drifting, non-quality issues and, in particular, misunderstandings between suppliers. Additionally, it enables the optimization of the NDT process through careful coordination of the different steps of the development, which are often interdependent of each other. With one sole project management function and execution, each step can be optimized and adapted according to the others.

ADAPTIVE DESIGN OF EQUIPMENT

Most of the time, providers of NDT equipment offer off-the-shelf products or systems, which forces the customer to adapt its inspection process to the proposed equipment. It removes flexibility and may complicate inspection procedures, the whole development phase, and the certification and approval of the inspection process.

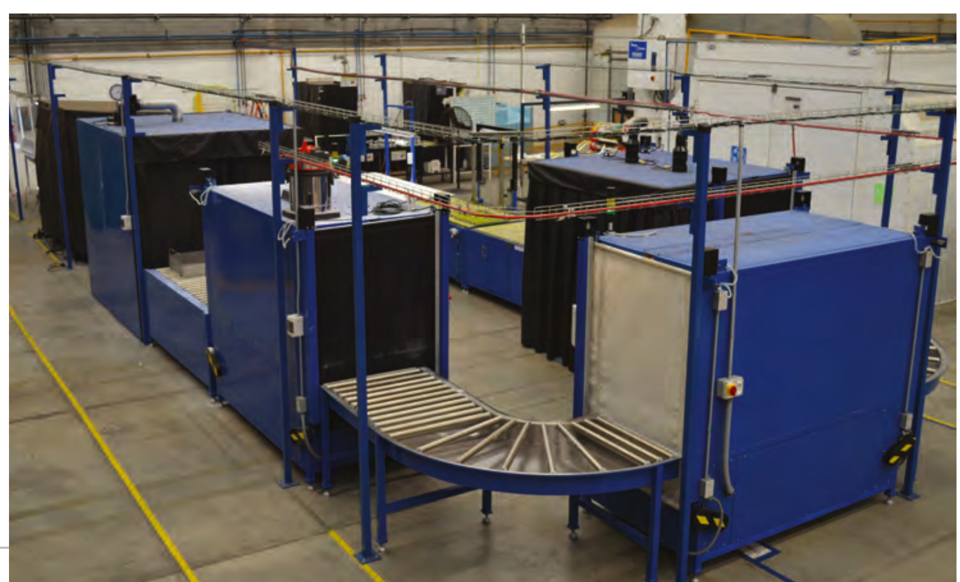
The principle of the adaptive design concept is to orientate the design of the automation process toward the specificity of the parts (design, shape, inspection criteria, etc) to optimize the inspection procedures. The inspection system is adapted to the component, not the opposite. This lightens the mechanical side of the machine and eases and drastically shortens the development process of the global NDT system. In addition, it allows time and cost savings regarding parts inspection and the resources required to perform the inspection.

How is this achieved? NDT equipment consists of various interacting subsets. Testia identifies as a first subset the detection equipment established by exciters (heating in infrared thermal imaging, x-ray tube, etc) and sensors (ultrasonic translator, thermal camera, etc). This first block communicates with the acquisition system consisting generally of an electronic system and monitoring software. Once processed, the data is transmitted to the analysis system. The mechanical and automated system secures compliance between components and testing equipment and communicates with the other subsystems for the definition of the inspection sequence.

The nature and type of the constitutive components of the subsystems and their interactions reflect the choices made during the response to the initial need. It is necessary to adapt each elementary component to the conclusion of the analysis. The principle is based on the exploitation and assembly of homogeneous and flexible bricks.

BENEFITS

Once developed, delivered, approved and ready for inspection, Testia says its turnkey solutions, developed according to the principle of adaptive design, can save up to 50% on costs and inspection time at its customers' facilities. Although its capabilities include methods of inspection such as PT, RT, MT and UT in emerging markets such as Mexico, the company's main focus is currently on manual and automated UT, PT and cleaning lines. Some of its completed projects have seen the company produce parts for Airbus, Rolls-Royce, Honeywell, P&WC, Boeing, Bombardier, Eaton and Goodrich.



ABOVE: **Ultrasonic machine developed for the inspection of 5m long composite frames at a rate of 8 per hour. The inspection requires only one operator to run the machine, which gives an automatic diagnosis as a final result**

RIGHT: **Semi-automatic Dye Penetrant and Cleaning Line delivered in 2014 in Mexico**

ACQUISITION UNLEASHED

Perfectly synchronized real-time noise measurements over large areas are simplified with independent, wireless modules

Brüel & Kjær's LAN-XI data acquisition hardware is highly flexible due to its modularity. These individual modules can be collected or distributed at will, allowing diverse parts of an organization to each use some modules, and then combine them for larger tests whenever necessary.

The GPS time-stamping capability built into the LAN-XI system provides a highly accurate time signal that allows modules to be distributed far and wide, and still achieve perfect sample synchronicity. This means testers can have several completely detached acquisition stations that each record their data to the same absolute time, so the data can be seamlessly synchronized later.

The shared, absolute time base from the GPS satellites also means sound and vibration data can be easily correlated with data from any other source with a GPS time stamp, such as weather information or airplane tracking data in the case of flyover noise certification. This also means that cross-spectral analysis can be performed between data sets collected on independent systems, in perfect sample synchronicity. A case could be where data measured on a flying test aircraft can be easily matched to the external acoustic information perceived on the ground.

Critically, the GPS capability allows synchronization that is wireless. To acquire sample-synchronous data on all acquisition front-ends, traditional data acquisition configuration required a cabled synchronization mechanism. However, it is cumbersome – and often impossible – to deploy a synchronization cable between front-ends.

With independent, synchronized data acquisition stations, a whole new world of flexibility is opened up. Unlimited by the impact of cable length on signal quality, the whole data acquisition system can span large distances – making it perfect for acoustic flyover research and certification tests. Here, the completely independent acquisition stations are like nodes in a virtual network. The only cables needed on the ground are the short transducer cables, so they don't need to cross runways, and reduce the danger of damage – such as from lightning strikes. Structural analyses of large objects, like GVT tests, are also vastly simplified.

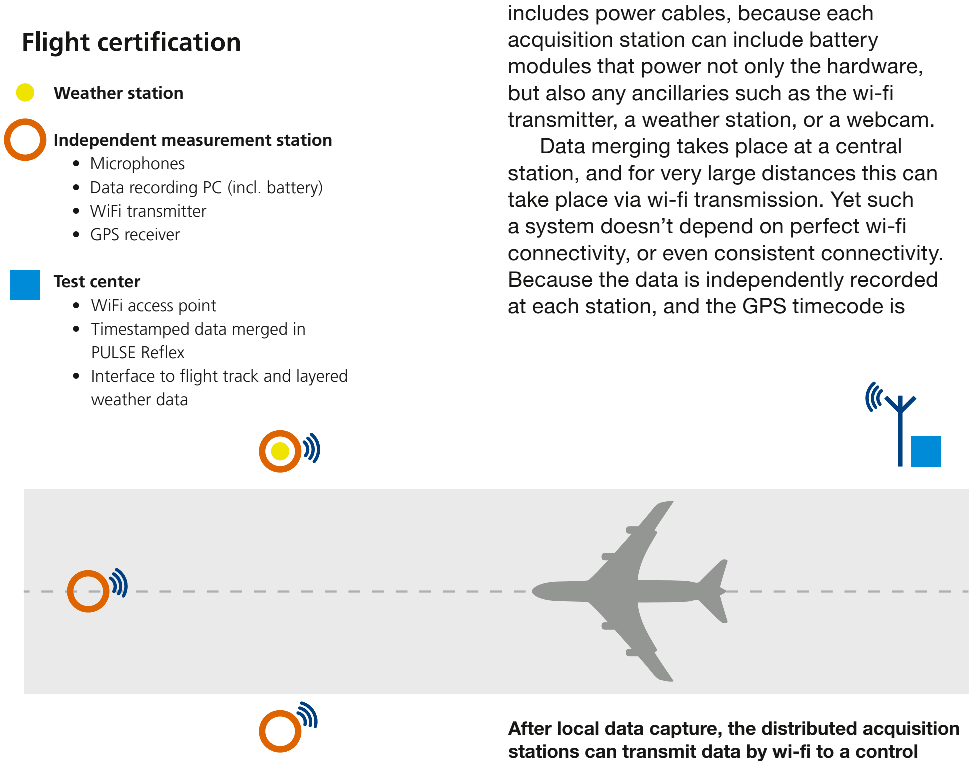
With LAN-XI, the absence of wires connecting each acquisition station even includes power cables, because each acquisition station can include battery modules that power not only the hardware, but also any ancillaries such as the wi-fi transmitter, a weather station, or a webcam.

Data merging takes place at a central station, and for very large distances this can take place via wi-fi transmission. Yet such a system doesn't depend on perfect wi-fi connectivity, or even consistent connectivity. Because the data is independently recorded at each station, and the GPS timecode is stamped into the data, these independent data sets can be merged at any time, in a post-processing environment such as PULSE Reflex. The system will normally perform this immediately (and automatically), but when that is not possible for connectivity reasons it will simply do it later, when the connection is re-established.

Test control is also centralized in a control room from where all of the independent acquisition stations are operated – wirelessly or not – and where personnel are safe from loud noise events such as sonic booms. Here, testers can start and stop measurements, and even live-stream some channels to monitor actual measurements.

From this central station, the controller can remotely check the whole system. With a press of a single button, the automated calibration feature sends a signal out to every transducer in the network, to check all connections are working, and all microphones are calibrated properly. On large systems spread out over a wide area, this feature saves a huge amount of time on individually checking microphones.

The rock-steady, absolute time base provided by GPS also means large systems can be paired, to overcome any data throughput issues. All data acquisition systems have a limit to the density of data they can handle, but by pairing completely separate systems (and then synchronizing the data), higher channel counts and bandwidths are easy to achieve. With essentially two separate systems, data can still be harvested regardless of the factors that limit each independent system, such as computer processing capacity. Critically, though, the data merging post-measurement is straightforward and automated in PULSE Reflex. ∎

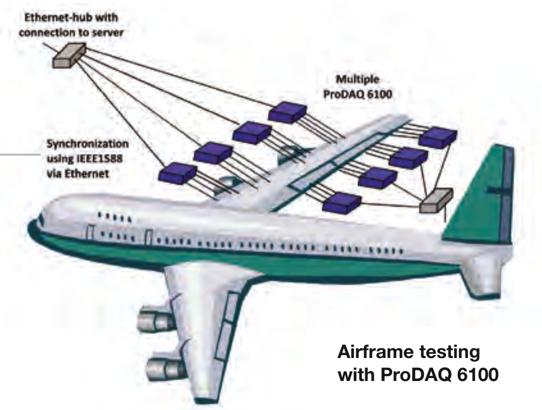


After local data capture, the distributed acquisition stations can transmit data by wi-fi to a control room where PULSE Reflex software automatically merges the independently time-stamped data sets

A rugged data acquisition station with battery module, built-in GPS receiver, and interchangeable input/output panels for different sensors and accessories

CONFIDENCE BOOSTER

How to achieve a measurement precision of 0.01% in a large distributed environment



Airframe testing with ProDAQ 6100

Measurement strategies for applications including engine test stands, structural analysis or wind tunnels involve precision, ease and speed of calibration, synchronization of all data channels, and a solution for handling the distributed character of the test system. Increasingly, fast channels (vibration, for example) are no longer separated from slow channels (temperature, for example). In most modern systems, the user wishes to synchronize these groups of channels with different acquisition speeds. In addition to these technical challenges, manufacturers are faced with price pressures and ensuring the longevity of their test system.

Let's start by looking into the question of how to achieve the best measurement precision. The total measurement error ΔE_T is a combination of different errors, such as the error of your sensor, the error of your data acquisition card together with the error of your signal conditioning, the induced error due to the electromagnetic radiation present in most environments, as well as additional smaller ones.

In most modern acquisition systems, a measurement error of less than 0.01% is the design goal. As the biggest error is dominating all other errors, you can see that special care should be given to the proper calibration of your sensor in view of minimizing its inaccuracy. Before we look into the error produced by the ADC card itself, we will try to minimize the error that comes from the connection between the sensor and the ADC card or signal conditioning unit. This implies that the user should rely only on true differential measurements as most test systems are located in electromagnetic noisy environments. Therefore the test system must have the same input impedance for the positive and negative arm of your inputs. Single-ended measurements will not provide you with meaningful data. This, in turn, has direct implications to the choice of cables used. The sensor should be connected to the signal conditioning unit (SCU) with twisted pair and shielded cables. (Using BNC cables produces an error of 0.05% due to the limited signal to noise ratio of only 70dB of such cables.) In addition, the cable should be as short as possible. This can be achieved by having a distributed data acquisition system.

After looking to the sensors and cables, it is necessary to investigate the precision of the combination of the signal conditioning together with the ADC card. To achieve an overall accuracy of 0.01%, the combined (SCU + ADC) DC measurement error should be smaller than 0.005%. This implies the use of modern 24bit Σ-Δ ADCs. As an example, the ProDAQ family of ADCs from Bustec have a typical measurement accuracy of 0.003%.

The next most important aspect of measurement accuracy is the quality and traceability of the calibration source. Bustec's ProDAQ 6100 carrier holds up to four function/measurement cards. In addition, users can plug in a programmable voltage reference. During calibration, this voltage reference will inject ±90% of any chosen full scale range of any chosen gain and 0V. It also allows the user to undertake a complete end-to-end calibration in less than a second – helping to reduce costs. Customers can also calibrate against temperature swings between day and night – the ProDAQ 3202 voltage reference has a very good temperature stability of only 1.5ppm/°C and an accuracy of better than 0.0013%. In addition, the ProDAQ 6100 carrier has in the back an output of the voltage reference, so the user is always able to trace the calibration source ProDAQ 3202. The voltage reference can be integrated between the SCU and the ADC card by means of connection cables.

SYSTEM ARCHITECTURE

With regard to system architecture, the user has a choice between a centralized or distributed approach. A centralized system with long cables to the different sensors creates two major problems. One is the degradation of the signal quality as you take μVolt level signals over long cables in a high electromagnetic noise environment. This will have a detrimental impact on achieving a 0.01% margin of error. The other problem is the expense involved with long signal cables, which can represent one-third of the cost of the total system. A better solution would be a fully distributed system with the ADC and SCU channels close to the sensors and a connection between these different systems with low-cost cables.

A good solution is found in pairing Ethernet with CAT5 cables. However, this generates the problem of synchronization of the different units. But since the invention of IEEE1588 this problem has been solved. Bustec achieves a synchronization level between all distributed channels of roughly 20ns FWHM. In addition, as all channels independent of their measurement speed are driven from the same clock, the old approach of a slow system (with slow channels for temperature and pressure), and a dynamic system for faster channels such as vibration, is no longer needed. This solves the inconvenience of the previous approach where these two different systems were never really synchronized.

Ethernet brings the user one additional but important advantage. It has now been in existence for 38 years and has decades to come as the world's IT infrastructure is based on it. Compare this to any PC-related quasi standard, where even the newest versions like PCI and PCIe and PXI and PXIe are not compatible with each other, meaning the user will not be able to maintain those PC-based systems over longer periods.

To summarize, Bustec's ProDAQ line of products and systems provides users with a measurement accuracy of better that 0.01% for static and dynamic systems, which no longer need to be separated, as both slow and fast channels can be recorded in one system and are perfectly synchronized. In addition, the use of Ethernet helps to cut the costs of any data acquisition system. ∎

Formula:

$$\Delta E_T = \sqrt{\Delta E_1^2 + \Delta E_2^2 + \Delta E_3^2 + \cdots \Delta E_n^2}$$

ProDAQ 6100 LXI carrier opened

MULTIPLE CHOICE

InterConnect Wiring increases test efficiency by 500% as a result of DIT-MCO's multiple bus architecture

It is said that success is often a matter of being in the right place at the right time. When InterConnect Wiring found itself in danger of falling behind its delivery schedule on a US$50m contract, it found success by having the right supplier in place at just the right time.

InterConnect Wiring boasts over 20 years' experience in the manufacture of wiring harnesses, power distribution, relay and cockpit panels, and other electrical equipment, for military aircraft. Established in 1993 in the home of one of its founders, InterConnect Wiring today employs some 100 workers in three buildings at its headquarters in Fort Worth, Texas, USA. Customers include Lockheed Martin for F-16 and F-2 wiring harnesses and panels; Boeing for B-1B harnesses; BAE Systems for F-16 ground support equipment; Sikorsky for S-92, S-76, UH-60 and H-92 harnesses; L3 for EC-130 electrical harnesses; and the US Department of Defense for F-15 electrical power distribution harnesses and panels.

But a US$50m contract from the US Air Force to rewire the electrical power distribution system in 72 F-15 aircraft proved to be a testing challenge for the company. InterConnect's chief test programmer, Mike Winters, says there were two main challenges: all the electrical panels require power during testing; and InterConnect had never delivered so many of them to such a tight schedule.

For years, InterConnect had been testing all its products on DIT-MCO Model 2115 wiring testers. For products requiring power during testing, InterConnect built a patch panel to inject power through 'Y' connections in test cables. However, this patch panel had become a bottleneck. Connecting it to the test interface and power supplies was time consuming. And after years of use, it had become unreliable. Man-hours were being wasted troubleshooting frequent false alarms.

AVALANCHE ALERT!

InterConnect's test department was soon under an avalanche of panels: "It got so stacked up over there, they were just buried in them," says Winters. "It was frustrating, because the department was seen as holding up production. And that's always a focus you don't want."

InterConnect was in danger of falling severely behind schedule and making late deliveries. Its customer relationship and reputation were at risk. It needed to reduce testing time on these products – and fast. Luckily, Winters didn't have to search long to find a solution.

Instead, the solution found him. One day, while InterConnect was preparing its first deliveries, a DIT-MCO International sales manager happened to be at the plant. He stopped to watch the testers troubleshoot a panel. Seeing the difficulties they were having with their patch panel, the sales manager described how the DIT-MCO Model 2650, with multiple bus architecture (MBA), could help. Winters says that until then they hadn't known such a technology existed: "I remember we kind of looked at each other and thought, 'Now that would be a lifesaver'."

When InterConnect was forced to take a hard look at how to get back on schedule, Winters began pressing for a DIT-MCO Model 2650. What really interested Winters was the Model 2650's MBA option. MBA adds either two or four buses in parallel with the standard instrumentation bus, plus a routing matrix that can connect any instrument or power supply to any bus, and any bus to any test point. Power is routed – by software control. No manual connections are required. Winters and his team could eliminate their troublesome patch panel, and save many, many man-hours.

Winters says the Model 2650 exceeded expectations right from the start: "I think the first time that we ran a panel, the technician thought the program had aborted, it was over so quickly – it tested the product so fast! Once we started using the 2650, I don't think it was two weeks before we had the shelf cleared."

That quick turnaround helped the assembly department. "There's a lot of preparation that goes into the product after it leaves the testing department," says Winters. "Being able to get the product faster from us gives them more time to concentrate on delivering a quality product. So it has boosted morale in that area, as well."

EFFICIENCY SOARS

Eliminating the patch panel has greatly reduced InterConnect's test setup time and troubleshooting time, while improving safety. "We go through those panels a lot faster than we did, and more reliably," says Winters. "And I'm not as concerned with operator safety as I was before."

As an example, Winters cited testing times for one particular part, which dropped from more than six hours to just 22 minutes – an improvement of 1,536%.

But the most important improvement has been to InterConnect's bottom line. Winters reports that testing man-hours have been reduced so dramatically since adopting the Model 2650 (MBA) that test department efficiency has jumped by over 500%.

FAR LEFT: **InterConnect's engineers check a relay panel for compliance**

LEFT: **Panels are electrically tested using DIT-MCO test system**

THE NEWEST GENERATION OF MEASURING AND DOCUMENTATION SYSTEMS

Karl Storz Industrial Group has unveiled the latest generation of measuring and documentation systems for the remote visual inspection market. The TECHNO PACK T LED features a powerful LED light source, which, in conjunction with either a borescope and camera or a videoscope, ensures excellent, high brightness, high-quality images. On the large high-resolution 15in monitor, even the smallest details can be viewed by several people simultaneously. The measuring system for depth, height, length, area, reference, and line-to-point measurements guarantees accuracy in any starting position of the videoscope, as well as on any surface. The larger screen also offers improved ergonomics and reduced user fatigue.

The all-new software ensures simple, intuitive and user-friendly operation. Furthermore, the system offers users multiple, easy-to-use storage and file transfer options. Captured data (images/videos) can simply be transferred to a USB stick or SD memory card, directly onto a computer, or onto an additional external monitor, as desired. As a result of the highest quality standards being adhered to during production, the devices are ideal for rugged industrial use.

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HIGH-SPEED CAMERA FOR STORES SEPARATION

High-speed cameras used in store separation recordings provide essential insight into the mechanical and aero-dynamical processes taking place. The Q-MIZE EM with its 3MP sensor has been designed for such testing. Parameters and recording options such as multiple buffers, trigger points, resolution and framing speeds are pre-programmed into the camera via comprehensive supplied software. Q-MIZE EM has a built-in, removable fast flash card of up to 128Gb in size. This non-volatile memory is used to store the recordings in the camera memory, freeing space for subsequent recordings. Further saving precious image data, the flash card ensures that data from the tests is retained after return of the test aircraft.

The Q-MIZE EM series is a semi-customizable camera. The design can be easily adapted to existing camera mounts in test environments. This flexibility reduces the need for costly changes to the aircraft, and widens the range of application because cameras fit in compartments they haven't before. The control and analysis software is a great help when parametrizing cameras, editing sequences, playing back events in slow motion step-by-step, or when converting the data into standard movie formats such as avi or mpeg. The Q-MIZE EM is designed and certified to withstand *g*-forces in excess of 100*g* and spikes of up to 200*g*. Certified according to MIL-STD-810 standard for vibration and environmental conditions, the camera optionally comes with MS27473 series standard plugs.

The camera is available in a 180° version in which all the connectors are on the rear end, or in a 90° version where the connectors are located on the side.

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TIME TO DITCH THAT TAPE DATA RECORDER?

For the large-scale testing of aerospace applications, data losses are simply not acceptable. This was the ethos behind the development of the TEAC WX-7000 series, which offers wide-band, multichannel, and long-time recording in comparison with commonly used AIT tape data recorders. It protects customers from catastrophic data loss by providing dependable data back-up recording solutions for PC-based, front-end measurements. TEAC has provided instrumentation data recorders since the analog tape era, but the new WX-7000 series features only the very latest technologies: 24-bit analog-to-digital conversion provides a wider dynamic range than conventional systems; an RDX removable HDD and SD card can be used as the recording media instead of tapes; TEDS information can be loaded from connected transducers such as accelerometers and measurement microphones; and a Gigabit Ethernet interface allows for control and faster data transfer to a PC. In addition, up to 128 channels can be recorded by configuring the WX-7000 main unit with 8 x 16 channels, while two units can be synchronized together to provide a maximum of 256 channels.

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MOBILE ARINC 429 SOLUTION FOR AVIONICS TESTING

Vector is extending the range of uses of its CANoe and CANalyzer development and analysis tools to cover important avionic networks by offering the A429 software option and a USB interface for ARINC 429. This gives developers of line-replaceable units (LRUs) in aircraft a flexible and powerful solution for testing and bus analysis.

The compact VN0601 USB interface for the ARINC 429 bus system can handle up to four RX and four TX channels simultaneously. Flexible bit-rate settings, precise time stamps and refined error detection mechanisms simplify bus monitoring for the electronic developer. In stimulating ARINC 429 channels, the user has full control over cycle times and message intervals within the microsecond range. It is also possible to inject errors into a system in a controlled way, to test the behavior of the connected devices. When a laptop is connected via the USB port, this gives the user a high-performance, mobile test system.

The multibus tools CANoe.A429 and CANalyzer.A429 simplify testing of networked systems considerably. With minimal training effort, users will easily learn how to quickly analyze or generate complex communication. The developer is supported by the well-organized and comprehensible representation of bus activities and flexible adaptation options. For example, Vector applies the proven concept of the database in ARINC 429 and makes the ARINC 429 messages available as objects within the tool.

"The ARINC 429 solution now allows our aeronautical customers to work on key bus systems in use today – AFDX, ARINC 429 and CAN – time-synchronously in a single tool, which lets them test modern multibus architectures efficiently," says Dr Arne Brehmer, head of aerospace at Vector Informatik.

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www.karlstorz.com

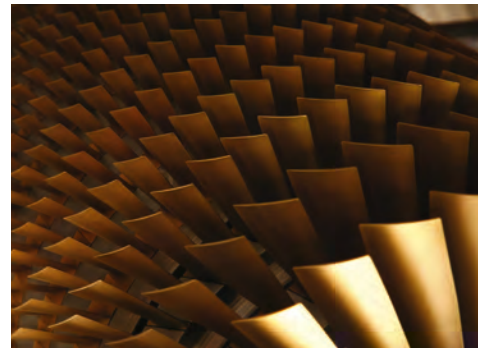
NEW DESIGN ANALYSIS TOOL FOR AERO ENGINE DEVELOPMENT

Frewer Engineering has recently introduced a range of new design analysis techniques for the aerospace testing market in the challenging field of aero engine development.

The need to create aerofoil shapes for testing based on full-scale, in-service aerodynamic requirements is a common one. For example, the need to replicate the shape of fan blades and compressor and turbine blades in a test rig (to verify performance) that is of smaller scale than the actual engine shapes is a complex one.

This requires a process called an 'un-running', whereby the analyst takes an aerofoil shape from the end-customer from when the engine is running (for example, in cruise mode) and then scales the surface down to match the smaller test vehicle. Loads are then applied to the new aerofoil to simulate the aero, centrifugal and thermal loading of the shape. Complex analysis is then performed to essentially 'un-run' the shape back to a cold and unloaded form for manufacture.

Frewer Engineering's special software tools and techniques have been developed to achieve extremely high accuracies in this process, which will benefit the aero industry in obtaining more accurate performance testing results quickly.



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DATA RECORDERS FOR EXTREME ENVIRONMENTS

Testing in extreme environments has always been a complex undertaking. Tight space constraints, weight limitations and temperature can make it challenging to capture high-fidelity data whether you are on the ground or in the outer stratosphere. There's also added pressure that many inflight and structural integrity tests are often a one-chance, must-collect test, so the right test setup and equipment is critical.

Enter SLICE data acquisition systems from DTS. First, the ultra-small size catches your attention right away. SLICE is available in two models, NANO and MICRO, both built on the same platform but with different form factors. But what's not evident at a glance is that SLICE is a complete, custom-configurable data recorder with built-in signal conditioning, gain, offset, trigger, anti-alias filtering and user-adjustable sample rates from 10-500,000sps per channel. Each SLICE stack can record on up to 24 channels simultaneously, capturing seconds to hours of test data, which is stored on its onboard 16Gb flash memory. The software is intuitive and SLICE supports a variety of sensors including bridge, IEPE, temperature and voltage.

SLICE also meets the rigors of MIL-STD-810-E, which addresses a broad range of environmental conditions including low pressure for altitude testing, exposure to high and low temperatures (-40°C to 60°C), and vibration. Packaged in a rugged aluminum enclosure, SLICE is shock-rated up to 5,000*g*.

For almost 10 years, NASA and the JPL have relied on DTS data recorders and high-rate sensors for a variety of critical test applications including the Low-Density Supersonic Decelerator (LDSD), Orion Space Capsule re-entry testing, helicopter hard landings, and rocket sled testing.

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Spitfire P9374

In July 2015, Christie's auction house will be selling an aircraft for charity. This is the story of the remarkable discovery and reconstruction of an iconic Supermarine Spitfire...

BY CHRISTOPHER HOUNSFIELD

In September 1980, the wreckage of an airplane emerged from the sands of a Calais beach, where it had crash-landed some 40 years earlier. It had eight Browning machine guns hiding beneath elliptical wings.

Initially, the identity of the aircraft was in question, but following its recovery by the manager of the nearby hoverport in January 1981, it was recognized as a Spitfire P9374 – an early Mk1 version of Supermarine's finest creation. Further research established the details of its build history and its engine, and of the story behind its arrival on a French beach and the background of its pilot.

Flying Officer Peter Cazenove, later a veteran of the Great Escape, was flying the aircraft on May 24, 1940, during the Battle of Dunkirk, when it was attacked and hit by what is thought to have been a single bullet fired from a Dornier 17-Z bomber. Before belly-landing on the beach, Cazenove had radioed that he was okay: "Tell mother I'll be home for tea!" However, Cazenove was soon captured as a prisoner of war and Spitfire P9374 was consumed by successive tides and sunk deeper into the sand.

Post-recovery, the P9374 went first to the Musée de l'Air et de l'Espace at Le Bourget, Paris, and subsequently to further collections. The parts eventually ended up with the Aircraft Restoration Company/Historic Flying Ltd at Duxford, and it has since been brought back to life. A team of 12 skilled engineers spent three years carrying out what is considered to be the most authentic restoration of an original Mk1 Spitfire to date, incorporating many components from the original airplane into the build.

THE RESTORATION

The rebuilding of P9374 involved a 100% faithful following of the original build and fit, down to sourcing correctly dated instruments and equipment. If a piece of kit was the correct type but was dated, say, 1940 or 1941, then it was discarded in favor of a correctly dated item. This meticulous approach even ensured that the ammunition for the guns was correctly dated.

The fuselage 'tube' was constructed by Airframe Assemblies on the Isle of Wight, not far from its original birthplace, and the wings were built at Duxford in 2007 by the Aircraft Restoration Company.

Original components from the wreck were used in the engine, which was re-engineered and constructed along with the propeller by Retro Track & Air of Cam, Gloucestershire. Successful ground runs of the installed engine were conducted in June 2011.

The completed aircraft was first flown at Duxford on September 1, 2011, by John Romain, who later remarked of P9374: "This is a fantastic restoration to be justifiably proud of. Spitfire P9374 is a truly lovely aircraft, and she flies beautifully."

The P9374 is one of only two remaining Mk1 models restored to the original specification and still flying, and both are owned by Thomas Kaplan, a US philanthropist and art collector who, on October 13, 2000, purchased P9374 from a French aircraft enthusiast. As part of a gift from Kaplan, Spitfire P9374 will be sold at Christie's of London to benefit the RAF Benevolent Fund and also Panthera, a leading wildlife conservation charity. It is expected to fetch an estimated £1.5m to £2.5m (US$2.4m to US$3.9m). The other restored Mk1, Spitfire N3200, is to go to the Imperial War Museum Duxford, in Cambridgeshire, UK.

Kaplan said of the restoration and sale: "When my great childhood friend, Simon Marsh, and I embarked upon this project, it was to pay homage to those who Churchill called 'The Few' – the pilots who were all that stood between Hitler's darkness and what was left of civilization. The upcoming events are, more than anything else, concrete gestures of gratitude and remembrance for those who prevailed in one of the most pivotal battles in modern history." ∎

At time of going to press, Christie's was due to offer Spitfire P9374 in an exceptional sale on July 9, 2015, in London

THE MAN BEHIND THE MACHINE

The Spitfire was the brainchild of Reginald Mitchell, who left school aged 16 to start an engineering apprenticeship. By the early 1930s, he was chief designer at Supermarine Aviation, a subsidiary of Vickers-Armstrongs, based in Southampton, UK, where he worked on world-beating racing seaplanes. When the Air Ministry announced it was seeking a high-speed, all-metal monoplane fighter, Mitchell went to work. After much trial and error, his thin-winged design, teamed with a Rolls-Royce Merlin engine and eight Browning machine guns, was accepted in June 1936 and the Spitfire was born. Mitchell died a year later of cancer, aged 42.

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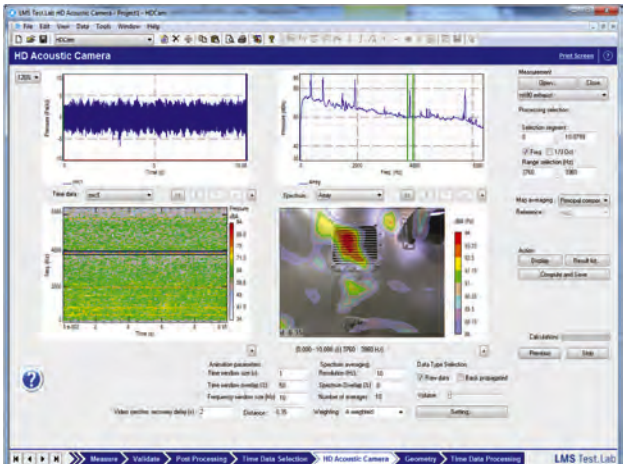

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