AEROSPACE TESTING INTERNATIONAL

NOVEMBER/DECEMBER 2015

SUPER SONIC

How the quest to develop a low sonic boom aircraft has inspired NASA to reinvent a 150-year-old photography technique to help visualize supersonic flow phenomena

C SERIES TEST UPDATE

Exclusive interview with Sebastien Mullot, director, C Series Program, Bombardier Commercial Aircraft

PERLAN II

The world's first engineless aircraft designed to reach the edge of space and set a new world altitude record

WEAPONS TESTING

Inside the latest guided firing trials of the Meteor missile from a Eurofighter Typhoon combat aircraft

HIGH-SPEED IMAGING • P-8A POSEIDON • MD HELICOPTERS • STRUCTURAL TESTING • INSTRUMENTATION

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The venerable T-34C Mentor turbo-prop aircraft has been retired from its 'pace and chase' duties at Redstone Test Center

Safety, safety, safety. The oft-repeated mantra of the aerospace testing industry, central to any test plan, and the first topic of conversation in every preflight meeting.

However, occasionally things can – and do – still go wrong. Two test pilots for Finmeccanica-AgustaWestland, Pietro Venanzi and Herb Moran, lost their lives while flying a prototype AW609 tiltrotor aircraft at the end of October, about 30 miles from AgustaWestland's airfield at Vergiate, in northern Italy.

Fortunately such incidents remain rare. The AW609 is a remarkable aircraft. As the world's first civil tiltrotor vertical take-off and landing (VTOL) aircraft, similar in design to the twin-engined Bell Boeing V-22 Osprey, it combines the benefits of a helicopter and a fixed-wing aircraft into one platform. The test program to date has been extensive, with the first flight taking place back in March 2003.

The aircraft that crashed was the second prototype of the program, performing its first flight back in November 2006, before going on to record 567 flight hours. The aircraft (registration N609AG) was due to complete its test flying duties by the end of next year. A third AW609 prototype is currently being assembled in Italy and is expected to be completed by the end of 2015, while certification for the program is scheduled for 2017.

Since the accident, AgustaWestland has confirmed that N609AG was conducting a flight plan that included tests at high speed, as part of a test to demonstrate certain capabilities as agreed with the FAA. The high-speed maneuvers in question had already been successfully performed in previous flights.

Both of the test pilots were highly experienced and had been recognized by the Society of Experimental Test Pilots (SETP) for their individual flying skills. Venanzi began working as an experimental test pilot for AgustaWestland back in 2000, having recently returned to Italy after a period flying the AW609 in Texas. He had also been instrumental in the development and testing of the AW139. In 2014, along with fellow AW609 pilots Dan Wells and Paul Edwards, Venanzi was awarded the Iven C Kincheloe Award for his outstanding contribution to flight testing.

Meanwhile, Moran, an experimental test pilot with over 27 years of military and commercial aviation experience, had been on the AW609 flight test program for more than a decade, having previously been a Lieutenant Colonel in the US Marine Corps, where he was involved in various military test projects and helicopter upgrade programs. He received the Iven C Kincheloe Test Pilot of the Year award from SETP in 2002.

"Our thoughts are with their families and friends," said Daniele Romiti, CEO of AgustaWestland. "Pietro and Herb were experienced pilots with long and successful test flying careers, who will be remembered for their exceptional personalities, passion and skills. Their significant contribution to the AW609 program and other rotorcraft programs will be remembered by their colleagues at AgustaWestland and across the industry worldwide."

All of us here at *Aerospace Testing International*, and on behalf of all of our readers, would like to extend our deepest sympathies to the families affected by this accident, as well as to all those who worked alongside the pilots as part of the testing team.

Despite this tragic loss, flight testing of such amazing and revolutionary aircraft must continue. This issue of the magazine highlights a number of fascinating test programs currently underway, from the experimental Perlan II glider that hopes to sail to the very edge of space (page 26), to ongoing efforts to develop a 'low boom' supersonic aircraft, which is the subject of our cover story on page 32.

The pioneering spirit, bravery and can-do attitude that underpins the history of aviation is particularly evident within the Perlan II program, which is unique in that it relies upon the efforts of multiple volunteers, as opposed to a large, full-time staff. Meanwhile, the technical mastery and engineering innovation of NASA's ongoing low-boom experiments are further proof, if any were needed, of our desire to challenge ourselves in the pursuit of progress.

However, safety should never be overlooked in that quest, as recognized by all those working in the industry, including Boeing's Steve Brown, interviewed on page 46. "In everything we do, we are trying to be safe and we are trying to make a safe product, and there's a lot of great people dedicated to making that happen," he says.

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The views expressed in the articles and technical papers are those of the authors and are not endorsed by the publishers. While every care has been taken during production, the publisher does not accept any liability for errors that may have occurred. *Aerospace Testing International* USPS 020-657 is published quarterly, in March, June, September, and December by UKIP Media & Events Ltd, Abinger House, Church Street, Dorking, Surrey, RH4 1DF, UK; tel: +44 1306 743744; fax: +44 1306 742525; editorial fax: +44 1306 887546. Annual subscription price is £42/US$75. Airfreight and mailing in the USA by agent named Air Business Ltd, c/o Worldnet Shipping USA Inc, 155-11 146th Street, Jamaica, New York 11434. Periodicals postage paid at Jamaica, New York 11431. US Postmaster: send address changes to *Aerospace Testing International* c/o Air Business Ltd, c/o Worldnet Shipping USA Inc, 155-11 146th Street, Jamaica, New York 11434. Subscription records are maintained at UKIP Media & Events Ltd, Abinger House, Church Street, Dorking, Surrey, RH4 1DF, UK. Air Business is acting as our mailing agent.
Printed by William Gibbons & Sons Ltd, 26 Planetary Road, Willenhall, West Midlands, WV13 3XT, UK.

COVER IMAGE: Schlieren image of a T-38C, showing shockwave structures; NASA

Average net circulation per issue for the period 1 January 2012 to 31 December 2014 was 9,657

Published by UKiP MEDIA EVENTS

WORLD TEST UPDATE

1 JOINT STRIKE MISSILE COMPLETES FLIGHT TEST

The Joint Strike Missile (JSM) successfully completed a missile flight test at the Utah Test and Training Range in the USA in the week ending November 6, 2015.

The missile was launched at 22,000ft from an F-16 that flew from Edwards Air Force Base, and performed a number of challenging flight maneuvers. The test proved the maturity of the missile and its flight control software. The missile is specifically designed to fit inside the F-35A's weapons bay.

The JSM is being developed in partnership with Raytheon for the Norwegian Armed Forces. The missile will enable the F-35 to attack well-defended targets across long distances. Although designed to fit the F-35A, the weapon can also be integrated into other types of aircraft, extending its market potential.

The missile flight test program started in early 2015 with numerous captive carry tests on an F-16 and it will continue with increasingly complex trials through 2016-2017. The flight test program is scheduled to finish in 2017.

Edwards Air Force Base, California, USA

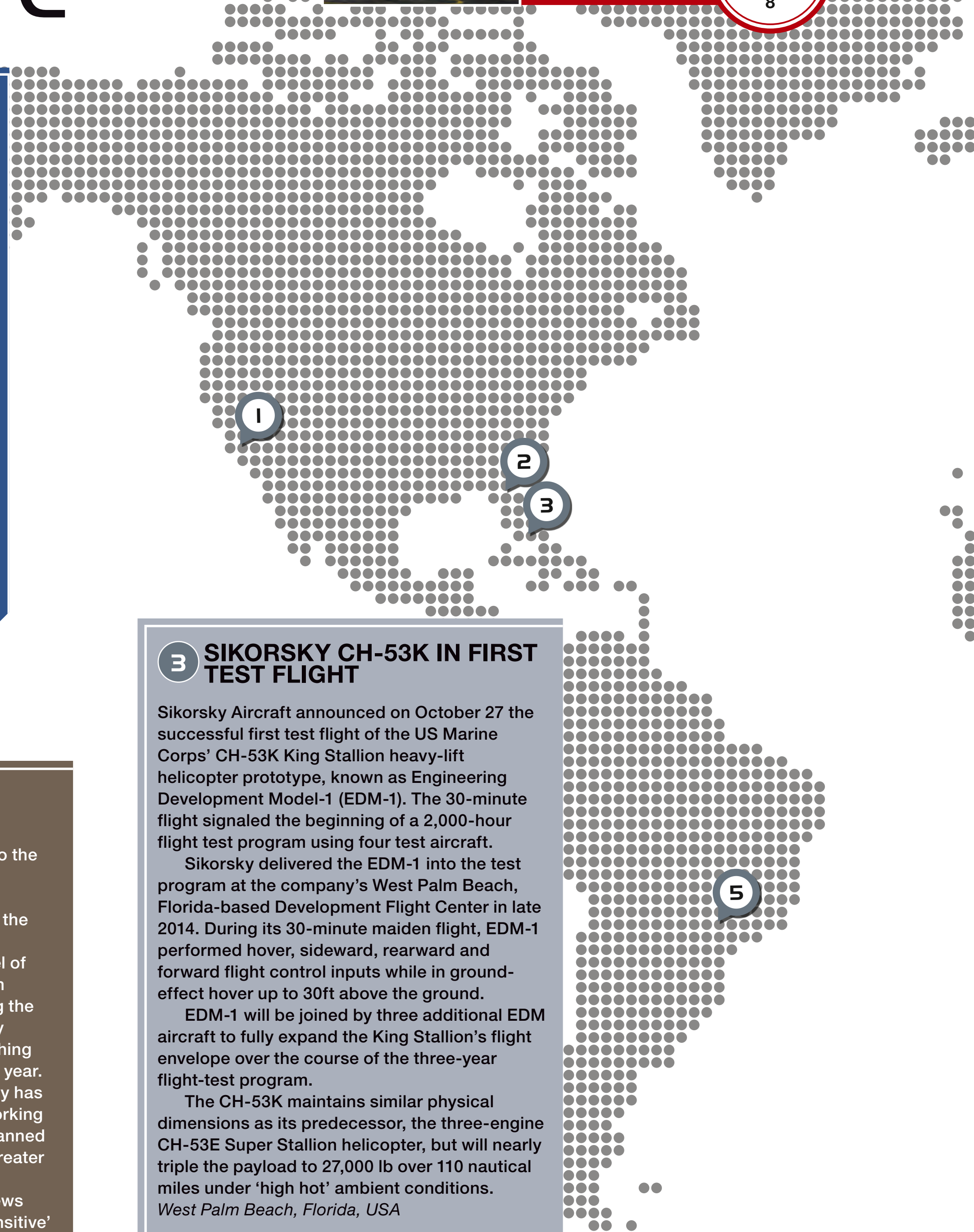
2 UNMANNED BLACK HAWK PASSES AUTONOMOUS FLIGHT TESTS

A US Army Sikorsky UH-60 Black Hawk helicopter passed a critical test in autonomous flight by successfully delivering an amphibious all-terrain vehicle (AATV) to a Florida drop zone on October 27. After picking up the AATV, the helicopter flew 7km, delivering it to a specified location. The AATV (also unmanned) then traveled on a 10km route, during which it faced various chemical and biological hazards. It relayed its operating data back to the chopper via satellite.

The success of the autonomous missions of the Black Hawk and AATV demonstrates a new level of robotics. It also marks an important step to making the Black Hawk an optionally manned aircraft – something Sikorsky announced last year.

The US Army currently has 2,500 Black Hawks: reworking them to include the unmanned technology would give greater flexibility in prioritizing manned operations – crews could focus on more 'sensitive' missions, while the autonomous vehicles would fulfill resupply missions without increasing fleet size.

Florida, USA



3 SIKORSKY CH-53K IN FIRST TEST FLIGHT

Sikorsky Aircraft announced on October 27 the successful first test flight of the US Marine Corps' CH-53K King Stallion heavy-lift helicopter prototype, known as Engineering Development Model-1 (EDM-1). The 30-minute flight signaled the beginning of a 2,000-hour flight test program using four test aircraft.

Sikorsky delivered the EDM-1 into the test program at the company's West Palm Beach, Florida-based Development Flight Center in late 2014. During its 30-minute maiden flight, EDM-1 performed hover, sideward, rearward and forward flight control inputs while in ground-effect hover up to 30ft above the ground.

EDM-1 will be joined by three additional EDM aircraft to fully expand the King Stallion's flight envelope over the course of the three-year flight-test program.

The CH-53K maintains similar physical dimensions as its predecessor, the three-engine CH-53E Super Stallion helicopter, but will nearly triple the payload to 27,000 lb over 110 nautical miles under 'high hot' ambient conditions.

West Palm Beach, Florida, USA

4 AIRBUS HELICOPTERS FLIES HIGH-COMPRESSION ENGINE

Airbus Helicopters successfully completed the first flight test of the High-Compression Engine (HCE) demonstrator aircraft on November 6, at Marseille Provence Airport, France.

Integrated into an H120 helicopter, the 4.6-liter, high-compression piston engine incorporates numerous technologies already applied in advanced self-ignition engines, and runs on kerosene fuel already widely available at airfields.

Marseille, France

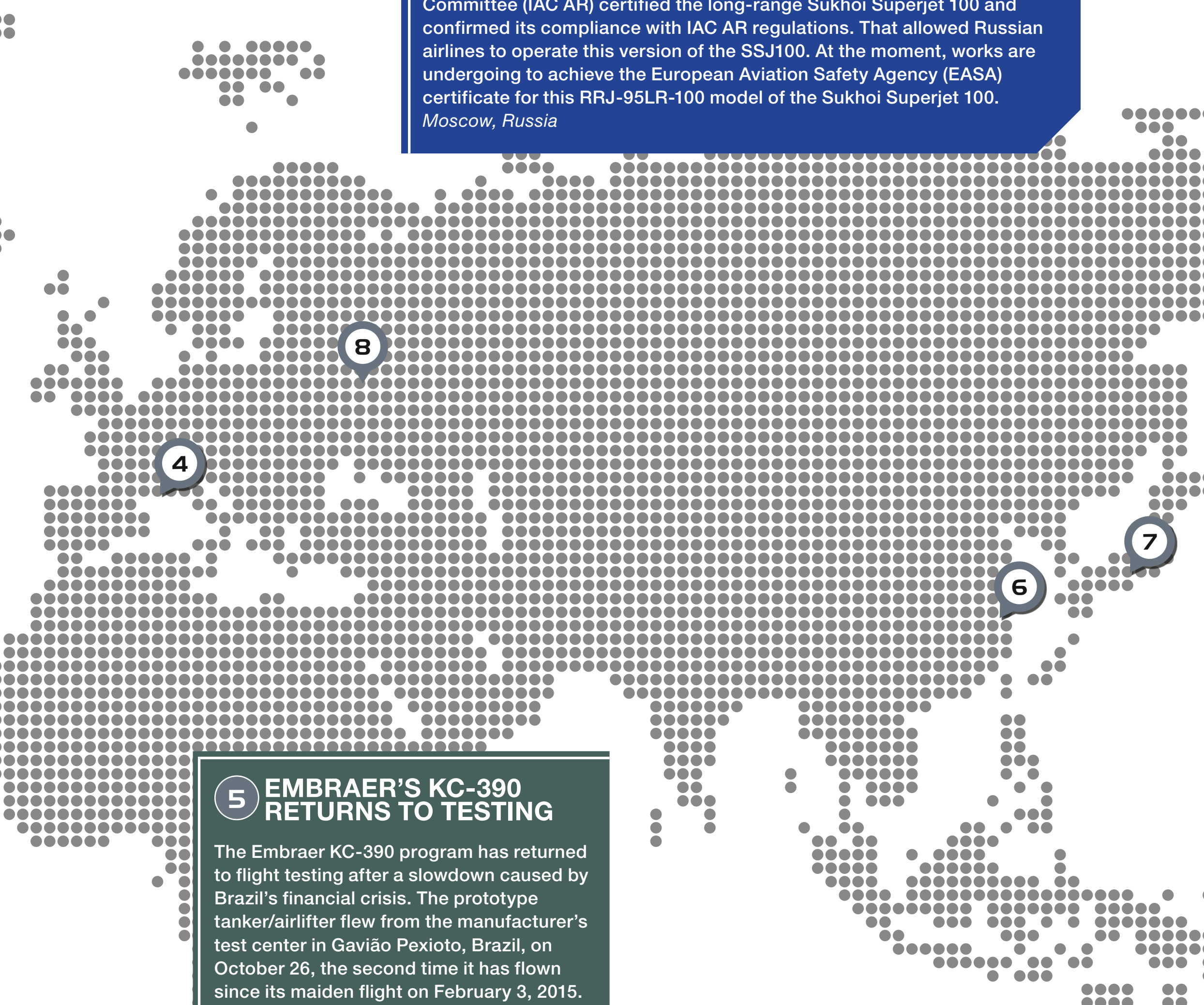
SEE INTERVIEW ON PAGE 8

8 FATIGUE STRENGTH TESTING OF RRJ-95LR-100 STARTS

Fatigue strength testing of the long-range version of the Sukhoi Superjet 100 (RRJ-95LR-100) has started at the Central Aerohydrodynamic Institute in Moscow, Russia, to confirm the designed service life (70,000 flight hours and 54,000 cycles) of the extended range version of the aircraft. Currently, the confirmed designed service life of the aircraft is 9,000 flight hours and 6,000 cycles.

In 2013, Russia's Aviation Register of the Interstate Aviation Committee (IAC AR) certified the long-range Sukhoi Superjet 100 and confirmed its compliance with IAC AR regulations. That allowed Russian airlines to operate this version of the SSJ100. At the moment, works are undergoing to achieve the European Aviation Safety Agency (EASA) certificate for this RRJ-95LR-100 model of the Sukhoi Superjet 100.

Moscow, Russia



7 MRJ COMPLETES FIRST FLIGHT

Mitsubishi Aircraft Corporation and Mitsubishi Heavy Industries conducted the first flight of the Mitsubishi Regional Jet (MRJ) flight test aircraft, their next-generation regional jet, on November 11, 2015.

The MRJ took off from Nagoya Airport in Japan, and the test confirmed its basic characteristics and functionality in ascent, descent and turning, in airspace off the Pacific coast during its 1.5-hour flight.

Mitsubishi Aircraft Corporation and Mitsubishi Heavy Industries will continue to conduct flight tests ahead of the first delivery, which is scheduled for the second quarter of 2017. Flight tests in the USA are scheduled to start in the second quarter of 2016, from the MRJ base at Grant County International Airport at Moses Lake in Washington State.

Nagoya, Japan

READ MORE ON THE MRJ ON PAGE 52

5 EMBRAER'S KC-390 RETURNS TO TESTING

The Embraer KC-390 program has returned to flight testing after a slowdown caused by Brazil's financial crisis. The prototype tanker/airlifter flew from the manufacturer's test center in Gavião Pexioto, Brazil, on October 26, the second time it has flown since its maiden flight on February 3, 2015.

Embraer flew the prototype again before the Dubai Airshow in November. During this second flight, of approximately an hour's duration, Embraer tested the initial flight profile, flight-control responses, and general aircraft behavior.

An earlier program schedule called for Embraer to certify and deliver the first KC-390 to the Brazilian Air Force in 2016, but the slowdown was announced in July, when the company cited devaluation of the Brazilian real and government spending cuts. The manufacturer now expects to certify the aircraft in 2017 and to begin deliveries the following year.

Gavião Pexioto, Brazil

6 COMAC COMPLETES FIRST C919

The first COMAC C919 to be assembled in Shanghai rolled out of the newly built final assembly workshop on November 2, 2015. The event signals completion of the assembly of body segments and airborne systems, which are now ready for ground tests, after which the aircraft will be readied for flight tests.

The C919 is a short-medium range single-aisle jet, for which design began in 2008. The basic version seats 158 passengers in a two-class cabin, or 168 in all-economy class layout. A high-density layout can seat 174 passengers. The standard range is 4,075km and the extended-range version should reach 5,555km. The company says it is designed for an economic service life of 90,000 flying hours – or 30 years.

The maiden flight is expected in 2016, after the completion of the adjustment of airborne systems and installation of flight test equipment.

Shanghai, China

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AEROSPACE TESTING INTERNATIONAL NEWS EXCLUSIVE

SEE OUR WEBSITE FOR VIDEO!

ABOVE: **Without a Fly-Bag installed, an explosion erupts from the luggage hold of a 747 during a test**

BOMB-PROOF BAG

Novel technology applied to counteract the threat of onboard explosive devices on passenger jets has just completed successful testing at the Cotswold Airport, near Cirencester, UK.

The Fly-Bag is a bomb-proof lining used inside luggage containers in an aircraft's baggage hold, or inside the passenger cabin, to contain detonations from an explosive device. Fly-Bag was developed by a European consortium including Blastech (UK), a spin-off company from the University of Sheffield, as well as partners from Greece, Spain, Italy, Germany, Sweden and the Netherlands.

Fundamental to the design of the bag is a combination of fabrics that have high strength, plus high resistance to impact and heat. The fabrics include aramid, which is used in ballistic body armor.

A key feature of the Fly-Bag is its flexible lining. "This adds to its resilience when containing the explosive force and any fragments produced," explained Andy Tyas, of the University of Sheffield's department of civil and structural engineering. "It ensures the Fly-Bag acts as a membrane rather than as a rigid-walled container that might shatter on impact.

"We extensively tested Fly-Bag prototypes at the University of Sheffield's blast-testing laboratory," he continued, "but the purpose of these latest tests was to investigate how the concept works in the confines of a real aircraft. The results are extremely promising."

The Fly-Bag is designed to resist and contain the main three threats from a cargo hold detonation: the initial shock pressure, the longer-term gas pressure build-up, and the production of projectiles from fragments of luggage. "It does the first by being reinforced in key areas by composite panels," said Tyas. "The gas pressure is managed as the flexible bag inflates and slowly releases the pressure into the cargo hold. The fragments are contained by the bag as it is strong enough not to be perforated on impact, and flexible enough to softly catch and decelerate the projectiles – a bit like a 'soft hands' catch in cricket or baseball."

TEST PROGRAM

In a series of about 40 tests in the laboratory and 15 tests using actual aircraft fuselages, the device has shown it can contain blasts during controlled explosions. "A lot of tests have been carried out on the different Fly-Bag devices in the open air at Blastech facilities," said Danilo Bardaro, an engineering specialist at Italian engineering consultancy D'Appolonia, and project coordinator of the Fly-Bag project.

The average cost for a testing campaign on a decommissioned aircraft is £30,000 (US$45,000) – a cost partially funded by the European Fly-Bag2 project.

Acceleration data was collected from sensors on dummies placed in close proximity to the explosion. After the tests, explosives were placed in the aircraft without the lining to show the damage that could be caused (pictured, above).

Tyas said, "The tests were designed to see whether the bags could be installed on the aircraft and withstand internal detonations of certain magnitudes without deforming so greatly that they would impact the aircraft structure."

Bardaro added: "The explosive charges used during ground tests were optimized to take into account the pressurized effect when the aircraft is in flight. During the full-scale tests, the Fly-Bag devices were tested several times to investigate the threshold charge they could withstand to protect the aircraft fuselage."

The testing program is now finished but there may be further tests for customers or authorities, if required.

Two versions of the bag have been developed to date. The first is made of textiles and is foldable for the passenger cabin, weighs roughly 10kg, and can provide the crew with a means to deal with devices found on board.

The second is designed for narrow- or wide-bodied aircraft cargo holds and is installed inside the contoured metallic containers (for example, ULD or AKE types) already used for luggage transportation. This version, which is also foldable so does not need to be installed permanently, consists of a textile envelope plus a composite floor and weighs 50kg.

"The additional weight of combining the Fly-Bag kit with a lightweight composite container is negligible," said Bardaro.

Hardened luggage containers have previously been developed to deal with bombs hidden in passenger luggage, but these containers are heavier and more costly than conventional baggage handling options.

Several companies are interested in bringing the product to market, possibly in 2016, confirmed Bardaro. ∎

RIGHT: **A controlled exposion in a container with a Fly-Bag leaves the hold undamaged**

BELOW: **The damage after an explosion, without a Fly-Bag fitted within the fuselage**

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ALEXANDRE GIERCZYNSKI

HCE project manager, Innovative Power Solutions, Airbus Helicopters

The HCE demonstrator aircraft during its first test flight

SEE OUR WEBSITE FOR VIDEO!

Alexandre Gierczynski recently oversaw the first flight test of Airbus Helicopters' High-Compression Engine (HCE) demonstrator aircraft, as part of the European Clean Sky initiative's Green Rotorcraft Integrated Technology Demonstrator (ITD) program, in partnership with TEOS Powertrain Engineering and Austro Engine

Meet Alexandre Gierczynski, the man responsible for Airbus Helicopters' innovative High Compression Engine (HCE) demonstrator, which first flew on November 6, 2015 at Marignane Airport, France. Integrated into an H120, the 4.6-liter, dual-channel FADEC controlled, high-compression piston engine incorporates numerous technologies already applied in advanced self-ignition engines, and runs on widely available kerosene fuel. Its V8 design has the two sets of cylinders oriented at 90° to each other, with high-pressure (1,800 bar) common-rail direct injection and one turbocharger per cylinder bank. Other features include fully machined aluminum blocks and titanium connecting rods, pistons and liners made of steel, liquid-cooling and dry sump management for the lubricating motor oil as used on aerobatic aircraft and race cars.

WHAT INTERESTED YOU IN A CAREER IN AEROSPACE TESTING AND ENGINEERING?

I have a background in automotive engines, but I was interested in understanding how a helicopter works, so I applied for this position at Airbus Helicopters [then Eurocopter] about six years ago, at the suggestion of a friend from university. It's a dream for me to see things flying. I 'fly' myself – but not with an engine. I like to paraglide. It's a nice feeling.

WHAT IS DIFFERENT ABOUT THE HCE DEMONSTRATOR AIRCRAFT?

The demonstrator is basically a flying test bed. We will use it to verify that we can install a piston engine on a helicopter, using a diesel cycle. The HCE uses kerosene, as used in turboshaft engines and the fuel most in use at airfields today. There are some key differences between the HCE and a turboshaft, including engine mass, torque, vibration and the cooling system.

HOW IS THE HELICOPTER INSTRUMENTED FOR TESTING PURPOSES?

We take temperature and pressure measurements, displacement/movement measurements, and on the airframe we use sensors to measure strain. There are also sensors on some shafts to measure torque. We also have the standard flight test instrumentation, including GPS, measurement of collective and cyclic pitches, etc. All this data is stored on a recorder on board. For cost reasons, we do not use telemetry.

DESCRIBE THE FIRST FLIGHT TEST

The first flight lasted 30 minutes. It began with the helicopter hovering in ground effect, then some lateral translations were made and finally the helicopter flew forward at up to 60kts. The flight test took place after a long period of ground testing. Work on the HCE began in 2011, followed by bench tests and system simulations, including successful 'Iron Bird' tests in February 2014. The objective of the Iron Bird testing was to validate a number of technical challenges related to the installation of the new powerplant, including: damp piston engine torque oscillations and engine vibration; cool engine when hovering; master clutching sequence; and control rotor speed (low engine inertia versus high rotor inertia). Ground runs with the HCE-equipped helicopter were then performed during February and March this year, before the first flight.

WHAT ARE SOME OF THE ADVANTAGES OFFERED BY HCE TECHNOLOGY?

Fuel consumption. We are able to save up to 50% of fuel depending on the duty cycle. The first test flight showed a minimum saving of 30% at take-off power and up to 50% at best fuel economy power. Engine performance in hot and high conditions is also improved. A turbocharged engine is able to compensate for the air density loss experienced at a higher temperature or higher altitude, by maintaining the same power output of the engine at heights up to 2,500m. In a turboshaft, as soon as you get to an altitude of 50m you start to lose kilowatts. The third advantage is financial. We can save 30% in direct operating costs. We are burning less fuel, which means less money, but maintenance is also cheaper than for a turboshaft.

AND THE MAJOR DISADVANTAGES?

There is one drawback – the mass of the engine. The current demonstrator engine is twice as heavy as an equivalent turboshaft unit. Our target with the HCE demonstrator aircraft is to achieve a weight to power ratio of 0.8kg/kW for the installed engine. A turboshaft engine typically requires around 0.4kg/kW. Our target for the final sales product is 0.6kg/kW – it needs further development but we're getting pretty close to that already. As a result of the much lower fuel consumption, the additional mass of the engine is compensated for while flying.

WHAT NEXT FOR THE PROJECT?

The next step will be to go out of ground effect, to climb in altitude and also to take the demonstrator up to its maximum speed and carry out some turns and various maneuvers. That will help us check rotor speed control and how all the components of the engine perform, as well as their condition after each flight. We estimate it will take about six months to complete the flight test sequence. ∎

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GARNET RIDGWAY

TECH ADVANCES

The development rate of consumer electronics has been meteoric over the past few decades, whereas aircraft undergoing testing are often fundamentally unchanged. Does this huge technological advance make aerospace testing a formality in this day and age?

SOPHIE ROBINSON

Ask any aerospace testing professional whether technology has made their lives easier, and at best you'll receive a wry smile. The simple fact is that, yes, testing technology has advanced, but expectations from customers and users have risen at least as quickly.

Although it's true that many aircraft types currently undergoing testing were in service before the widespread use of personal computers, it would be a gross oversimplification to say that they are unchanged. Yes, a new Boeing 747 may look like the same aircraft that rolled off the production line in the 1960s, but beneath the surface it's a totally different beast. It's also often the case that the newest features (avionics, software and human-machine interface modifications) are the most difficult to assess, and the availability of raw computing power is not always useful for their evaluation. The age-old problem of turning data into information requires the same depth of expertise that it always has, and remains a big and costly challenge in the aerospace testing community.

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

It should also be considered that, just because exciting new technology such as touchscreen tablets and miniature HD cameras is available in the stores, it may not be immediately available for use in aerospace testing. Challenges such as airworthiness assessments, equipment qualification and licensing issues often make it prohibitively expensive to introduce new equipment, particularly if the main justification is 'just' to make someone's job easier! Indeed, being forced by commercial pressures to use aging and obsolete testing equipment can make the job more challenging than ever.

In the event of new technology finding its way into an aerospace testing environment, it should be noted that it does not necessarily reduce the difficulty of the task. For example, post-flight interpretation of recorded video and audio from multiple crew stations can be far more complicated and time-consuming than simply observing operation of the system in person (or simply speaking to system users). Similarly, flight test instrumentation with increased numbers of parameters and greater resolution can pose considerable challenges in terms of data processing and interpretation of results.

In summary, aerospace testing is as challenging as ever, regardless of the availability of new technology. However, this does ensure that the traditional skills required to deliver safe and effective capability in air systems are protected, which is surely beneficial to customers and users of aerospace products.

The positive impact of advancing technology is evident in all areas of modern aerospace testing. From small gains like decreasing the amount of time taken to analyze data, to more sizeable gains in increasing sustainability and safety, advancing technology has played the leading role in allowing us, as engineers, to achieve everything we achieve today.

Technology allows us to do more for less, in less time, for less cost, with fewer people involved. Gone are the days of teams of engineers spending hours poring over UV recorder tapes of flight test data and analyzing films of auto-observer instruments; tasks that previously might have taken a team days or weeks are accomplished by a single individual in a matter of hours, allowing us to more rapidly deliver safety and capability.

Issues and concerns are much more easily identified, and often solved, due to the capacity that we have to delve deeply into the hundreds, if not thousands, of parameters recorded by a modern flight test instrumentation system – a capability that wouldn't exist without technology. In this regard, the facts speak for themselves: flight has become demonstrably safer in the last few decades; this is no coincidence.

Advances in aerospace technology also enable much closer scrutiny to be applied to our work, producing higher-quality outputs by eliminating errors. Higher levels of automation remove the human element from our output – which is often the primary source of error. Additionally, this degree of automation provides a superior audit trail to support flight safety arguments, ultimately making the job of an aerospace testing professional easier.

Technology has also allowed for the de-risking of flight test programs during the preliminary stages. Better, more accurate simulation techniques are helping us define safe flight envelopes without the need to even turn a rotor or fire up an engine. A consequence of this is a reduction in the number of flying hours required, making flight test leaner and greener, and improving the sustainability of our industry.

So, fundamentally, yes, advances in technology have made the job of early-development aerospace testing easier over the last few decades. However, this does not mean that it is without its challenges. Although the technical element may be easier, customer expectations have never been higher and nor budgets tighter. In future, the toughest challenge facing the industry is unlikely to be a technical one; rather, it will be convincing customers of the need to continue investing in aerospace testing.

Sophie Robinson works on 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

C of approval

Bombardier hopes for C Series approval and a US$1bn provincial government investment by year's end

BY IAN GOOLD

Announcing the planned C Series airliner at the 2004 Farnborough Airshow, Bombardier said the initial letter was for "Competitive, Continental [and] Connector". Now the Canadian manufacturer might have two other 'C' words in mind: certification of the aircraft and a recently promised Christmas present of a US$1bn Quebec government investment in a new entity to establish full production.

The company remains confident that the design will meet specific global market requirements "and has long-term market potential". There has been a recent dearth of the new sales needed to boost existing firm C Series orders of almost 250. Undefined commitments cover a further 360 aircraft.

As Bombardier's flight-test (FT) fleet has grown to six aircraft, certification flying has intensified. On one day the fleet logged more than 20 test flight hours. More than 11 years after the aircraft's unveiling, testing is almost complete, having gone "extremely well", according to C Series program director Sebastien Mullot. "Flight-testing continues to make solid progress. We obtained all the test points we planned for."

Bombardier says key flight and structural test results exceed original targets for airfield performance, fuel consumption, payload and range (under specific operating conditions when compared with aircraft currently in production for flights of 500 nautical miles).

FLIGHT LOG

Eight Bombardier C Series Flight-Test Vehicles (FTVs) have logged more than 2,800 flight hours in the certification program (although Bombardier says the sixth CS100 being used for reliability trials is not officially an FTV). Some of the flight-test work performed is summarized below:

FTV1 (MSN 50001): Used for flight envelope establishment, handling characteristics, and flutter tests at a wide range of speeds (including Mach 0.82 maximum operating and Mach 0.91 maximum dive speeds) and altitudes (up to 41,000ft [12,500m]).
FTV2 (MSN 50002): Auxiliary power unit and engine hydraulics, and pneumatic propulsion and mechanical systems tests; low-temperature, cold soak, natural icing and high-temperature trials in the McKinley Climatic Laboratory at Eglin Air Force Base in Florida; hot-weather flight tests in Arizona; high-altitude testing in Colorado.
FTV3 (MSN 50003): Avionics and electrical systems; community noise tests in Oregon.
FTV4 (MSN 50004): Airfield, cruise and take-off and landing performance, including speed, range, aerodynamic drag, airflow characteristics and fuel consumption.
FTV5 (MSN 50005): Full passenger-cabin interior to test all environment control systems and crew/passenger interfaces; and used for passenger emergency-evacuation test.
FTV6 (MSN 50006): Sixth CS100 and first production unit: function and reliability flights only (not officially designated FTV6).
FTV7 (MSN 55001): First larger CS300 variant, built to latest production standards. Used to test flutter, handling (including cross-wind take-off and landing), in-flight cruise and airfield performance (including braking and anti-skid testing) and engine differences.
FTV8 (MSN 55002): Second CS300. Full passenger-cabin interior scheduled for completion in late 2015 to test environmental-control system differences.

The manufacturer says that C Series is the only totally new aircraft – and the first in 30 years – being marketed globally in the 100-149 seat category. Because of this, the C Series designers have had computer and simulation technologies that were not available to competing designs from earlier eras.

Such technological evolution has enabled Bombardier to generate the "most aerodynamically efficient aircraft, with integrated components from the start", asserts Mullot. The C Series variants share 95% of their parts and a single pilot's type-rating.

Technology has also provided additional FT leverage, according to Mullot, who cites advances in telemetry that allow real-time data transmission to the ground.

Development of so much onboard equipment has brought a challenge, however. Since the single-aisle C Series is much narrower than twin-aisle aircraft, such as the new Airbus A350, there is less room to accommodate lots of FT instruments.

CERTIFICATION TIMEFRAME

Officially, the program remains on target to receive Canadian certification for the 100-passenger CS100 by the end of 2015, with entry into service (EIS) scheduled for the second quarter of 2016. With most work complete, Mullot sees that approval lying very much in the airworthiness agency's hands. Despite saying that Bombardier trusts Transport Canada (TC) to reach a decision soon, Mullot concedes that formal approval might only emerge "in the new year". Certification from EASA and the FAA would follow within "a few weeks".

ABOVE: Bombardier's Complete Integrated Aircraft Systems Test Area (CIASTA) houses the C Series Integrated Systems Test and Certification Rig – dubbed Aircraft Zero or 'Iron Bird' – that has enabled early product maturity

BELOW: Aircraft are run through a water trough to confirm that operations in wet conditions do not result in the engines or APU ingesting water

All CS100 certification work had been completed (subject to TC review) by mid-November 2015 and the configuration was frozen; CS300 certification work was over 60% complete. Bombardier believes that it is the first manufacturer to certificate two variants of a new aircraft simultaneously.

Approval for the 130-passenger CS300 is about six months behind that of its smaller sibling.

An initial consideration for Bombardier was how quickly it could accumulate FT time on the first aircraft, dubbed Flight Test Vehicle Number 1 (or FTV1). The company had been keen to fly it during northern summer of 2013, but the program was delayed until the third quarter of that year (first flight September 16, 2013).

Mullot acknowledges that plans did not allow for the possible loss of time

ENGINE HOURS

Pratt & Whitney conducted over 4,000 hours of engine testing to obtain Transport Canada certification for the C Series PW1525G-JM geared-turbofan powerplant ahead of certification in February 2013. This included 340 hours with an engine flying on the engine manufacturer's Boeing 747 testbed.

603
Orders and 'commitments' received for C Series aircraft, including firm orders for 243

2,800
flight hours logged on CS100 flight-test vehicles by November 2015

3,300
nautical miles – maximum range for C Series aircraft

due to external factors, such as the failure of a Pratt & Whitney PW1525G-JM geared-turbofan – possibly caused by an oil-seal fault. This incident kept the aircraft grounded for several weeks in mid-2014. "[In future], we could do more ground work during [such a] time," says the program director. The incident cost Bombardier precious flying time while Pratt & Whitney analyzed the engine and improved manufacturing quality control, but the test aircraft logged more flying than expected once FT resumed. Other lessons from the almost-complete flight-testing include Mullot's belief that more can be learned through additional ground work ahead of first flight: "We have not done so much of that historically."

Bombardier also discovered a drawback when flights go well. The FT team and aircraft can return early from a scheduled assignment, but they need to have additional pre-planned work that they can do before landing should time permit. Accordingly, Mullot believes that planning should be more flexible so as to accommodate more tasks, something Bombardier was able to do when flying resumed after the pause due to the failed engine.

A welcome discovery was that effort invested early in the design phase meant that "very little" change to structural or system components was required. "The challenge lies more in the software, where you have to integrate millions of lines of code." Bombardier planned phased software iterations, for which its Complete Integrated Aircraft Systems Test Area (CIASTA) and wide FT expertise were instrumental.

Some of the C Series FT aircraft might be refurbished for subsequent airline service. Each has a principal role, although the FT program permits duties to be switched between airframes (as European manufacturer Airbus did with A320neo FTVs, following a GTF engine incident of its own). Individual test flights have averaged about three hours, but vary in duration between 30 minutes and nine hours (see *'Flight Log'*, opposite, for FTV duties).

"APPROVAL FOR THE 130-PASSENGER CS300 IS ABOUT SIX MONTHS BEHIND THAT OF ITS SMALLER SIBLING"

FINAL TEST PROGRAM

In November, a few repeat certification tests were flown as Bombardier finalized FT reports for Transport Canada. "Not too many more hours were required," says Mullot, who concedes that the company would have flown "as many as needed".

The final phase will conclude in early 2016 as Bombardier completes function and reliability (F&R) trials with the first production CS100, ahead of EIS with launch operator Swiss International Air Lines. F&R testing, or 'route proving', sees the aircraft flying on representative airline routes, schedules and operational procedures.

Overall, the work includes airfield performance, landings and airport turnarounds, and on-ground operations at over 30 Canadian and US airports, and others in Europe. In initial North American F&R tests, the FT fleet demonstrated a 100% dispatch reliability rate (the proportion of flights departing within, typically, 15 minutes

BELOW AND RIGHT: **Bombardier engineers work hand in hand: ground-test workers ensure aircraft systems are ready to fly safely, while flight-test crews validate them in the air to obtain results**

ABOVE: C Series CS100 FTV2 has been used to test the engine hydraulic system and the auxiliary power unit

BLOWING HOT AND COLD

Climatic testing of the C Series saw the jetliner subjected to a temperature range of 107°C (193°F) in a three-phase trial at the McKinley climatic laboratory in Florida, to assess engine-start performance and deployment of other systems such emergency-evacuation slides and landing-gear 'swings', and refuel/defuel tests under environmental extremes. Aircraft FTV2 was left overnight in a sub-zero chamber at temperatures as low as -54°C (-65.2°F) for engine and APU test starts the next morning. Warm-up procedures that operators will use in extreme cold conditions were measured. Engines were run at maximum power to ensure correct functioning. In the second phase, engine and APU operations were assessed in heavy snow, freezing rain and fog, along with aircraft performance during ice build-up on the airframe. Finally, operations were simulated under varying degrees of heat up to 53°C (127.4°F) to confirm the efficiency of the environmental control system in cooling the passenger cabin in desert climates.

of schedule) "comparable to production units", says Bombardier.

Further planned testing – not required for initial type certification – includes 'extended-range' operations to qualify C Series aircraft and engines for flights up to 90 minutes – initially 120 minutes later – away (at single-engine flying speed) from available diversionary airfields.

TEST HOURS

By early November, CS100s had logged more than 2,800 hours, representing 97% of the projected total FT time. The original 2,400-hour estimate, based on experience and numbers of test points to be completed, was extended by 400 hours following a review in early 2014, four months after first flight, that concluded more FT time was required to ensure "overall system maturity at EIS".

Bombardier has confirmed the maximum range of the C Series as "up to" 3,300 nautical miles (6,110km) – 350 nautical miles (650km) above the original design target. Claimed fuel-burn advantage, compared with in-production aircraft, is put at "more than 20%" – or "greater than 10%" over re-engined aircraft" (read A320neo or Boeing 737 Max).

COMPLETED CS100 TESTS

Bombardier, by November, had completed flight tests covering airfield and cruise performance, anti-skid braking, cabin environment control, high-altitude airport operations, hot-weather operations, minimum-control speeds, natural icing, passenger emergency evacuation, smoke/fire detection and suppression, water ingestion, and all avionics, communications and navigation systems.

Following completion of noise-performance work, Bombardier says FT data confirms the C Series as the "quietest in-production commercial jet in its class". Combined with claimed

35,000+
simulated flight cycles applied to fatigue-test specimen

41,000ft
maximum altitude achieved by C Series flight-test aircraft

97%
proportion of C Series flight-test program completed by November 2015

95%
parts commonality between CS100 and CS300 variants for certification purposes

"outstanding short-field capability", Mullot says this makes the new jetliner ideal for a wide variety of operations.

CS300 TESTS

The CS300 needs more testing in areas such as aircraft handling, brakes and cruise/climb performance, according to Mullot. With five CS100s completing FT work, and all systems "performing well", the first CS300 FT aircraft has been used for anti-skid testing, braking, cross-wind take-off and landing, cruise performance, flutter and handling. The second CS300 FT craft should be rolled out before the end of the year. "All the aircraft are displaying a high level of reliability, and performance and test results are in line with expectations," says Bombardier.

TEST CENTERS

Bombardier has invested "infinitely more" in ground testing for the C Series project, according to Mullot. Compared with previous Bombardier commercial programs, the manufacturer gained a time advantage for C Series aircraft by using two flight-test centers – at Montreal's Mirabel Airport and at Wichita, Kansas. Mullot says Wichita's "very beneficial" climate has enabled Bombardier to gain greater productivity from the FTV fleet. "We make the best use of the weather at each location."

All required C Series static testing – which includes exceeding ultimate load (defined as 150% of the design load, which is that most likely to be encountered in service) on Bombardier's Complete Airframe Static Test (CAST) unit (see '*Loading Bay*' sidebar, overleaf) – was completed by early 2015. The fatigue-test specimen being tested in Dresden, Germany, has logged more than 35,000 cycles, "well

RIGHT: **Water tanks in the cabin are used to simulate passenger weight and adjust aircraft center of gravity**

BELOW: **The single-aisle cabin leaves little room for lots of instruments**

ABOVE: **Flight-test crew prepare to fly in the second CS100 (FTV2)**

LOADING BAY

Bombardier developed its C Series Complete Airframe Static Test (CAST) unit to simulate flight loads on a 'free-floating, non-restrained, counterbalanced' airframe. The structure demonstrates the aircraft's static strength and integrity and compliance with certification requirements. Tests include wing up-bending and down-bending trials that apply representative loads, including those encountered in flight maneuvers, take-off and landing, and other in-flight and on-ground conditions. Most spectacularly, the wing up-bending ultimate-load test – replicating 150% of the highest forces the aircraft might experience – can see the wingtip raised about 10ft (3m) above its usual relative position. The CAST structure will continue to be used for the collection of performance data.

over the quarter-life testing required at EIS", with "no issue".

Bombardier's CIASTA, which incorporates multiple rigs to test aircraft systems' hardware and software, and their interactions, remains in use to ground-test various improvements arising from flight testing. CIASTA houses, among other things, the aircraft Integrated Systems Test and Certification Rig (ISTCR) – dubbed Aircraft Zero, or 'Iron Bird' – that has enabled early product maturity.

Bombardier was able to test avionics systems, electrical and environmental controls, and flight-control systems a year ahead of the FT program. Other test equipment includes an engineering simulator, flight-controls integration laboratory, interiors rig and systems-integration test stand.

UPDATING FTVS

Since the C Series first flew, Aircraft Zero has been constantly updated to match the other FTVs. It is fitted with all key systems, including production-standard equipment permitting interaction between the test specimen and real production units. It has run since December 2012 and has also been used for trouble-shooting that has reduced demand on the FT fleet.

How much integration is there between the ground and flight test departments? "They work hand-in-hand. Ground-test engineers ensure that aircraft systems are ready to fly safely, and the FT team validates them and brings back results," says Mullot. "The engineering team integrates adjustments, and the cycle starts again. One team could not work without the other."

One pilot from launch customer Swiss made a familiarization flight when CS100 FTV5 flew to Zurich after June's Paris Airshow. EASA is also accruing similar experience, soon to be followed by regulators from the FAA.

National airworthiness agency Transport Canada has been flying the C Series FTVs in recent months, while Swiss is working with Bombardier Customer Services as flight crew train on the engineering simulator.

Bombardier hopes more customers will follow after certification and the Quebec government's Christmas present investment promise. ▮

Ian Goold is a UK-based aviation journalist, specializing in the civil sector

Detonation squad

Weapons testing remains complex, challenging and costly; however, BAE Systems' ongoing effort to integrate the Meteor AAM with the Typhoon fighter provides a good insight into current best practice

BY PAUL E EDEN

BAE Systems conducted guided firing trials of the Meteor beyond visual range air-to-air missile from a Eurofighter Typhoon combat aircraft earlier this year

Attaching anything to an aircraft introduces variables affecting the object, the platform and their interface, electronically and aerodynamically. When that object is a weapon, typically as the 'sharp end' of a complex system, the test variables to ensure safe operation are multiplied.

"Safety is a top priority through all the work we do," says Dom Patel, senior weapons engineer for BAE Systems' Military Air and Information, "and there are standard processes and procedures for the weapon supplier and aircraft integrator, resulting in detailed, documented system safety assessments. The process does not change with the role of the aircraft, but the numbers may differ depending upon intrinsic weapon safety performance. Safety reviews and committees are held regularly, ensuring risks have been mitigated and the product is safe and fit for purpose before flight trials take place."

When a trial reaches the weapons release or firing stages, the test team looks far beyond the aircraft/weapon combination in its risk assessment, as range safety adds another layer of assurance. BAE Systems works closely with the UK Royal Air Force's 41 (Reserve) Test and Evaluation Squadron on Tornado and Typhoon. "The mindsets toward safety precautions for air-to-air [A/A] and air-to-ground [A/G] weapons tests are inherently similar, but differ in their specific requirements," explains Flight Lieutenant Dan 'Lowesy' Lowes, a Typhoon flight-qualified weapons instructor on the unit, when describing the scope of range safety. "An

2
The Phase of Typhoon enhancements under which Meteor is being integrated

4
The number of Typhoons in service with 41(R) Sqn – it also has three Tornado GR4s

> "SAFETY IS A TOP PRIORITY THROUGH ALL THE WORK WE DO"

A/A sortie will require a safety trace that takes into account missile fly-out depending on the height and speed at which the weapon is fired, its kinematic ability, fuel burn and type. We also need to take into account where the weapon will fall and where the target will land if it's hit/not hit. A safe height for the firing aircraft, deconflicted from the target height, is also required. An A/S [air-to-surface] sortie requires a weapon safety trace depending on the height, speed and range from the target at which it is released. This needs to cater for the weapon kinematics, whether it's high explosive or inert, and so on. If dynamic maneuvers are flown – for a strafe, for example – then a recovery profile is also briefed. An aircraft-safe distance is required for both types of sortie, instructing the pilot on a post-release maneuver that keeps the aircraft as safe as possible."

INTEGRATION PLAN

Weapon integration and testing tends to be unique to particular aircraft/weapon combinations. "Very little evidence can be read across from other platforms as hard evidence," says Patel, adding, "the environments can be quite different as well as the methods of attachment, release, and so on. The weapon's own qualification data will be used to assist with flight certification and associated limitations, but all weapon integrations are generally bespoke."

Test campaigns therefore tend to follow similar patterns, although some stages may be omitted or varied depending on system maturity. A typical sequence involves: trial installation; loading; pit drops; engine ground runs; electromagnetic compatibility (EMC) tests; carriage; structural coupling; ground resonance; flutter; environmental and aerodynamic data gathering; flight controls; aircraft handling and performance; avionics testing; safe separation release and jettison; and guided firings/releases. A separate procedure is applied at each stage to test and prove that the system meets requirements.

ABOVE: The trials formed part of the flight test campaign for the Phase 2 Enhancements (P2E) program which will introduce a range of new and improved long-range attack capabilities including Meteor and Storm Shadow missiles

The essence at every stage is data gathering, with gigabytes of information collected directly from avionic data buses in the aircraft's systems. Patel explains that key data includes, "GPS satellite alignment, cockpit displays, aiming, tracking, data linking, navigation, release sequencing, failure modes, end-to-end performance, laser guidance, arming, and safety interlocks, etc."

In the case of Meteor, "The weapon needs to be able to receive comms from the aircraft, perform safely, datalink, seek out the target, complete pre-

"THE MINDSETS TOWARD SAFETY PRECAUTIONS FOR A/A AND A/G WEAPONS TESTS ARE INHERENTLY SIMILAR, BUT DIFFER IN THEIR SPECIFIC REQUIREMENTS"

ABOVE: Typhoon aircraft IPA6, a Tranche 2 standard aircraft equipped with the latest P2E software, was used for the trials

launch transfer alignment, and so on," he continues. "We analyze all this data to confirm correct functionality of the aircraft systems and software [flight control, utility control, avionics, armament control] during weapon carriage and release. The data gathered from flight trials is fed back into our models to check if the model predictions were good/correct, allowing us to build more confidence in the model(s) for further trials planning activities."

SIMULATION AND MODELING

Simulation and modeling have roles to play in weapons testing, primarily in de-risking flight trials. "There are models of aircraft performance and maneuvers, radar track and search, and missile fly-out that are interconnected to simulate complete weapon system behavior – they're used to predict what the aircraft and weapon are likely to do during a firing trial," says Patel. "This is vital to provide an early view of any risk so that we can put appropriate measures in place to ensure the trial's success. We also model weapon release trajectories to compare with flight data and interpolate for many other flight conditions so that we can determine and confirm safe release and jettison characteristics, while missile plume effects are modeled for impingement and ingestion," he continues. "Wind-tunnel testing and aerodynamic modeling in the early stages of the weapon integration process help ascertain what effects the introduction of a new weapon may have on the existing aircraft; the designers and pilots use the simulators to develop and assess the weapon system from the cockpit and prepare for test flights."

DROP PIT

An essentially simple, long-standing test facility, the drop pit continues to have an important weapon test role. An aircraft is positioned so that the weapon under test is directly over the pit and its characteristics on release can be minutely examined – often using high-speed photography.

Dom Patel explains BAE's procedures: "Pit drop testing is used early on prior-to-flight testing, to check initial release performance; test lanyard functionality; confirm correct rigging, dressing and operations; check cartridge firing of ejector release units; check initial trajectories; and other parameters. The data from these trials helps verify the modeling predictions for subsequent aircraft firing trials."

Drop testing complete, a program is likely to move on to captive carry trials, where a weapon is attached to the aircraft pylon and flown, without being released. "We test for flutter, avionics, handling, data gathering and other functions," says Patel. "Captive carry allows us to step through the

METEOR INTEGRATION

Work continues to integrate Meteor onto Typhoon, through the aircraft's Phase 2 Enhancements Program (P2E). "To date, we've carried out aircraft systems design development and rig tests; aircraft ground trials (ground resonance, structural coupling, EMC); and aircraft flight trials (flutter, avionics, performance, handling and several missile releases/ firings)," says BAE Systems' Dom Patel. "There are more flight trials and firings to come over the next 18 months as increments of P2E."

The Meteor P2E program involves the Eurofighter partner companies, which have responsibility for some of the aircraft design and rig and aircraft testing. Some Meteor trials work has taken place in Sweden and the USA, but BAE Systems has not been involved with this, since all Meteor firings in support of Typhoon integration are being conducted in the UK.

LASER QUEST

Lockheed Martin made global headlines back in October when it announced it was continuing to test a prototype laser turret for the Defense Advanced Research Projects Agency (DARPA) and the Air Force Research Laboratory (AFRL), paving the way for laser weapon systems on tactical aircraft.

"Because enemy aircraft and missiles can come from anywhere, a laser weapon system on a military aircraft will need to be able to fire in any direction," says Doug Graham, VP of missile systems and advanced programs, Strategic and Missile Defense Systems, Lockheed Martin Space Systems. "However, the laws of physics say that a laser can only engage targets in front of an aircraft that is traveling close to the speed of sound – unless atmospheric turbulence can be counteracted."

Lockheed Martin believes its aero-adaptive Aero-optic Beam Control turret is the first unit ever to demonstrate a 360° field of regard for laser weapon systems on an aircraft flying near the speed of sound. Its performance has been verified in nearly 60 flight tests conducted in 2014 and 2015 using a business jet as a low-cost flying testbed. As the aircraft traveled at jet cruise speeds, a low-power laser beam was fired through the turret's optical window to measure and verify performance in all directions.

The design uses the latest aerodynamic and flow-control technology to minimize the impacts of turbulence on a laser beam. An optical compensation system, which uses deformable mirrors, is then used to ensure that the beam can get through the atmosphere to the target. Left unchecked, turbulence would scatter the light particles that make up a laser beam, much like fog diffuses a flashlight beam.

DARPA and AFRL will use the test results to determine future requirements for laser weapon systems on high-speed aircraft.

18
The number of remaining months scheduled for Meteor/Typhoon integration

41
The name/number of the RAF's fast jet test and evaluation unit, based at RAF Coningsby, Lincolnshire, UK

process of 'firing' a weapon without actually releasing it. The main objective of a captive carriage trial is to exercise the avionics system as though it is going through an actual firing sequence. So from an avionics system perspective a weapon is fired, but physically the test weapon remains attached to the aircraft. This gives a real benefit to trials efficiency, since the aircraft can carry out a substantial number of firings in the same flight, capturing data from each."

WEAPON LAUNCH

When it comes to the next phase of testing, Flight Lieutenant Lowes says, "Primarily, you're looking to assess the weapon integration on the aircraft. How do they talk to each other, do they pass the correct information – if a pilot plans a mission, or sends coordinates to an A/S weapon, will it go where it's intended to? Does the required data transfer from the radar to prime a missile correctly? How does an IR weapon communicate to the pilot when it has a heat source? Does it 'know' how to reject countermeasures? These are just a few very simple parameters for weapons testing – it can get much more complicated."

By the time a weapon comes to 41(R) Squadron, the target used during its trials is largely irrelevant, since its effect has usually been designed and assessed by industry. BAE Systems is involved at an earlier stage in the process, however, when the weapon has been proven, but not in combination with the aircraft platform. For its airborne trials, it therefore uses a variety of target scenarios. "For air-to-air we can use a break-up unit to destroy the missile at a set distance (with no real target) or use a drone (a Mirach for Meteor firings), but again operate the break-up so the drone can be used again," says Patel. "For air-to-surface, a barge target is often anchored at sea and the weapon is usually guided to just miss."

ABOVE: High-speed camera footage of a Meteor missile being fired from Typhoon aircraft IPA6

For flight test, aircraft and weapons are instrumented to measure parameters including vibration, temperature, noise, loads, acceleration and databus transactions. Data is recorded on board and transmitted live to one of BAE Systems' telemetry ground stations, or a mobile ground station positioned at the firing range.

High-speed photography is used to capture footage of the weapon leaving the aircraft and the data fed back into the safe separation modeling to validate the model. Cameras are mounted on the aircraft or in dedicated pods (often modified drop tanks) depending on the angle of footage required. Chase aircraft occasionally accompany a release trial, especially if video footage is required.

Weapons testing is a costly, demanding process, accomplished most efficiently through close cooperation between weapon manufacturer, integrator and customer. The Meteor/Typhoon integration is a fine example: "We have a very close relationship with MBDA as the weapon supplier and we place a contract with them to support the integration, including testing on rigs and aircraft," explains Patel. "We also work closely with 41 Squadron, especially via the Combined Test Team, and there are several Meteor working group meetings each year, where the stakeholders come together to review progress against requirements, maturity and performance evaluation. For Meteor integration we've taken customer-specific requirements into the planning and definition phase of our test firing scenarios. Working closely with the customer means that we can combine integration-specific firing conditions and operational firing conditions, and greater trials efficiency can be achieved by capturing test evidence that both industry and customers can use." ∎

Paul E Eden is a UK-based specialist freelance writer and editor in the aviation industry

Pioneer spirit

If flying a sailplane to the edge of space isn't demanding enough, try doing it with a team composed almost exclusively of volunteers!

BY THOMAS NEWDICK

A member of the test team gives Perlan 2 one final check before its first flight in early September, 2015

Successor to the Perlan 1 research sailplane, in which the late Steve Fossett and Einar Enevoldson captured an altitude record for gliders of 50,722ft (15,460m) in August 2006, the Perlan 2 is designed to fly higher still: exploring the 'mountain waves' encountered at 90,000ft (27,500m). In the process, the two-seat sailplane will fly higher than the U-2 and the SR-71 and gather data on climate change and depletion of the ozone layer. It will also give its crew the feeling of what it might be like to fly a winged aircraft over the surface of Mars.

Described as a "spacecraft with glider wings", the two-seat Perlan 2 represents a major technological and human challenge. Its design brief includes the ability to fly in less than 3% of normal air density and at temperatures of -70°C. To do this, the lightweight aircraft has a wingspan of 84ft (26m), pressurized accommodation for two pilots, provision for a scientific payload, life support equipment and two safety parachutes.

To date, the Perlan 2 has completed one flight, out of Redmond Municipal Airport, Oregon, USA, on September 23, 2015. However, a large amount of data was gathered in advance of this milestone, and tests continue to ensure that the aircraft will behave as

> “IN THE GROUND VIBRATION TESTS ... WE CAN LOOK AT THE STRUCTURAL LOADS AND USE THE MODEL TO PREDICT FLUTTER”

expected once at very high altitude. The project did not conduct a wind tunnel test, even with a model. Instead the key piece of simulation was a CFD test phase.

GROUND TESTING AND FIRST FLIGHT

Ed Warnock, CEO for the Airbus Perlan Mission II project, outlines the next three tests completed on the ground: “The first test we did on the ground was on a duplicate of the cockpit and fuselage section that we tested for pressure and strength. We sealed up the cockpit and pressurized it to 25psi – three times the maximum pressure we expect to see on our missions. We then loaded it up with sandbags and pulled on the fuselage to create the same stresses as for our 6g flight load. The pressure bulkhead failed at exactly 25psi. Later on we tested the wings to 3g, to prove their design and strength were adequate for the first flight. Then after the first flight we did a 5g test on the wings.”

Between the 3g and 5g tests, both of which were successfully concluded, the team completed its first flight with the Perlan 2, with pilots Jim Payne and Morgan Sandercock at the controls. Before taking the sailplane into the air for the first time, the flight controls were tested for the envisaged stick and rudder forces and a handful of ground tows brought the Perlan 2 up to flying speed, ensuring that it tracked straight, that basic control was as expected, and that the brakes worked.

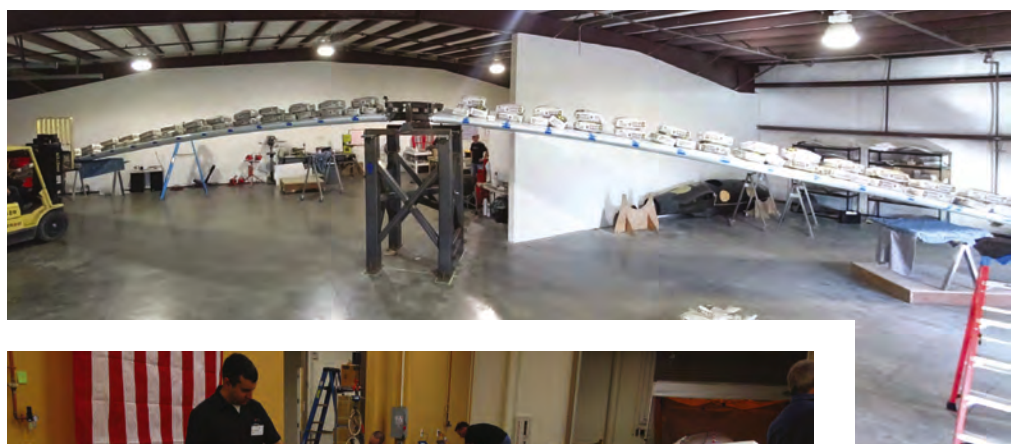
Perlan 2 chief pilot Payne takes up the story: ”For the first flight we basically just wanted to prove we could take off and land and get some basic flying qualities data. We made a normal take-off, towed to a height of 5,000ft (1,500m) and then released and did some basic stability checks, dynamic stability checks and turns. We did not intend to stall it on the first flight – stall speed is predicted to be about 33 KIAS [knots indicated airspeed], but we slowed down to 38 KIAS. The airplane was great and we didn’t have any buffets or indications of a stall. It recovered fine and then we came back and landed.”

As this magazine was going to press (November 2015), the Perlan 2 was in San Diego, California, for ground vibration tests. Payne continued: “We have a computer model of the structure and in the ground vibration tests we’ll have accelerometers all over it so that we can look at the structural loads and use the model to predict flutter. So as we do envelope expansion we’ll be doing flutter test points to verify if the

0
Number of engines

2
Number of crew

8.5
cabin pressure (PSID)



RIGHT: Perlan 2 wing-load test

BELOW RIGHT: Perlan 2 is currently in San Diego undergoing ground vibration tests

THE TEST TEAM

The Perlan 2 project brings together flight testers from a variety of backgrounds – but all are volunteers. Apart from project founder Einar Enevoldson and chief pilot Jim Payne, both of whom are retired, most of the team have day jobs. In terms of flight test experience, Enevoldson spent many years in the US Air Force before becoming a NASA test pilot. He is also a graduate of the Empire Test Pilot’s School in the UK. Payne is another USAF veteran, having spent 22 years with the service and graduating from the USAF Test Pilot School. Thereafter he worked at Northrop Grumman, where he managed the flight testing of the Global Hawk unmanned aerial system. Finally, Roger Tanner, another Test Pilot School graduate, is a USAF reservist assigned to flight test duties at Edwards Air Force Base, California. The team’s flight test engineer is Miguel A Iturmendi, a graduate of the National Test Pilot School with around 9,000 flight hours and type ratings in 10 heavy aircraft. In common with the team’s three most experienced pilots, Iturmendi is also an active glider pilot. When not working as flight test engineer for Perlan Mission II, he undertakes test pilot contract work for the US Department of Defense.

5,000 Altitude (ft) at which Perlan 2 was released for its first flight
72,000 Maximum altitude (ft) of the U-2 spy plane
85,069 Maximum altitude (ft) of the SR-71 Blackbird (current world record)
90,000 The altitude (ft) that Perlan 2 is aiming to reach in 2016 to set a new world record

dynamic behavior of the structure is as predicted. If not, we'll try to figure out why not before we get to any airspeed and altitude conditions where we might have flutter conditions – and we want to avoid those at all costs."

A week into vibration testing, and Payne seemed pleased with progress: "The testing is going very well," he said. "We will not know the final results until they analyze the data, which will take about three weeks."

FLIGHT TEST ENVELOPE EXPANSION

Once ground vibration tests are complete, the Perlan 2 will move to Minden, Nevada, where flight trials will continue to expand the envelope, exploiting a wave season that runs from approximately February to May.

"In late November and December [2015] we'll be using tows and gradually expanding our envelope during systems integration tests. We'll have the pressurization system installed and we will be testing that the pressurization comes on as desired and behaves as desired at lower altitudes."

THE FUNDING CHALLENGE

Run as a non-profit organization, Airbus Perlan Mission II has depended on gifts from individuals to achieve its aims. The first sizeable donation was from one of the team's pilots, Morgan Sandercock, who provided funds for the initial engineering work, including building a mock-up of the cabin. Dennis Tito, the first person to fly to the International Space Station on his own finances, then injected enough funds to complete the design and the CFD work, and to purchase major components. At that point, however, the team was out of money.

For around a year progress was very slow, but in 2014 Airbus Group stepped in and resolved the financial problems, providing a budget to complete aircraft construction and for a first phase of flight tests in Argentina. "Without the support of Airbus, we would still be a happy bunch of volunteers, probably in a garage somewhere dreaming about doing this," says Ed Warnock. The team is still actively raising money for education and research elements. In particular, it is hoped to take on board a package of experiments being built by high school students, to increase interest in this type of research among a younger audience.

ABOVE: Perlan 2 first flight at Roberts Field, Redmond Municipal Airport in Oregon

The team will then gradually start to expand the envelope. "Up to 30,000ft (9,100m) our VNE (never exceed speed) is 121 KIAS, and then above 30,000ft our VNE gradually decreases so that at 90,000ft (27,500m) it is 54 KIAS. We use a standard altitude airspeed diagram with the test points scattered around it. At each of these test points we'll be doing standard flutter and flying quality maneuver blocks."

The team is currently working on a data acquisition system for the sailplane. An inertial measuring unit will be used to gather dynamic data, and other instrumentation will measure load distribution and other factors. Payne considers expansion of the flutter envelope to be the most important flight test element. "Because we are going so high, we are going to get some really high true airspeeds. Even though our indicated airspeed is pretty low, at 90,000ft you get 6.7kts true airspeed for each knot of indicated airspeed. So that's going to be an interesting situation because we'll have really high true airspeed and really high wind speed in the wave. When you're climbing, they sort of balance each other out which makes it kind of easy, like an elevator ride, but when you turn downwind you're going very fast." Ultimately the team hopes to have a real-time data-gathering capability for monitoring flutter data.

One of the biggest challenges for the project is its dependence on the weather. The team is confident of being able to routinely reach an altitude of around 30,000ft in the waves around Minden. If things go well, the sailplane could get to around 40,000ft. Around

"THE DATA WE ARE GATHERING WILL BE APPROXIMATELY EQUIVALENT IN THE FLIGHT REGIME TO A FLIGHT ON MARS"

10 hours of flying at 30,000ft and above will be sufficient to verify the cabin pressurization and the oxygen rebreather system.

UNIQUE CHALLENGES

The provision of a rebreather is very likely a first for a sailplane, and its use reflects concerns for both safety and keeping the weight of the sailplane to a minimum. "By taking the carbon dioxide out and rebreathing the air, we will be using 100% of the oxygen we take out of the tank," Warnock says. "That means we can have a smaller tank. One of the attractions is simply that the weight of the rebreather system is lighter than a standard oxygen system."

While weight is a key factor to take into account, Payne considers that the aircraft's power requirements are just as big a problem to overcome. "We have just 100A of battery power. Meanwhile, we have a new inertial measuring unit weighing less than a couple of kilograms. So we are installing maybe a total of only 10-15 lb (4.5-7kg) of test equipment in the aircraft. Compared with the maximum 1,800 lb (800kg) expected flying weight, it's insignificant."

The next phase of the flight test program will take the glider to Argentina in 2016, where it will be able to benefit from the effect of the polar vortex, which pushes the mountain waves above the troposphere and into the stratosphere. It is these waves that will be responsible for taking the Perlan 2 to its planned record altitude – all the way to 90,000ft. For Warnock, the most important thing before the team goes to Argentina is gaining enough flight experience at altitude to confirm that the pressurization and life-support systems work and that the aircraft has the predicted handling and stability qualities.

VOLUNTEER EFFORT

Airbus Perlan Mission II is clearly an innovative project, not just in terms of technology but also in how it is being run as a non-profit, volunteer-led effort. Daniel Werdung, spokesman for Airbus Group, highlights the "pioneer enthusiasm" behind the project but doesn't see it as a model for future research by the company. "Currently we think this is a great project and we want to support the people working there," he says. "We don't see it as a prototype. We just want to promote this project and see the research they can do, and then we will see where we take it. Right now it is about enthusiasm, research and the testing – pushing the limits."

Once the Perlan 2 is operating at very high altitude, the data gathered may well contribute to the dream of flying a winged aircraft on Mars.

"The data we are gathering will be approximately equivalent in the flight regime to a flight on Mars," Warnock explains. "The air densities and temperatures will be approximately equivalent. We will be sharing that data with universities and much of it will go into the public domain to enrich and excite exploration in very thin atmospheres. Airbus Group will be sponsoring that data and we hope to give it wide distribution so that it can be used by researchers doing projects that may see flight on Mars. We want to make sure that data is available to aerospace engineers and researchers all over the world."

Following the ground vibration tests, it is likely that the Perlan 2 will start flying again at Minden in early December 2015. And once flight testing in Nevada is complete, the aircraft will move to Argentina.

For chief pilot Payne, the biggest challenge at that point is going to be the weather.

"There are a lot of unknowns about the polar vortex," he admits. "We have got models that the meteorological community has built and I am hoping they are all accurate. But we won't know until we go out there and fly. It's going to be a lot of fun comparing the predictions with what we find." ▮

TOP: Perlan 2 separates from a Piper Pawnee towplane during first flight

ABOVE: Perlan 2 takes off for its first flight, September 23, 2015

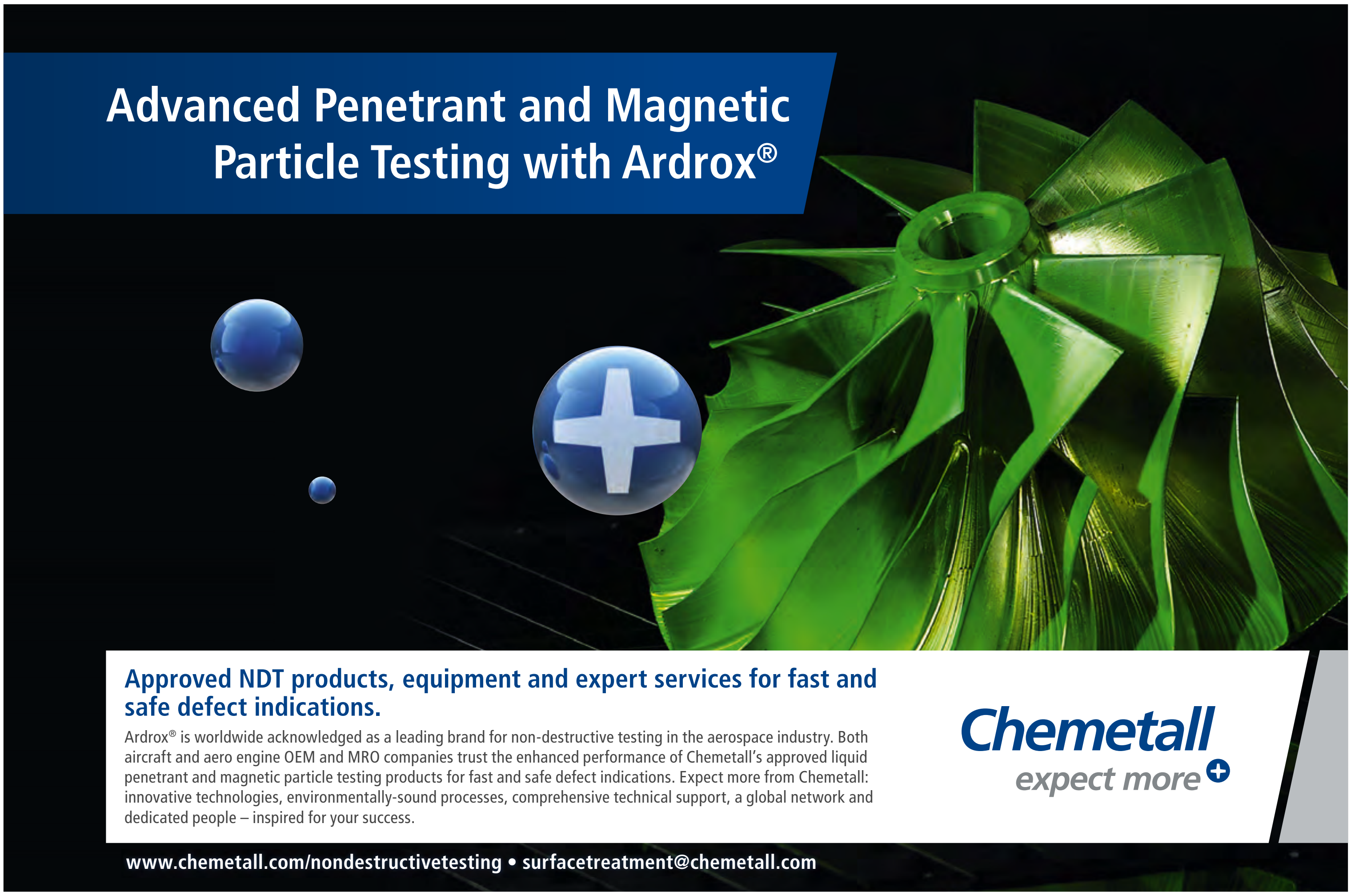
84 Wing span (ft)

263 Wing area (ft²)

1,265 Empty weight (lb)

1,800 Gross weight (lb)

Thomas Newdick is an aviation and defense writer based in Berlin, Germany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Sonic tonic

NASA and other leading aerospace companies and agencies are determined to develop a low sonic boom aircraft – but what are some of the testing challenges involved?

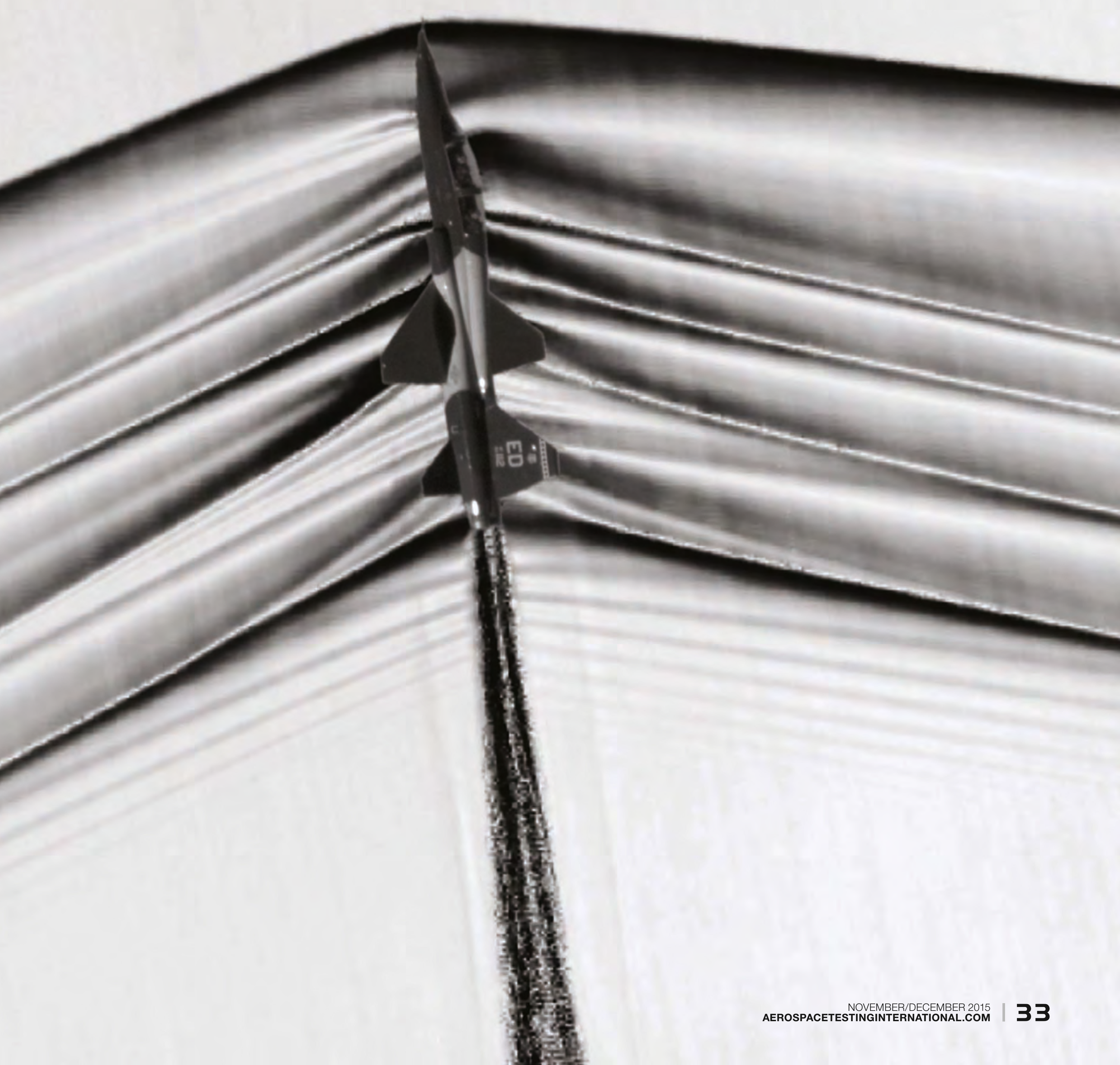
BY GEORGE COUPE

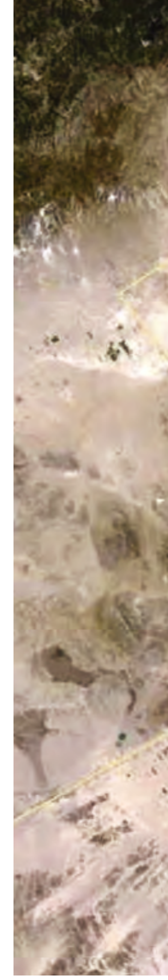
The chief barrier to a new age of supersonic commercial flight has always been the loud complaints from below about the noise. A near total ban on supersonic flight and sonic booms over land put paid to Concorde's chances of becoming a commercial success and has grounded the industry ever since; and while propulsion technology has continued to advance, the much more difficult challenge of developing a low-boom aircraft has remained unsolved.

But that could be about to change as a crop of research projects around the globe attempt to get to grips with the problem. Airbus recently filed designs with the US Patent and Trademarks Office for a low-boom supersonic aircraft, and the Japan Aerospace Exploration Agency (JAXA) announced that in July this year it completed the world's first successful flight test of a low sonic boom concept aircraft (see *Global efforts continue* sidebar, overleaf).

Some of the most intensive work in this area is being carried out under NASA's Commercial Supersonic Technology (CST) Project, which encompasses many aspects of supersonic flight technology and involves the Armstrong, Glen, Ames and Langley research centers. Brett Pauer, the project support manager at the Armstrong Flight Research Center

"WE ARE TRYING TO FIGURE OUT HOW SONIC BOOMS PROPAGATE THROUGH THE AIR"





GLOBAL EFFORTS CONTINUE

The Japan Aerospace Exploration Agency (JAXA) completed the world's first successful flight test of a low sonic boom concept aircraft, July 2015. This was the second phase of its D-SEND project (Drop test for the Simplified Evaluation of Non-symmetrically Distributed sonic boom). The vehicle was dropped from a high-altitude [30.5km] balloon in a test carried out at the Esrange Space Center in Sweden. The aircraft then flew over a series of microphones that measured sonic booms generated by the aircraft.

JAXA has since completed analysis of the flight test data, which shows a reduction of both front and rear shockwaves. This low sonic boom design technology could, for example, reduce Concorde's sonic boom by half. If this was applied to a small supersonic civil transport aircraft for 50 passengers, a 25% reduction would be achieved. The data from the test and its analysis will be used to contribute to an international standard for acceptable sonic boom levels, due to be discussed at an International Civil Aviation Organization (ICAO) meeting next year.

Meanwhile, Airbus has filed designs for a low-boom passenger aircraft, dubbed Concorde 2, with the US Patent Office. The "ultra rapid air vehicle" would cruise at an altitude of more than 100,000ft powered by a combination of conventional jets, ramjets and rocket motors. Both the height at which the aircraft would fly, and the angle at which the shockwave would propagate from the aircraft, said to be between 11° and 15°, will help to reduce the noise of the sonic boom.

75
The number of decibels the NASA research team is aiming for as a standard for acceptable sonic booms

109
The rate of frames per second at which NASA's AirBOS camera captured the Schlieren images of an F-18 in supersonic flight

100,000ft
The cruising altitude of Airbus's proposed low-boom passenger aircraft

in California, says the goal was to gather data to enable the likes of the FAA and ICAO to establish a global low-boom standard.

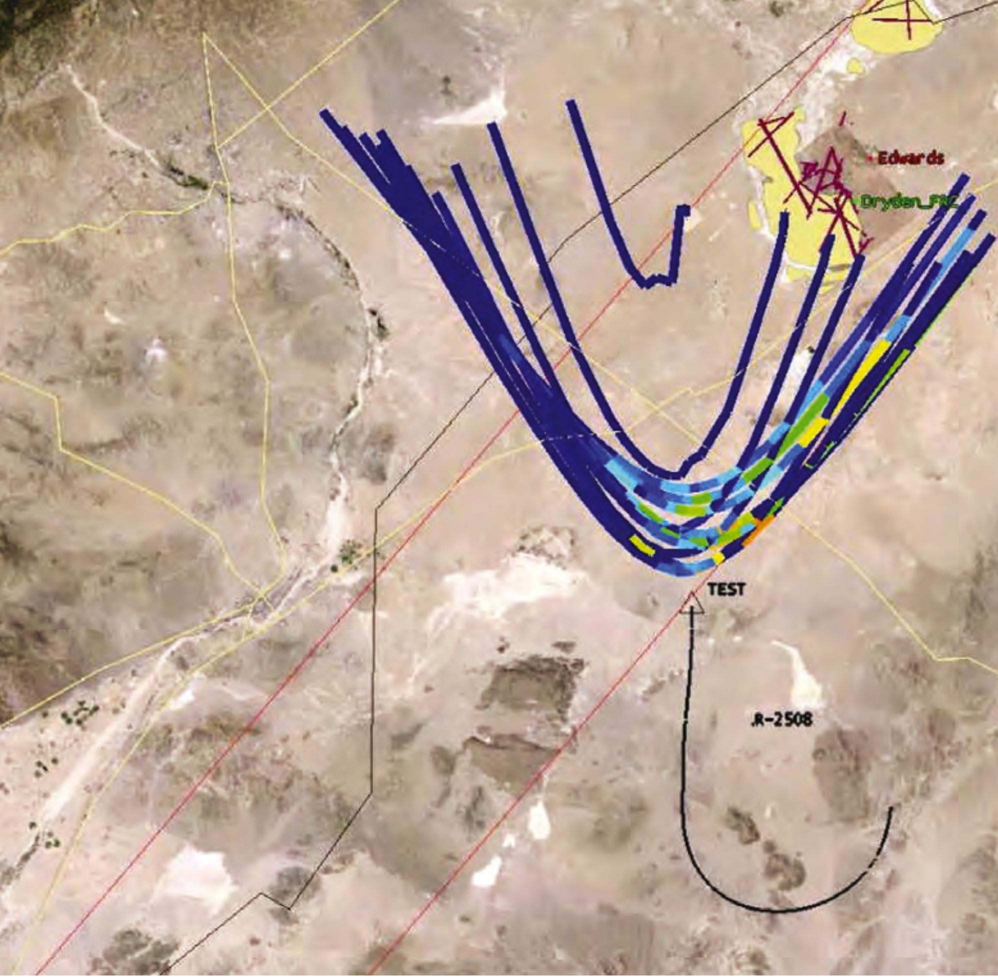
As part of that effort, the team is developing new technologies and test techniques that will lead to a better understanding of sonic booms – in particular, the complex fluid dynamics immediately around the surface of the aircraft. "At Armstrong in particular, we are trying to figure out how sonic booms propagate through the air," explains Pauer. This includes work with local communities on the ground to find out how they respond to the noise generated by supersonic flight. "In the future, it is our hope, although this is not approved, that we can fly a low sonic boom aircraft over communities that have not been exposed to booms. So we are moving toward designing test techniques that would enable us to accomplish that."

The Armstrong team recently tested a cockpit display (see *Boom predictor* sidebar, top right), which shows the extent of the sonic boom on the ground. "This takes information from the aircraft, and weather data from below, and predicts where the boom generated by the aircraft will hit the ground. We have just recently tested that in the back seat of an F-18 while going supersonic," notes Pauer. The boom footprint is superimposed on a moving map, with color-coding to show the intensity.

NASA's fleets of F-15s and F-18s at Armstrong are used like "a flying wind tunnel", adds Pauer; items of high technology readiness level are loaded onto the airplanes and tested in actual flight, at speeds of Mach 1.7 and higher. "A recent test involved a laminar flow wing section that we turned sideways and mounted vertically on the underside of the aircraft. And we took it up to speed and were able to see the extent of laminar flow on the aerofoil design. We can do that with all kinds of different fixtures – not just wings, but propulsion items and probes as well."

Probes are a vital test tool for gathering information about the behavior of supersonic flows immediately around the surface of the aircraft. Pauer says standard probes tend to incorporate a 'lag' in their design, because the measuring device was separated from the tip of the probe by a long tube of air. He says researchers are working on a new design, in which the sensor is much

BELOW: Overland supersonic aircraft concept used by NASA in computer simulations and to create models for wind tunnel tests



ABOVE: Real-time sonic boom display in NASA control room

BOOM PREDICTOR

NASA's Armstrong Flight Research Center has developed a real-time, interactive sonic boom display, which can be integrated into any cockpit or flight control room to help pilots place loud booms in specific locations away from populated areas – or prevent them from occurring.

Many factors influence sonic booms: aircraft size, weight, shape and trajectory; weather and atmospheric conditions; and terrain and topography. NASA Armstrong's patented technology integrates and processes vehicle and flight parameters, as well as three-dimensional Earth modeling and atmospheric data to predict sonic boom parameters. Prediction data is integrated with a real-time, local-area moving-map display that is capable of displaying the aircraft's current sonic boom footprint at all times. The processor calculates the sonic boom near a field source based on aircraft flight parameters, then 'ray traces' the sonic boom to a ground location, taking into account the near-field source, environmental condition data, terrain data, and aircraft information. The processor 'signature ages' the ray trace information to obtain a ground boom footprint and calculates the ray trace information to obtain Mach cut-off condition information. A pilot can choose from a menu of pre-programmed maneuvers – such as accelerations, turns, or pushovers – and the predicted sonic boom footprint for that maneuver appears on the map display. This allows pilots to select or modify parameters to either avoid generating a boom, or to place it in a specific location.

The FAA is expected to require a system of this type to approve flight plans, monitor aircraft in flight, and review flight data to enforce noise regulations. "No other system exists (to our knowledge) to manage sonic booms," explains NASA engineer Edward Haering. "Our system is unique in its ability to display in real time the location and intensity of shockwaves caused by supersonic aircraft."

closer to the surface of the aircraft and therefore is able to provide a more instantaneous reading.

Further out from the aircraft, the team is working on sonic boom propagation and how that is affected by the weather and other phenomena such as turbulence. As in the JAXA tests, this usually entails an aircraft flying at supersonic speeds over a series of microphones on the ground. However, to measure the affect of low-altitude turbulence on the boom, they plan to record the aircraft from both above and below at the same time and analyze the differences.

Pauer explains, "The way we plan on doing that is to use a motor glider, and we shut the motor down above the turbulent level at about 10,000ft, well above the turbulent layer. This will capture the sonic boom above the turbulent layer and then we'll have microphones underneath so we'll capture the influence in the microphone recording."

SCHLIEREN IMAGING

Most significantly, however, has been the progress made in improving on a 19th century method of photographing shockwaves. The technique, known as Schlieren imaging, is an important testing tool and has long been used in wind tunnels to capture the flow around scale models and other test objects.

Five years ago, NASA began a program to develop the technology for imaging shockwaves in close proximity to full-scale aircraft in supersonic flight – a much more challenging task.

The Schlieren images reveal the presence of shockwaves due to the change in air density and the accompanying change in the refractive index. Originally, this required the use of complex optics and strong light sources; more recently image-processing technology has been used to develop 'synthetic' Schlieren techniques, in particular background-oriented Schlieren (BOS). Researchers take a series of photographs of the object in supersonic flow against a speckled background – the shockwave image is derived from analysis of the distortions in the pattern. BOS is light on complex hardware and heavy on computer processing, which makes it an attractive means to obtain high-spatial-resolution imaging of shockwaves in flight.

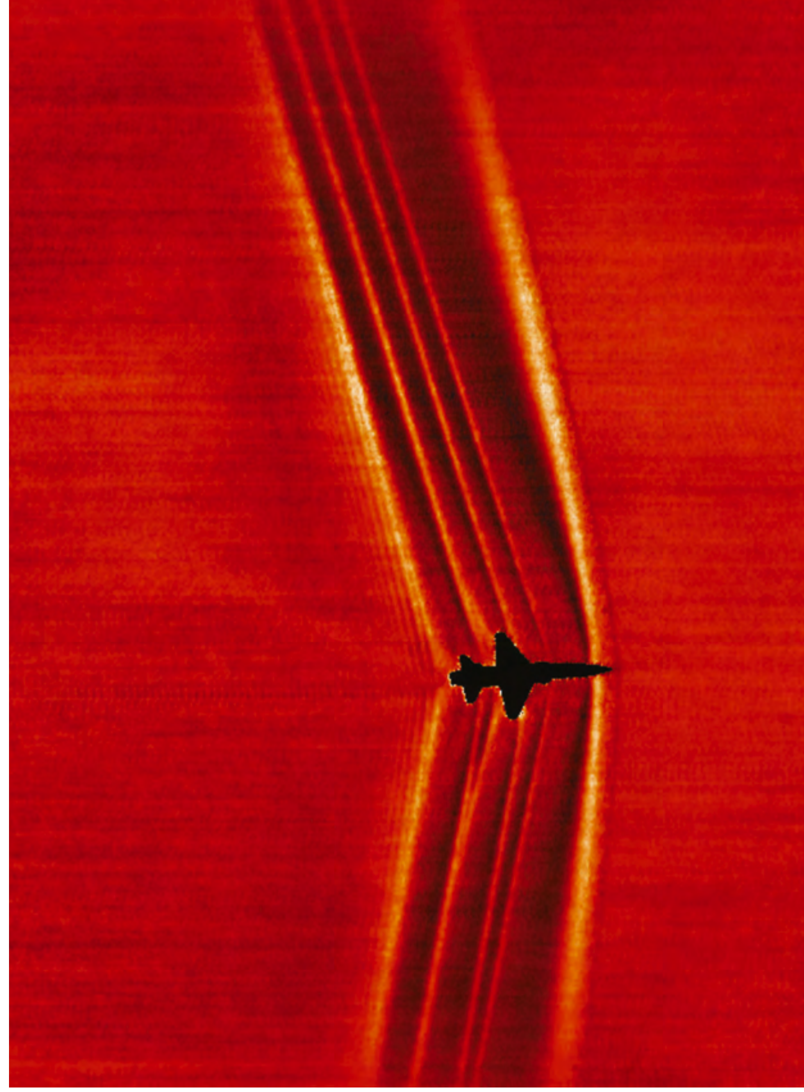
In April 2011, the first phase of Armstrong's AirBOS testing took place, to capture images of the supersonic shockwave created by an F-18. A high-speed camera on the underside of a B200 King Air captured 109 frames per second while the supersonic target aircraft passed several thousand feet underneath in straight-and-level flight at speeds up to Mach 1.09. The team took pictures with a relatively simple system consisting of a laptop with a frame grabber and using natural desert vegetation as the speckled background.

The test was run again in October 2014 with better resolution and higher frame-rate cameras, and achieved a dramatic improvement in the images.

The use of different lens and altitude combinations and knife-edge aircraft maneuvers by the pilot of the target aircraft provided the opportunity to obtain side-on images.

Further improvements were made for AirBOS 3 tests in February 2015. After each flight, the NASA-developed software was used to remove the desert background and then the frames were combined and averaged to produce clean and clear images of the shockwaves.

Air-to-air photography, however, is not easy. It involves synchronizing the flight paths of a supersonic and subsonic aircraft, which requires meticulous planning and precision flying, and a complex integration of the aircraft's navigation systems must be performed to ensure both are properly



COMPETITIVE SPIRIT

Quieter, greener supersonic travel is the focus of eight studies selected by NASA's Commercial Supersonic Technology project to receive millions of dollars in funding to help overcome the remaining barriers to commercial supersonic flight. Recipients include: the Massachusetts Institute of Technology, which has been awarded US$1.2m over four years to conduct a study entitled, *Global Environmental Impact of Supersonic Cruise Aircraft in the Stratosphere*; Wyle Laboratories of Arlington, Virginia, which has received US$1.2m over three years to conduct a study entitled, *The Influence of Turbulence on Shaped Sonic Booms*; Rockwell Collins, which has been granted US$698,000 to develop a sonic boom display; Honeywell, which will receive US$686,000 over two years to develop a pilot interface for mitigating sonic boom; and the University of California, which will receive US$575,000 over two years to work on quiet nozzle concepts for low-boom aircraft.

positioned over the background target area. The only alternative is to photograph from the ground and use the edge of the sun as a background.

While this method yields adequate results, it is only possible to make two observations in each pass as the target aircraft crosses the left and right sides of the sun.

SOLAR HARVEST

Then Armstrong engineer Edward Haering made a breakthrough when he noticed that the supersonic shockwave also distorted the visible sunspots on the sun's surface: "When you film the sun with the right filter you see a bright white circle of light with the black sky around it, and without the aircraft there, its just circular; but when the aircraft passes by, it ripples the edge," he says. "When doing some of those flights we also saw sunspots, and the sunspots would kind of twinkle as the shockwave went past so we thought, well, if we have a lot more sunspots, we could get a lot more information."

He then used some calcium-K optical filters to reveal more of the granulated texture of the sun's surface. "When you image it, you see all these little speckles on the sun, and when the shockwave goes across that you have all those speckles scintillating and twinkling, and mathematically when the flight is over we can look at the data and figure out how much each of those little speckles has shifted and extract back out how strong the shockwaves were."

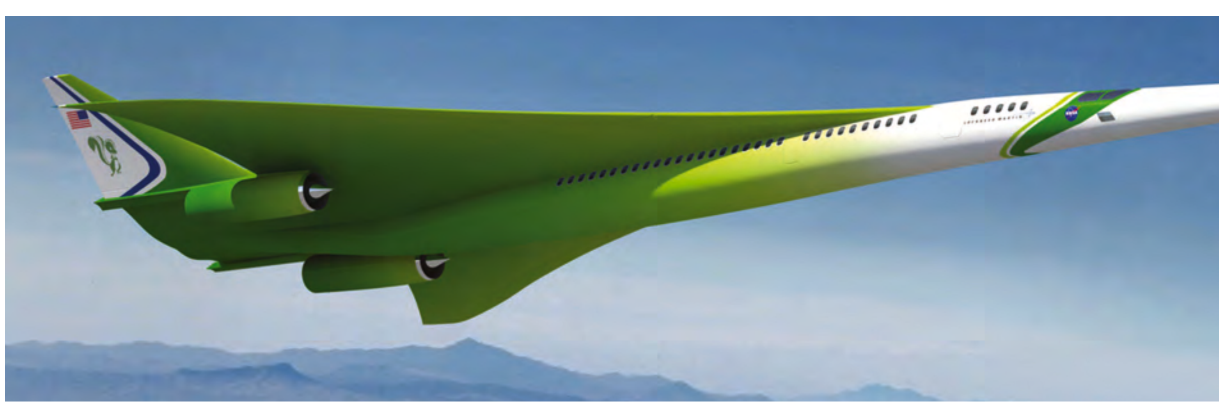
Haering is the originator of what is now known as the BOSCO concept, Background Oriented Schlieren using Celestial Objects, which potentially offers a practical and safe approach to studying the shockwaves of larger supersonic aircraft, such as a commercial transport demonstrator. "The nice thing about using the sun is that at sunrise it is level, so you can see shocks directly underneath, which are of most interest to us because those are the ones that hit the ground. For the flights where we have the supersonic airplane under the King Air aircraft, we have the pilot fly a 90° bank at the last second so we get knife-edge flight and we can see relative to the aeroplane the shocks above and below the airplane. That is great for a fighter, but if we ever get a low-boom transport aircraft, we won't be able to fly knife-edge, so we will probably have to look sideways at the sun."

The moon can also be used as a background, but Haering hopes that further advances in camera technology will enable his team to use the stars across the entire night sky, which would dramatically boost the amount of data they could capture: "We are limited right now by the size of the sun and the moon; they are about half a degree of the sky and there is no information outside of that. If you were able to use the stars, you would have the entire sky to look against. But for this technique we are looking at hundreds of frames per second, so you need a really bright source at this point. We are hoping that with better cameras in the future we can see dimmer things at high speed, at a high frame-rate, to be able to image that."

Haering says the next ground-based test, which is scheduled early next year, will employ a camera and telescope capable of producing images of five times the resolution of those already published. The team is also working on new processing techniques, which are constantly bearing fruit. "There are at least three different kinds of math that we are using and it seems like weekly we can come up with new details and features." Another round of air-to-air tests will be carried out this December.

NASA's research includes phenomena other than shockwaves,

BELOW: The Lockheed Martin future supersonic advanced concept features one engine on top of the fuselage and two under the wings (visible in this image)



such as wing tip vortices and engine plumes. Haering says the December tests will also involve observations of subsonic aircraft, such as high-lift aircraft, in the expectation that the findings will be of use to designers in that part of the industry.

NUMBER CRUNCHING

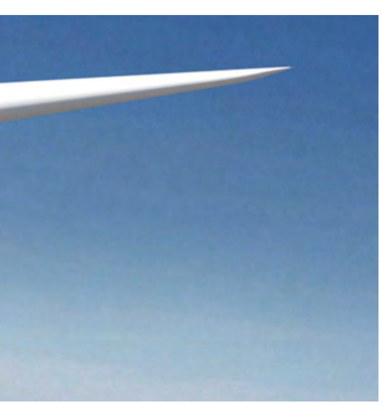
But what do the Schlieren images obtained so far suggest about the future design of low-boom aircraft, and what will the research team do with the data it has collected?

One of the main objectives is to validate current CFD code and wind tunnel testing technology, says Haering: "Close in to the aircraft, there is a lot of intense CFD that goes on; that part is difficult to do around propulsion systems in a wind tunnel. Once you are further away from the vehicle, the boom is pretty well established and it is pretty easy to compute how it is going to go down to the ground. So we are really trying to focus in, and look at how good our CFD tools are near the aircraft so we can take these existing F-15s, F-18s and, hopefully, later a low-boom demonstrator aircraft, and prove the CFD is right, and have confidence that in future designs we will accurately predict how loud it is on the ground."

ABOVE: **This Schlieren image of a T-38C was captured using the patent-pending BOSCO technique and then processed with NASA-developed code to reveal the shockwave structures**

In a conventionally designed aircraft, a shockwave is produced by every change in its surface; the shockwaves tend to coalesce at the front and rear of the aircraft, creating the boom. The low-boom design would have to prevent this from happening, keeping the shockwave separate.

"It's about distribution," says Haering. "The designers have a tough job having all the volume and lift changes so that individual booms are about the same level. When you have a bigger boom behind a smaller boom on the front end, it quickly overtakes it – it superimposes. So you would like to have nearly equal booms that stay separated. You can't change the energy, but what you can do is redistribute it so that it is less annoying to the ear. Instead of an instantaneous bang, you're going to have a bunch of little puffs or pops."



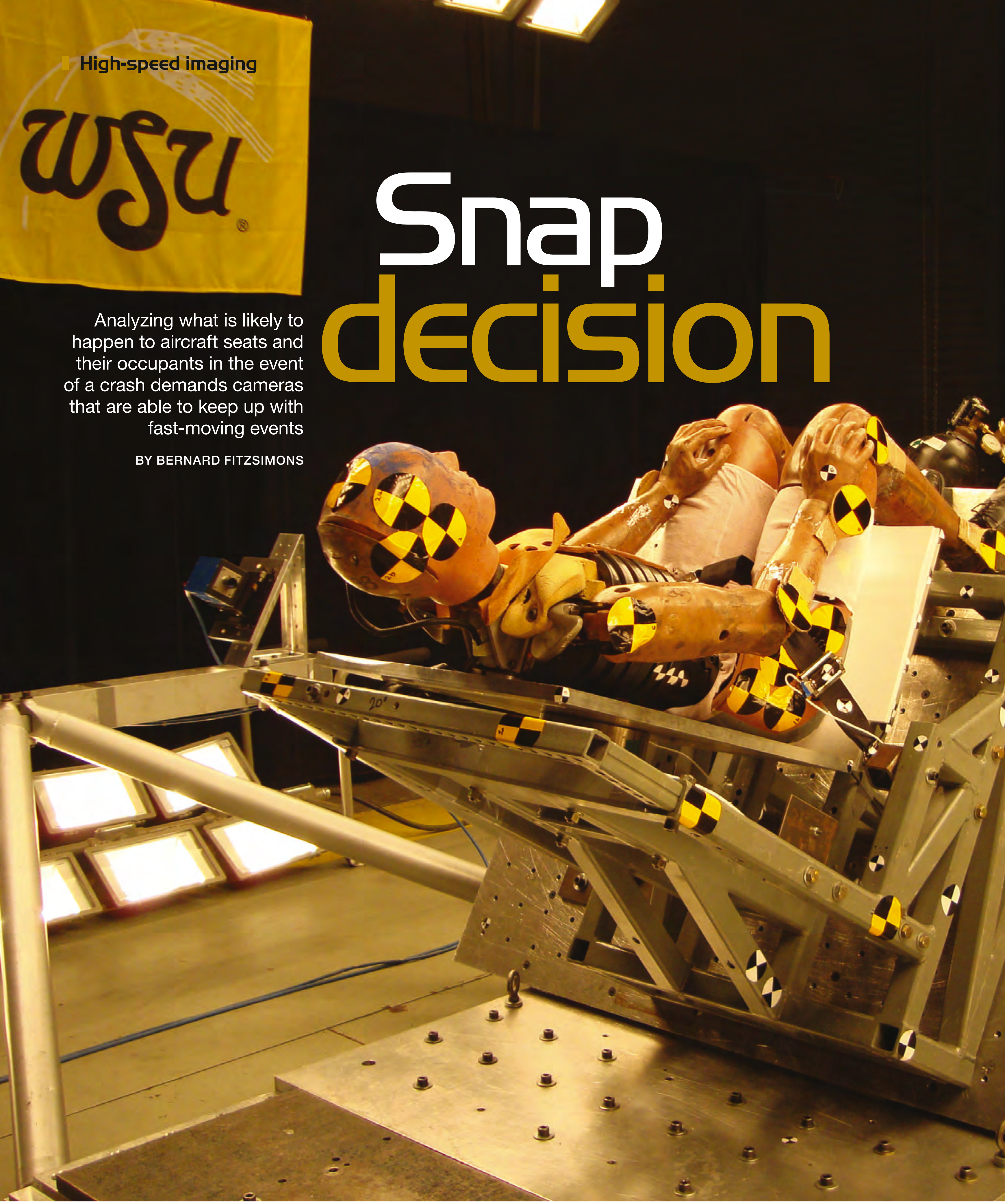
Just how quiet does it need to be? That's a question for the international aviation community, says Pauer, but maybe in the order of 75dB: "Plus or minus five is what we are looking at. Our role at NASA is to enable this as no designers are going to build an aircraft unless there is a set standard." ∎

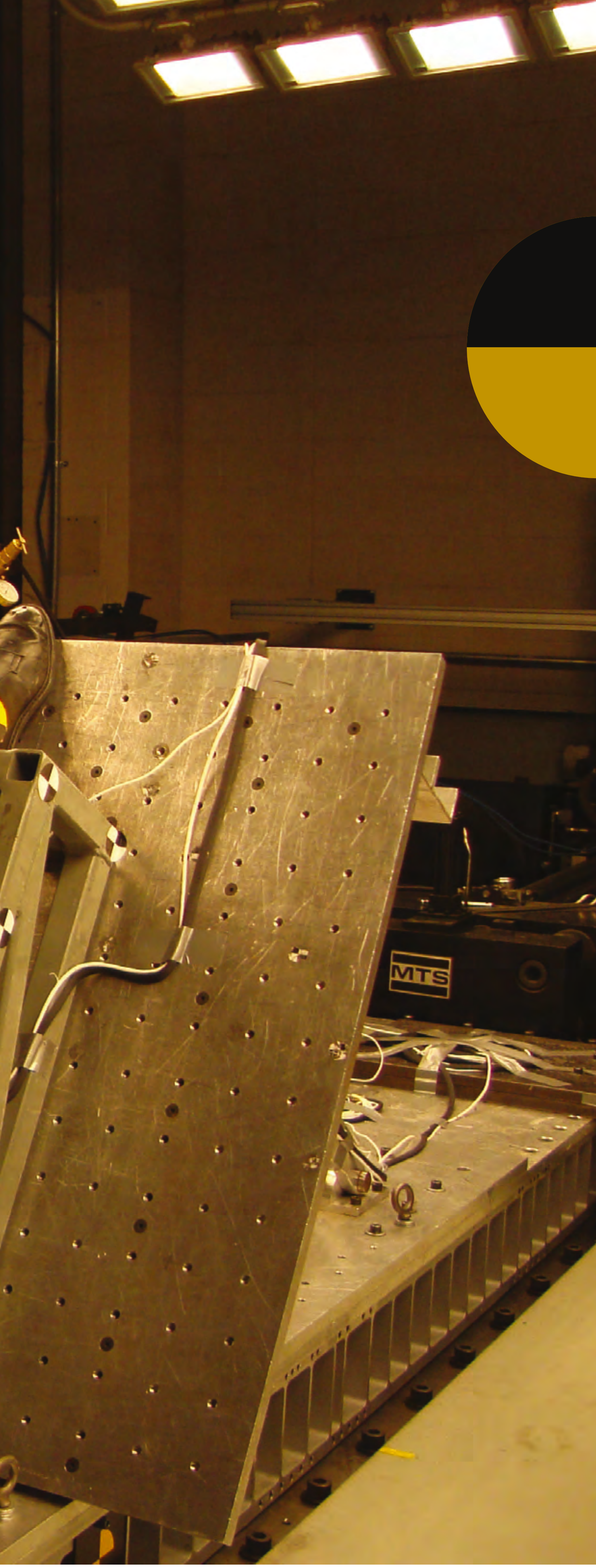
George Coupe is an engineering and technology writer based in the UK

Snap decision

Analyzing what is likely to happen to aircraft seats and their occupants in the event of a crash demands cameras that are able to keep up with fast-moving events

BY BERNARD FITZSIMONS





LEFT: **The Crash Dynamics Lab at Wichita State University's National Institute for Aviation Research**

Aircraft seats are designed to remain intact during a deceleration of 16g – not far short of the impact of a top golfer's driver on the ball – without deforming to the extent that occupants would be seriously injured. And manufacturers are required not just to design them that way, but to demonstrate that seats, restraints and associated systems actually work.

At least two physical tests of a seat row are required, one where the impact force acts predominantly along the occupant's spinal column, together with a forward impact force, and a second in which the impact force acts mainly along the longitudinal axis of the aircraft with an additional sideways impact force. Both horizontal sleds and vertical drop towers can be used for the tests.

Electronic and photographic instrumentation systems must be used to record seat test data. While electronic instrumentation measures and records data required to compare performance with pass/fail criteria, photography is used to document the overall results, the behavior of restraint systems, and the deformation of the seat, which must not be so great as to impede rapid evacuation by an aircraft's occupants.

FRAME RATE

The recommendations for photographic recording of crash tests are outlined in the FAA's 2006 advisory circular *25.562-1B, Dynamic Evaluation of Seat Restraint Systems and Occupant Protection on Transport Airplanes*. It specifies the use of cameras to confirm that the pelvic restraint remains on the pelvis of the anthropomorphic test device (ATD, or dummy), and that the upper-torso restraint straps remain on the ATD's shoulder during impact.

Performance of the optical system is defined in SAE International recommended practice SAE J211, Instrumentation for Impact Test Part 2: Photographic Instrumentation. As well as defining the methods used to track objects in space and how to set up the cameras to meet the required accuracy standards, the SAE document stipulates that high-speed cameras that provide data used to calculate displacement or velocity should operate at a minimum nominal speed of 500 frames per second (fps).

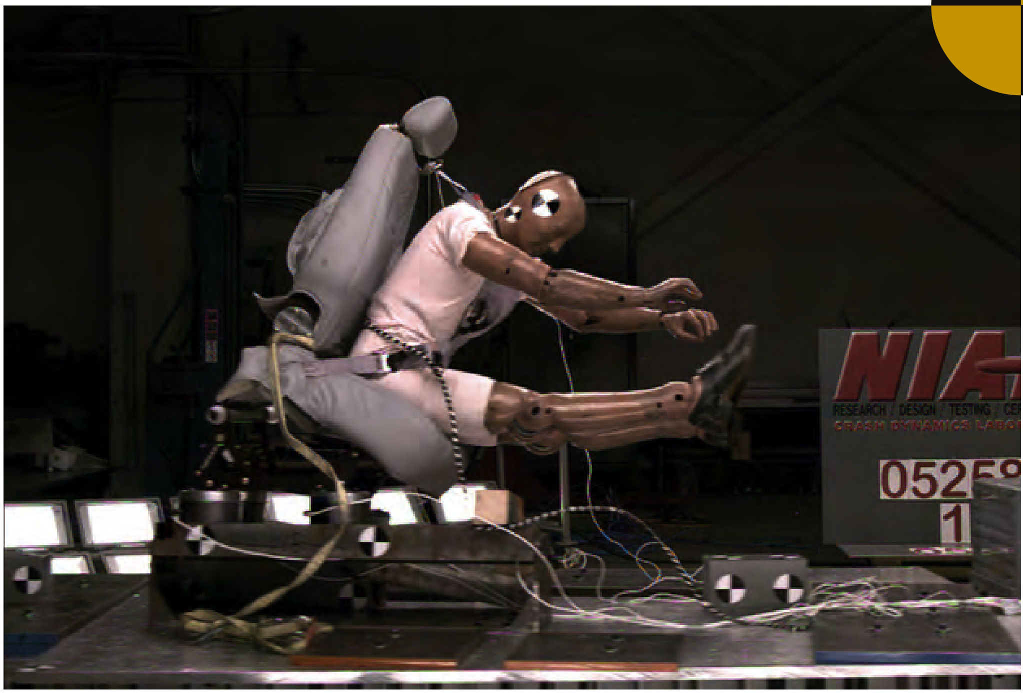
Andrew Mackey, who manages the camera setup in the Crash Dynamics Lab at Wichita State University's National Institute for Aviation Research, says that as well as the setup, it also deals with what needs to be visible in the frame to achieve accurate scaling and how to handle plane offsets in the image: "If you're tracking a dummy that's a foot behind the targets, it gives you your scale factor and how to handle offsets."

The FAA stipulates that targets – the yellow and black discs used as measuring points – should be at least 1/100 of the field width covered by the camera and their centers easily discernible. As for the cameras themselves, 1,000fps has become the de facto standard. Mackey says, "It makes life a little simpler when every frame is one millisecond, not to mention it looks nicer."

Required documentation includes a description of photographic calibration boards or scales within the camera field of view; the camera lens focal length; and the make, model and serial number of each camera and lens.

1,000fps
the de facto standard in high-speed imaging

300
microsecond exposure time at 1,000fps



Appropriate digital or serial timing should be provided on the image media, along with a description of the timing signal, the offset of the timing signal to the image, and the means of correlating the time of the image with the time of the electronic data.

If measurements are not required, the cameras used to document the response of ATDs and test items need only operate at a nominal rate of 200fps or greater. Actions such as movement of the pelvic restraint system webbing from the ATD's pelvis, for example, can be observed by documentation cameras placed to obtain a best view of the anticipated event. Like the cameras used to calculate displacement or velocity, they should be provided with appropriate timing and a means of correlating the image with the time of electronic data.

Still-image cameras should be used to document the pre-test installation and the post-test response of the ATDs and the test items, with at least four pictures from different positions around the test items in pre-test and post-test conditions. They should document whether the seat remained attached at all points of attachment to the test fixture.

"A LOT OF STRUCTURAL TESTS ARE LOOKING AT THE REAR LEGS AND THE TUBES THAT GO THROUGH THE SEATS"

TEST CONDITIONS

Unlike many test houses that cater predominantly to the much bigger automotive crash test market, the National Institute for Aviation Research (NIAR) works almost exclusively for aviation clients, and Mackey says most customers want very similar setups. "We'll typically have one off-board camera on the right and left sides, just looking at our sled," he says. "Our sled is an accelerator sled. It has a camera on each side, then we also have one overhead. Those are all off-board. Then on the sled we have three more cameras." These can be positioned wherever required, but usually two are on booms that extend a little way from the sides of the sled, while the third may be on the floor of the sled, "looking at whatever it is they want to look at".

In many tests, that means looking at the test specimen from a back angle. "A lot of structural tests are looking at the rear legs and the tubes that go through the seats, and if something breaks they want to know where and how and why it broke," says Mackey

All the cameras are the same model of AOS S-VIT, which are rated up to 100g. "I think the hardest we ever hit our sled was 75g," Mackey comments. "We only did it a couple of times when somebody wanted to hit a road vehicle seat as hard as they could."

TOP: NIAR's Crash Dynamics Lab uses high-speed cameras that can take 1,250fps in high-resolution (800x600) color and more than 10,000fps at reduced resolution

ABOVE: Cameras can be placed on the sled, providing the Crash Dynamics Lab with countless camera angle options

CAMERA TECHNOLOGY

NAC Image Technology claims to be the world's largest supplier of high-speed imaging systems. Jimmy Robinson, one of the company's software engineers, says that the two main goals in the high-speed camera world are faster frame rates and higher resolution, although light sensitivity is also a major consideration.

The first high-speed digital cameras were VGA resolution (640x480, or 0.3 megapixels) at a frame rate of 1,000fps, but cameras in NAC's current range operate at higher speeds with a resolution of 5MP. Maximum frame rates are constantly increasing, Robinson says: "Initially it was around 10,000fps. Now cameras can go in

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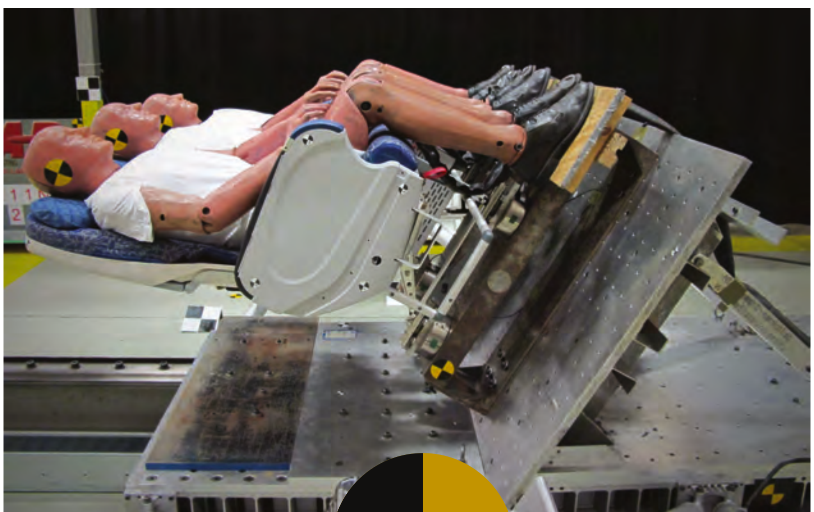
DIGITAL DIVIDEND

Photron's Andrew Bridges used to work for a company that made 16mm and 35mm high-*g* film cameras. "With a film camera," he says, "you have to get the camera started. The film has to get up to speed and then you have a certain number of seconds before you run out of film. Then two weeks later, after the film is processed, you find out whether or not you were successful."

The development of digital video of course changed the process. "Now we continuously overwrite – for weeks, months or years, in theory – until such time as you apply a trigger, be it a TTL [transistor-transistor logic] pulse or a switch closure or acoustic, or any form of trigger signal. So we can save the data before the trigger or after the trigger, or a percentage of it." He cites the example of filming a single cylinder in a six-cylinder engine: "You can record any number of frames, say 33 frames, every time the cylinder comes up to top dead center, so you're not running the camera while the other five cylinders are running."

Bridges explains that even the frame rate can be changed. "If you have a missile launch that you record at 1,000fps and then you have several seconds of flight where nothing much happens, you can record down to 25fps and then jump back up to 1,000fps for the impact. So digital gives us a lot more ability to be creative in the way we trigger and the way we save this data."



LEFT: **NIAR's Crash Dynamics Lab has anthropomorphic crash test dummies including 50th percentile males, a 95th percentile male, a fifth percentile female, and various child dummies**

BELOW: **Head Impact Criteria (HIC) test for an airline seat**

excess of one million FPS, although at reduced resolution."

Even faster ultra-high-speed cameras available from other manufacturers can operate at better than 1 billion FPS for applications that demand such speeds. Whatever the speed, images are typically stored by onboard very fast read-only memory and then downloaded to a PC after the recording is made.

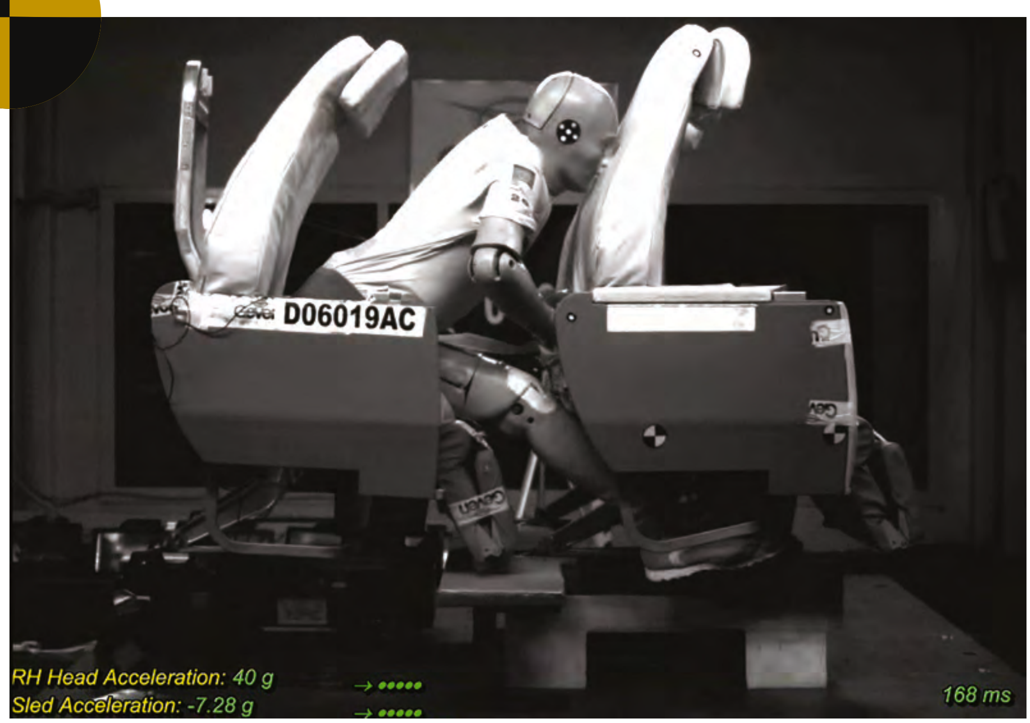
Lighting is very important, Robinson adds. "You need a lot of it, or a very light-sensitive camera. For recording at 1,000fps, you have a maximum exposure time of 1ms. Generally you would expose for an even shorter time, maybe 300μs. For that, you need a lot of light."

At NIAR, says Mackey, "We have a huge bank of what are essentially stage lights above the impact area of the sled." The lights, which have remained unchanged in the 10 years he has been at the lab, are incandescent. Fluorescent lamps take too long to achieve full brightness, but there are LEDs that can offer the necessary performance and are able to survive aboard the sled during impact. They can only remain illuminated briefly as they heat up very quickly at the output levels required, but "three or four seconds is more than enough time for us", he says.

NIAR has replaced its cameras during Mackey's tenure. The AOS models currently used are "quite a bit more light-sensitive", he says. "We don't have to have as much light as we did with the previous cameras, but it's still a great deal."

LIGHT SENSITIVITY

One of the key attributes of the FASTCAM Mini AX camera from Photron, a company founded 40 years ago to combine photo optics and electronic technologies, is its light sensitivity. "We're one of the few companies that uses the published ISO 12232 Ssat standard," says Andrew Bridges, Photron's sales and marketing director. "All too often, we'll lose out to a competitor who uses some bogus specification that gives fantastic light sensitivity ratings, but this particular camera has a monochrome ISO value of 40,000 and color of 16,000, which is quite remarkable for a high-speed camera. It's a 20 micron square pixel, and as with all our higher-resolution



“MODERN HIGH-SPEED CAMERAS REQUIRE LITTLE IN THE WAY OF MAINTENANCE BEYOND REPLACING BATTERIES”

cameras it has a 12bit pixel depth in the monochrome version and 36bit in the Bayer color version.”

The camera itself measures 120 x 120 x 90mm, and weighs approximately 6kg. “All our cameras are DC powered, so you can run them off the sled power, or if you need to you can provide them with an AC power brick,” he says.

Photron’s cameras cover the speed range from 60fps to over two million FPS, and include small camera heads that can be used on board and provide 512x512 pixel resolution up to 2,000fps. “We can have up to four of these miniature camera heads connected to a central processor,” says Bridges. “The nice thing obviously with small camera heads is there’s less mass, so you can position them in tricky-to-reach locations.”

Other options include a cubed camera head and a pencil camera head. “One option with that is a 90° relay on the optic, enabling you to can mount it onto a bulkhead or on the floor of the vehicle, so that you’re looking back at the dummy’s feet and can see how it’s interacting with the seat,” he says.

The 4MP FASTCAM Mini WX is also suited to crash test applications. Bridges continues: “The Mini WX [‘W’ for wide] can be 4MP up to just over 1,000fps or we can reduce the resolution to get 1080 high-definition resolution at 2,000fps, so if anybody needs the greater spatial resolution that a high-resolution camera can deliver, then that’s a very attractive option for them.”

Vision Research supplies both on- and off-board cameras for automotive crash testing. The company’s high-g Miro R and Miro 3 series of small, lightweight cameras are widely used in the field, and marketing VP Rick Robinson says they would be equally at home in the similar environment of aircraft seat testing. “The Miro C-Series we launched last year is a family of small, lightweight, high-g cameras specifically aimed at harsh environments such as automotive crash testing,” he says. Up to six can be connected to a junction box, and the junction boxes themselves can be daisy-chained if more than six are required.

“Connecting them to the junction box means you can connect the wiring from the control room to just a single point,” Robinson says. “So you can have one umbilical cable that is connected to the junction box with all the appropriate control signals and then break those signals out and send them to individual cameras as needed.

TOP: Technicians at NASA Langley assess the scene having dropped a helicopter from 30ft to test crashworthy systems as part of the Transport Rotorcraft Airframe Crash Testbed (TRACT 2) project

ABOVE: Up to six of Vision Research’s Miro cameras can be connected to a junction box to simplify wiring

It’s an architecture that works really well, especially for onboard camera applications.”

MAINTENANCE AND CALIBRATION

“Modern high-speed cameras require little in the way of maintenance beyond replacing batteries,” says NIAR’s Mackey, “but their lens setups do need to be calibrated. For photometric measurements using the side off-board cameras, you have to put a special sign board in front of it with everything set up exactly how it’s going to be when you’re shooting a test,” he explains. “Essentially, you move this target board around in front of the lens and the tracking software comes up with a lens correction for you.”

That is because the image will be distorted to some extent, depending on the focal length of the lens. “An 8mm lens is a fish-eye lens, which will be really distorted. But even when you get a 25mm lens, you’ve still got a little bit of distortion. It may not be obvious to you from looking at it, but when you try to do tracking, as the subject moves to the outside of the frames you can definitely tell that there’s some distortion there.”

The tracking software will correct that distortion. Then a second image with a different board is required to guarantee the accuracy, as specified by SAE J211. Recalibration is usually carried out whenever a new lens is installed in one of the off-board perpendicular cameras. ■

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

Q&A

TESTING TALK

Meet Steve Brown, lead instrumentation engineer, Boeing Test & Evaluation, and the man currently responsible for securing data from the Boeing 737 MAX test program

BY ANTHONY JAMES

HOW DID YOU BECOME A TEST ENGINEER?

I come from an aviation family. My grandfather was a World War II fighter pilot. I have an uncle that was an airline pilot, a cousin who flew for the Air Force, and my brother works for the FAA, so it's kind of in the blood. I went to college in Spokane, which is on the other side of Washington state, and I began working for Boeing less than a month after graduating from college. I started out as a flight deck engineer, working on the 777 pilot seats to ensure they conformed to the new 16*g* rules that were coming into effect, with the 777 the first Boeing aircraft to be fitted with 16*g*-compliant seating. I participated in some development testing and supplier qualification testing with crash dummies. It was quite an experience – actually getting to stand next to a crash dummy and watching what actually happens during a test is a lot of fun. Then almost 20 years ago, a good friend of mine who was working as a flight test instrumentation engineer suggested that I come over and join the group – I've been here ever since!

WHAT WAS THE MOST IMPORTANT LESSON OF YOUR EARLY CAREER?

I was only 22 years old when I joined Boeing. I remember working my first day with engineers from the 707 and Apollo programs. I am thankful to them for creating an environment that expects and delivers great products. Their absolute focus on safety made the greatest impression on me. My first flight test program was the 737 Next Generation. In all the pre-flight meetings, the first conversation was always about safety, and every single conversation that followed would examine each particular maneuver and how prepared we were for it. I remember sitting on the aircraft at my station by the instrumentation rack and just feeling extremely safe. In everything we do, we are trying to be safe and we are trying to make a safe product, and there's a lot of great people dedicated to making that happen.

DESCRIBE YOUR CURRENT ROLE.

Every day in flight test, we ensure Boeing airplanes are the safest and most efficient to fly. My team works with design engineers to collect flight test data that they can use to continually improve Boeing products. It can be challenging work. Some days it means diligently checking the performance of thousands of airplane system components while at cruising altitude. Other days it means monitoring systems while the airplane flies in ways that would spill a lot of coffee if paying customers were on board.

If the aircraft doesn't already have the measurement equipment on board, my team can usually get it – it's just a question of time and planning. In fact today's technology allows us to collect and analyze hundreds of times more data than when I started at Boeing 23 years ago – so much data, that we remove all passenger accommodation to make space for our equipment and build our own onboard intranet.

AND WHAT ARE YOU WORKING ON RIGHT NOW?

Right now we're starting the transition from the build phase into the testing phase for the 737 MAX. We have two aircraft in final assembly and I'm the lead instrumentation engineer on the first of these. What we are doing daily is primarily functional checkouts, where we make sure that every single one of our channels is functional, calibrated and operational in the way it is supposed to be.

My job is to coordinate these onboard calibrations while liaising with our manufacturing organization to ensure the airplane continues to get built at the same time. We're getting the aircraft ready for roll-out this year and flying next year.

RIGHT: Steve Brown on board the first 737 MAX Flight Test Vehicle (FTV)

“IF THE AIRCRAFT DOESN’T ALREADY HAVE THE MEASUREMENT EQUIPMENT ON BOARD, MY TEAM CAN USUALLY GET IT”

WHAT ARE SOME OF YOUR DAY-TO-DAY TASKS?

Currently we're doing calibrations of primary control surfaces. We'll put additional sensors on an elevator tab, for example, and then we will define our own calibration standard for that elevator tab and sweep it through its range of motion to generate a transfer function that we then use to correlate the voltage that we're getting out of our transducer with the actual position of that surface. We'll do the same for the aileron wheel position – putting in higher accuracy, higher sample rate measurement sensors, and then sweeping the control column through its range of motion to get a transfer function for calibration purposes.

We're also working with the production team on the functional check-out of the avionics, which features quite a few ARINC 429 databus components, to make sure that our connection is functional and safe. So, when we start preflight testing, we will be recording all the data that's required to show that the aircraft is ready for first flight.

There are four aircraft in the 737 MAX 8 flight test program, and each one of them will have a slightly different set of instrumentation with different channels depending on what the requirements are for testing. The first aircraft will be used more for controls testing, while the second will do more engine testing and the third will focus on systems testing. You can't fit all the instrumentation on one aircraft efficiently, so you spread it out between the different flight test vehicles.

WHAT ARE THE KEY CHALLENGES PRESENTED BY THE 737 MAX?

The 737 is a good and established platform that is well understood from a test and evaluation perspective. However, the main challenge is instrumenting anything that's new on the aircraft, such as the high-definition (HD) video display system in the flight deck, for example. In response, we've had to adapt our instrumentation system to be able to record HD video. The challenge is to work out how best to instrument that system and provide the data, and

LEFT: **Instrumentation racks fill the cabin of the first 737 MAX FTV**

> **“TODAY’S TECHNOLOGY ALLOWS US TO COLLECT AND ANALYZE HUNDREDS OF TIMES MORE DATA THAN WHEN I STARTED AT BOEING 23 YEARS AGO”**

then get that data from that system onto the recorder, so our team can examine the data after the test or even view it live during the test. That can be challenging, but so far it’s looking good – we’re pretty pleased with how things are going on this program to date.

AND BY TODAY’S AIRCRAFT IN GENERAL?

We all have laptop computers that we use all the time and we think that all the computers in the world can talk to all the other computers in the world. In reality, every single one of them speaks a different language. I liken it to the Tower of Babel. Every single model has slightly different hardware, using slightly different languages, and has software that allows it to interpret data from other computers. So the big challenge for any instrumentation engineer is how to record all of this different data from different computer models onto a single recorder while maintaining time synchronization. You could buy every manufacturer’s recorder, but you would have to change media for multiple systems during the flight and it becomes unmanageable. We record all of our data onto a single, really high bandwidth recorder – but to do that, everything has to be in the required format.

For example, a new display system may generate data in a format for a new avionics standard of fiber-optic HD video. We would then have to define a mechanical interface to connect the new fiber-optic bus with our computers and then design software to interpret that data and translate it into a format that’s acceptable for our recorder.

So every time we put a new avionics system on board an aircraft, we go through this challenge. And it’s not just avionics. The transducer and signal conditioning manufacturers within our own test equipment industry produce hardware and software that all ‘talk’ slightly differently. As a result, you often can’t just go and put a new sensor on the wing of an aircraft without first designing a system to interpret that data and get it on the recorder.

WHAT ARE THE CURRENT CAPABILITIES OF THE DATA RECORDERS YOU USE?

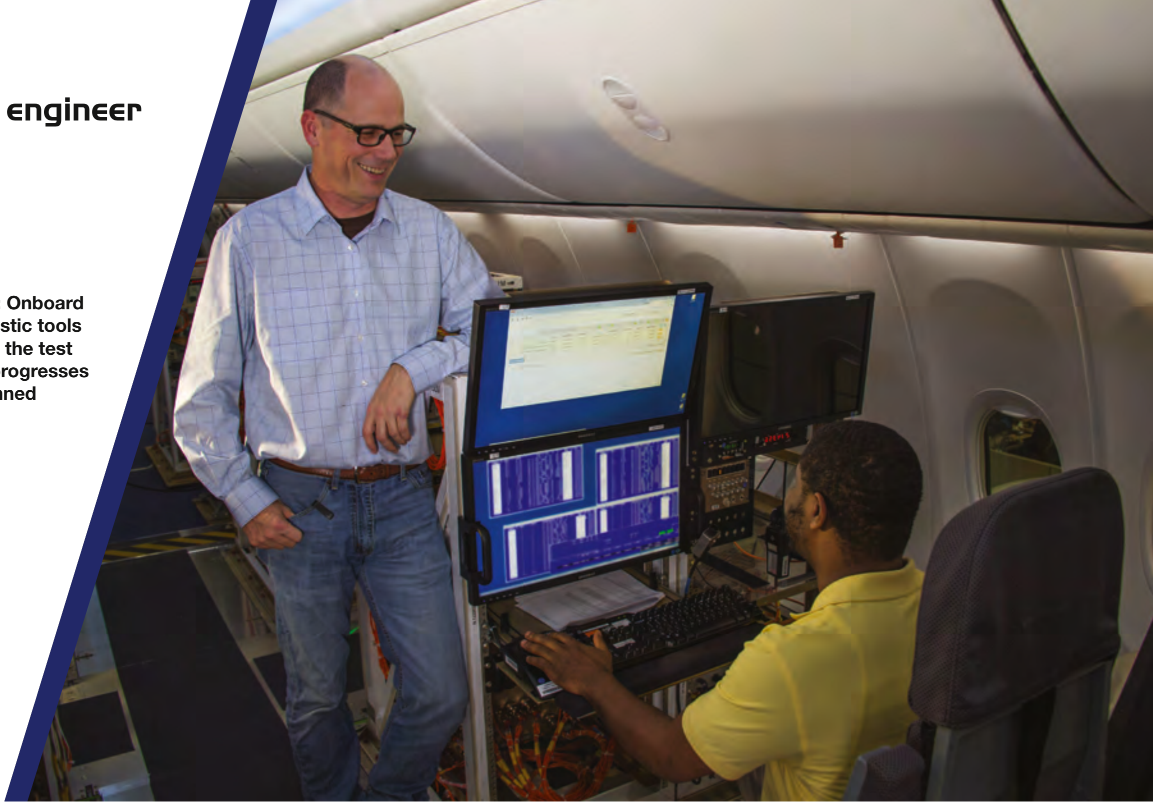
I don’t know the exact numbers, but they record a lot of data. Our current recorders are capable of recording more than 400Mbps, and our media holds a terabyte.

IS DATA COLLECTION EASIER OR HARDER THAN IT ONCE WAS?

Distributed signal conditioning architecture has made data collection much easier. When I started in flight test, if you had a particular parameter that you needed to record, you would have to run a wire from the relevant sensor, which could be anywhere on the aircraft, all the way into the cabin for signal conditioning on individual cards mounted in units in the racks.

For example, if you had an accelerometer on the wing tip, you would have to run the wire all the way down the leading edge of the wing, through a wing-to-body penetration, into the cabin, and to a rack-mounted multiplexer full of individual accelerometer cards for every sensor.

However, if we want to add an accelerometer out on the wing tip today, we just run the wire to a small piece of equipment mounted on the wing’s leading edge, which does the conversion from analog to digital right there on the wing. We can collect multiple measurements in that one spot. All we need to run from there is a power cable and a communications



RIGHT: Onboard diagnostic tools ensure the test flight progresses as planned

cable to the cabin. We can build communications networks exterior to the pressure vessel of the aircraft, with smaller penetrations through the side of the body.

My first flight test job was on the very first 737-700 some 19 years ago, and in order to run all those wires out from the wing into the fuselage, we had several 3.5in-diameter penetrations on each side of the aircraft. Now, we can get away with penetrations that are 1.5in in diameter as they only have to take a single bundle. This makes it easier and cheaper, and we can do functional checking of airplane components before they are installed in the aircraft, saving a lot of time. A distributed data system makes things a lot simpler, and we get a lot more data.

Modern data recorders are also far more advanced. For some of the programs just before I joined flight test, we had relatively limited bandwidth, so you would have to decide what measurements you were going to record for a particular test, because you didn't have the bandwidth to record all of them, all of the time. Every day, our job was to go out and reconfigure the data systems to record the measurements that were required for that particular test. Hence our overnight pre-flights would focus on reconfiguring the data system and making sure all the measurements worked before we could go and fly. We now spend a lot less time reconfiguring the data system due to the greater bandwidth of the recorders.

The computers have made it easier – not only can we record more data at better sample rates, it's also easier to do so on a daily basis.

HAS ANYTHING GOT HARDER?

Trouble-shooting digital data systems can be quite an opaque task – it's hard to see where you are having communications problems on a computer network. It requires a new set of tools and a new set of training. We need digital network communications experts in our crew, which is new. Trouble-shooting an Ethernet bus can be tricky because it could be either the hardware or the software that's running a particular box that has a bug in it – determining where the issues are is a lot more difficult than it used to be.

WHAT HAPPENS TO ALL THE DATA?

It is recorded onto a pair of recorders in the test instrumentation racks – we use two recorders for redundancy purposes. We monitor the data in flight via an onboard suite of data monitoring tools to validate the test conditions, and then we download that data into an archive after the flight. Once it's in the archive, various Boeing company personnel can make data requests and examine what happened on each day's flight.

"WE'VE SEEN LESS HARDWARE INSTALLED ON THE AIRCRAFT OVER TIME AND I THINK THAT TREND WILL CONTINUE"

The recorders were tape-based when I started, but now they are solid-state media. They are taken to a special archive computer facility for storage and access by Boeing engineers.

We also use telemetry, but we tend to limit this to safety-critical flights where we have an extremely limited crew, as telemetry limits where the aircraft can fly – you have to maintain a certain distance from base to stay within the available telemetry range.

HOW MUCH DATA IS CAPTURED DURING A TYPICAL FLIGHT TEST?

It will depend on the aircraft. If it's a brand-new digital aircraft like the 787, where a lot more digital measurements can be recorded, the data rates are pretty large, more than 200Mbps – we can fill up a recorder in about eight hours. But airplanes with fewer digital channels and fewer required analog measurements will be significantly less.

WHAT IS ONE OF THE HARDEST TESTS TO INSTRUMENT FOR?

Load survey testing is one of the hardest, as we have to put pressure sensors over the entire surface of the wing. This kind of testing is challenging because of the sheer quantity of pressure measurements being taken and their location on the aircraft. It can be in the range of a thousand individual pressure measurements spread over the wing to measure pressure distribution, which can be challenging. It takes a lot of pre-planning and organization.

WHAT'S THE MOST REWARDING ASPECT OF YOUR JOB?

The most rewarding aspect for me is working in a real team environment. Every day, we get together with the pilots, test ops and the mechanics that maintain the aircraft to plan testing. Then we go and test the aircraft. It's great to be part of such a highly qualified team, where everybody is focused on safety and making the product better by going out and testing it and finding its limits. I find that incredibly rewarding.

HOW DO YOU SEE YOUR ROLE CHANGING IN THE FUTURE?

Fundamentally, it's still just installing a sensor, changing the signal from the sensor into a digital signal, and then recording that signal. What has changed is the digital technology. The increased bandwidth, distributed signal conditioning and component miniaturization continues to develop at a rapid rate. The data system racks that we put on the aircraft today are nowhere near as full as they used to be when I started here. We've seen less hardware installed on the aircraft over time and I think that trend will continue. ∎

Anthony James is editorial director at UKIP Media & Events Ltd, publisher of Aerospace Testing International

Percentage play

As aircraft manufacturers increase the proportion of carbon-fiber composites in new aircraft, the testing requirements increase to reflect the novelty of the materials and fabrication methods

BY BERNARD FITZSIMONS

LEFT: IABG simulated 86,400 A350 flights in the EF2 fatigue test rig at Erding

Carbon-fiber composites have many virtues in aerospace applications. They can form structures that are lighter than their metal equivalents and are not prone to corrosion or fatigue, while offering high specific strength and stiffness.

But they are not a straight substitute for the aluminum alloys they have largely replaced in many new airliners. They tend to have low compressive and shear strength, are impact sensitive, and can suffer damage without exhibiting the dents that typically reveal damage in metallic structures.

There are also other differences. Marko Yanishevsky, who leads the structural full-scale testing team in the National Research Council of Canada's (NRC) structures, materials and manufacturing laboratory, says it is important to understand the effects of the environment – including temperature, humidity and ultraviolet radiation – on the material and structural performance of composites.

"They are very different from metals, with which we have much more experience as an aerospace industry," he says. "Initially this understanding is achieved through coupon test programs to determine their associated failure mechanisms and any reductions or changes in performance they cause, relative to established baseline performance."

Analytical models of failure mechanisms to date, though at times useful, "are not definitely able to forecast in-service behavior", says Yanishevsky. "OEMs have been able to quantify some of the associated factors and transfer functions and have used them in design to account for these effects. These efforts have not precluded the requirement for large-scale and full-scale tests to be conducted to ensure that these effects have been properly addressed to guarantee long-term durability and performance for the life of the structures in their operating environments."

NRC has carried out multiple tests for clients. In addition to coupon level tests under various environments, it has also carried out several elevated temperature tests, and both static and fatigue (durability and damage tolerance) tests on large- and full-scale structures as part of a range of certification and life extension programs, with representative damages and repair schemes to better understand in-service performance.

NRC's wide expertise and capabilities in several fields mean it has access to a wide range of staff and laboratories and can provide a specific environmental testing requirement as required by the client. "Our current approach has been to develop custom chambers that address specific client requirements," Yanishevsky adds. "At times the tests have to be conducted under more severe conditions, such as higher temperatures, to give confidence that the structures will perform as required during service."

WEIGHT AND DESIGN ISSUES

Despite the requirement for additional testing, the Boeing 787, Airbus A350, Bombardier C Series and Irkut MS-21 have all been designed to have largely composite structures, including the wings. This was not the case for the Mitsubishi Regional Jet, which flew for the first time on November 11.

The MRJ's decision to use metal rather than the composite wings originally planned illustrates how the attributes of metallic versus composite structures comes down to engineering compromises. Mitsubishi Aircraft (MAC) found that a composite wing could not be justified, since the typical quoted 10-15% weight savings offered by composites could not be achieved with such a relatively small wing. To achieve the requirements for strength, the composite designs became too heavy (and thus more expensive) compared with metal wings.

Toshio Abe, manager, fixed-wing aircraft engineering department, military aircraft division, aerospace systems, of MAC's parent company, Mitsubishi Heavy Industries, reported his research to a recent workshop organized by the International Council of the Aeronautical Sciences. His

IRKUT MS-21 TESTING

The Central Aerohydrodynamic Institute at Zhukovsky (TsAGI), near Moscow, has been testing various structural elements of the in-development Irkut MS-21. The first test cycle, completed in May 2011, determined the natural frequencies and mode shapes of a prototype composite wing box using sensors attached to the wing box lining and a non-contact vibrometer. The wing box is made using the relatively new process of liquid resin infusion and cured in ovens rather than more expensive autoclaves.

Frequency and stiffness tests, including shock damage and the effects of artificial defects and induced damage, were then carried out on two prototype wing boxes to confirm compliance with design models and parameters used at the design stage. Two Austrian companies, FACC and Diamond Aircraft, supplied four prototype wings for the tests; production wings will be built in Russia by AeroComposit. TsAGI went on to complete 120,000 simulated flight cycles, twice the structure's design life, over an 18-month period.

In December 2014 Aviastar-SP delivered a composite fin torsion box to TsAGI for certification testing. TsAGI had previously tested structurally similar samples and prototypes to confirm their compliance with analytical models and verify the calculated data. After testing for strength under operational loads the fin was due to be sent to the Central Institute of Aviation Motor Development (TsIAM) for bird strike testing before being returned to TsAGI for residual post-damage strength testing.

September 2015 saw the first full-scale strength tests of the fin box, with loading until failure. This concurred with calculations, confirming the specified strength value of the composite structure.

> "BOLTED JOINTS ARE ANOTHER WEAK POINT, DEMONSTRATING 40% LOWER BEARING STRENGTH THAN THOSE IN ALUMINUM ALLOYS"

findings discovered that even with toughened resin system composites in current use, strength deteriorates dramatically with impact damage. To overcome this, additional material must be used to provide redundancy which increases weight – and cost.

Bolted joints are another weak point, demonstrating 40% lower bearing strength than those in aluminum alloys and making them prone to bearing, shear-out and pull-through failure modes. There is also deterioration in strength in areas where stress is concentrated, such as holes and fillets, so again more thickness is demanded and weight is increased.

A fundamental concern of lightweight composite structures, however, is their susceptibility to inter-laminar failure – delamination and debonding. "These failure modes are unique for composite structures and have become our Achilles' heel on modern composite structures," Abe says. They mean that special treatment may be needed in critical areas, and in some cases demand reinforcement using heavy metallic fittings.

Metallic structures can withstand abrupt thickness changes produced by mechanical or chemical milling. However, the discrete plies within composite structures mean tapered or graduated thickness variations must be used to avoid the risk of inter-laminar stress failures,. This can mean using additional material resulting in a weight increase. Together these composite characteristics mean it is hard for designers of small aircraft to achieve the sort of weight savings that are possible with medium and large craft.

10-15%
Weight saving offered by composites on larger aircraft

2µJ
The minimum energy that can pose a risk to the fuel/air mixture inside a fuel tank

Composites also suffer from cost disadvantages compared with aluminum alloys. The material itself, the bagging film for the curing process, composite fasteners and the hardware needed to cope with electromagnetic effects, all cost more.

Parts fabrication demands expensive tools and equipment, while intensive non-destructive inspection and fine-tuned processes are needed to avoid wrinkles, voids and geometric imperfection in parts, which could slow assembly. Extensive systems are needed to cope with electromagnetic effects, adding further cost.

LIGHTNING STRIKE PROTECTION

Lightning strike protection is another problem area. US Federal Aviation Regulations stipulate that no ignition source may be present at any point in the fuel tank or fuel tank system where catastrophic failure could occur due to ignition of fuel or vapors – such as after a lightning strike.

BELOW: EW static and fatigue testing of an A350 left wing box at IABG's Erding facility

50%
Composite content of the primary structure of an A350 wing

86,400
Number of simulated flights conducted on the mid-section and wings of the A350 – three times the intended service life

TOP: Strength testing of a prototype wing for the Irkut MS-21 at TsAGI

ABOVE: The Mitsubishi Regional Jet flew for the first time in November with wings of aluminum rather than the carbon-fiber composite originally envisaged

As Abe points out, lightning can deliver several megajoules of energy into an aircraft which dissipates as it spreads through the structure. Sparks can be generated at joints in the structure, so lightning protection in the vicinity of fuel tanks is required to protect against sparks of as little as 2µJ – a level considered to be the minimum posing a risk to fuel/air mixture.

This testing must be conducted by first determining (with a safety margin) the highest internal tank temperature that will not result in autoignition of the mixture. It must be demonstrated that there is no place inside each tank where the temperature could rise to ignite the fuel/air mixture. This must be verified under all the probable operating, failure and malfunction conditions of each component. It must also be demonstrated that a ignition could not result from a single failure, or a combination of failures. Finally, the effects of manufacturing variability, aging, wear, corrosion and likely damage must also be considered.

One common method of testing fuel system components is to apply a simulated lightning strike to the exterior of a component while monitoring the fuel side with a sensitive, high-speed camera.

> **"WEIGHT SAVINGS IN THE RANGE OF 10-15% FOR COMPOSITE USE VERSUS ALUMINUM ON LARGER AIRCRAFT ARE POSSIBLE"**

A350 TESTING

Weight savings in the range of 10-15% for composite use versus aluminum on larger aircraft are possible. But each manufacturer has opted for its own combination of fiber and epoxy and its own fabrication methods, so the multitude of novel materials and techniques demands exhaustive testing.

Airbus has increased the proportion of CFRP in its airframes from just 5% (a mid-1980s A310-300) to 53% in the current A350.

For this new wide-bodied aircraft, there were three fatigue test specimens. EF1, tested in Toulouse, was the nose and forward fuselage section, while the rear fuselage EF3 was tested in Hamburg. EF2 (the center fuselage and wings) was tested by German company IABG, in a specially built hall that measures 71m² and nearly 30m high, at the German Air Force's Erding base. Eighty-eight servohydraulic cylinders were used to apply stress to the test specimen, which was subject to 86,400 simulated flights, representing three times the intended service life.

At the same time, IABG carried out tests to validate the behavior of CFRP in interaction with metallic materials in the A350's wing.

Over 50% of the wing's primary structure consists of fiber-reinforced plastics, and the objective of the tests was the verification of the wings' strength, fatigue and damage tolerance. The tests used 41 servohydraulic cylinders to stress the wing in the course of 43,200 simulated flights and more than 3,000 measuring channels to gather the data. After comparison with simulation and calculation data, the test results were used to support the A350's certification. ∎

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

Leveraging a lineage

MD Helicopters conducts in-house test programs to arm its light helicopters, enhance performance and advance systems integration

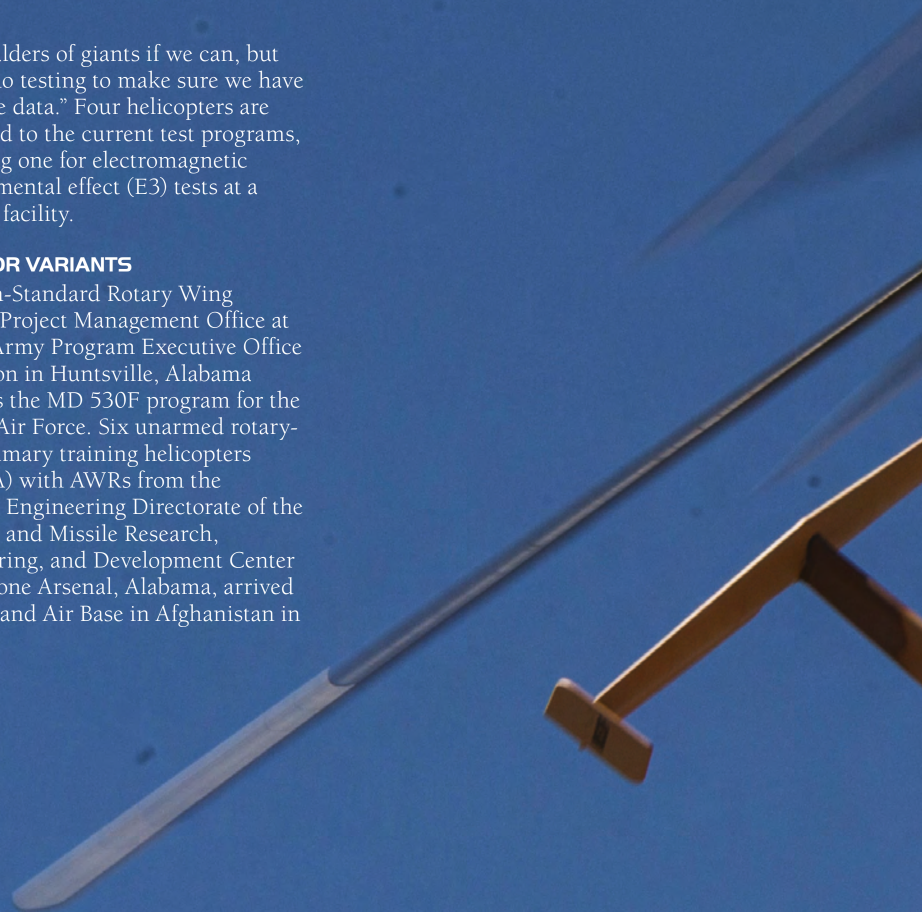
BY FRANK COLUCCI

Half a mile from Boeing's Apache attack helicopter factory in Mesa, Arizona, MD Helicopters Inc (MDHI) builds, integrates and tests light, single- and twin-engine aircraft. MDHI currently has three in-house test programs for derivatives of the 1960s Hughes Cayuse Light Observation Helicopter – the Vietnam-era 'Loach'. One effort will qualify rockets and a fixed weapons sight for the MD 530F Cayuse Warrior now operating in Afghanistan. The second will integrate a new ordnance control system, more fuel and precision weapons into the digital-cockpit MD 530G. The third will enhance the anti-torque capability of both the MD 530F and 530G to fly at high density altitudes. "Any test we do now, we look for opportunities to share with other configurations," explains MDHI chief engineer Doug Nichols.

Testing conducted over the Loach's long evolution has provided documentation for successive FAA Supplemental Type Certificates (STCs) and US Army Airworthiness Releases (AWRs). "There are volumes of data that have been collected over the past 50 years," acknowledges MDHI chief technical officer Dr Karl Schultz, a former US Navy helicopter pilot and test pilot/researcher. "If everything we need is there and we can validate the full chain of custody, we'll use that data in our justification. If anything is missing, we'll redo it. We'll stand on the shoulders of giants if we can, but we'll redo testing to make sure we have complete data." Four helicopters are dedicated to the current test programs, including one for electromagnetic environmental effect (E3) tests at a military facility.

WARRIOR VARIANTS

The Non-Standard Rotary Wing Aircraft Project Management Office at the US Army Program Executive Office – Aviation in Huntsville, Alabama manages the MD 530F program for the Afghan Air Force. Six unarmed rotary-wing primary training helicopters (RWPTA) with AWRs from the Aviation Engineering Directorate of the Aviation and Missile Research, Engineering, and Development Center at Redstone Arsenal, Alabama, arrived at Shindand Air Base in Afghanistan in



Unarmed Afghan Air Force MD 530Fs delivered in 2011 were followed by armed Cayuse Warriors in early 2015

"WE'LL STAND ON THE SHOULDERS OF GIANTS IF WE CAN, BUT WE'LL REDO TESTING TO MAKE SURE WE HAVE COMPLETE DATA"

STRETCHING THE LITTLE BIRD

The OH-6A Cayuse gave the US Army a 2,700lb light observation helicopter powered by a 317shp Allison T63 turboshaft and armed with a 7.62mm M134 minigun. The US Army Special Operations Command (SOCOM) began development of higher performance Little Bird helicopters for Special Operations Forces in 1981 with the AH/MH-6C. Subsequent versions of the armed AH-6 attack and MH-6 assault helicopters integrated a series of propulsion, dynamic, structural and systems improvements developed and qualified by the SOCOM Tactical Applications Program Office (TAPO).

The convertible MH-6M Mission Enhanced Little Bird (MELB) flown today by the 160th Special Operations Aviation Regiment (Airborne) has a 600shp Rolls Royce M250-30R/3M engine with full authority digital electronic control for responsive performance throughout the flight envelope and a transmission/drive system with 30 minutes run-dry capability. The drivetrain turns a six-blade main rotor and quiet, four-blade tail rotor. The tail rotor tops a cambered vertical fin riding an improved tail stinger. Different lightweight plank systems carry up to six troops externally or a mix of 7.62mm or 0.50 caliber guns, 70mm rockets and Hellfire missiles. The AN/ZSQ-3(V)2 FLIR sensor provides laser designation for the current Hellfire missile and future laser-guided rockets. A block 3.0 upgrade will see a digital cockpit using avionics elements common to the MH-60M and MH-47G helicopters.

2011. "The trainer really followed the STC," says Nichols. "There were unique variations for the customer, but the AWR for the 530F was used to put those original six aircraft in-country. They are really operated in the FAA envelope, not the military environment."

Twelve more Cayuse Warriors armed with FN Herstal HMP-400 heavy machine gun pods arrived in early 2015. The contract also included retrofitting the five flying MD 530F RWPTA. In July 2015, MDHI received a US Army contract to install, integrate, test and help qualify the M260 launcher for 70mm rockets and a fixed-forward weapon sight on the armed MD530F Enhanced Mission Equipment Package (EMEP) aircraft. "Internally we call it the Armed F," says Schultz. "The Cayuse Warrior name is a throwback in honor of the original Cayuse of 50 years ago."

For the MD 530F Cayuse Warrior program, the Army Aviation Engineering Directorate (AED) and MDHI's own company qualification were the qualifying authorities for the Army AWR. MD 500/530 helicopters have long been armed with guns, rockets, wire- and laser-guided missiles, and other ordnance for US Army Special Operations Aviation and international operators. Gun pods and their 'planks' – removable weapons carriers attached to the helicopter cabin floors – can now be used on all of the remaining 16 Afghan Air Force (AAF) MD rotorcraft. Reportedly, of the 18 delivered, one was damaged in an accident and the other was lost to an improvised explosive device in 2013.

The MD 530F model now in Afghanistan underwent a mini-weapons survey to meet an accelerated fielding schedule. The current Armed F rocket qualification includes additional live-fire testing. "Anytime you're putting armament on a helicopter, everyone's pulse goes up a little," observes Schultz.

"The aircraft in its baseline variant has been in the military for several decades," notes Nichols. "Because the aircraft is now modernized with new mission equipment on board...there's a lot of ground testing as well as flight testing. It's hundreds of flight hours. We continue to expand the aircraft capability."

BELOW: Afghan Air Force MD 530Fs have machine gun pods, but weapons sights and rockets will be integrated in early 2016

INTEGRATION AND ALTITUDE TESTS

Most MDHI flight testing is done around Falcon Field in Mesa. The company can also access Redstone Test Center in Alabama and uses Yuma Proving Ground in Arizona and the Mile High Resources range near Sierra Blanca, Texas, for live-fire tests. Flagstaff, Arizona, and other locations are used for high-altitude performance testing. How much testing has been or will be done remains proprietary, but AAF helicopters will have the sighting system and rocket pods by early 2016.

While the MD 530F trainers underwent some high-altitude testing to verify performance, the Armed F still requires more extensive testing to document handling qualities at higher weights, electromagnetic compatibility with weapons, consistent communications with new antenna patterns, and other changes. The new weapons sight with its aiming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3,600+
The number of MD 500 series helicopters produced to date

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Hours flown with the Afghan Air Force

14,400ft
Hover Out of Ground Effect (ISA) for the MD 530F

symbology, night vision goggle (NVG) compatibility, and adjustability, for example, drives a range of ground and flight tests. MDHI has to show that the sight allows safe egress and provides an ergonomic interface with 96th percentile aviators. "The entire helicopter is NVG-compatible in the cockpit per MILSTD 3009," explains Nichols. "The cockpit itself is always reassessed when there's new lighting in it to assess the impact on NVG compatibility. It's also integrated with the aircraft power system," continues Nichols. "It's not a standalone system, but it is a fairly simple fixed sight. It still has to go through safety-of-flight qualification and environmental testing for shock, temperature and humidity. Those things are all part of the component qualification." MDHI and its suppliers use a mix of systems integration labs and bench testing before flight test.

MDHI PRODUCT HISTORY

The Model 369 (OH-6A) and 500 Series light helicopter product lines begun by Hughes Aircraft were acquired by McDonnell Douglas Helicopters along with the Apache program in 1984. Boeing merged with McDonnell Douglas in 1996 and chose to rid itself of businesses such as small-lot commercial helicopter manufacturing. Boeing sold the Mesa facility producing single-engine MD 500 and twin-engined MD 900 series helicopters to Dutch holding company RDM, which launched MDHI in 1999. Entrepreneur Lynn Tilton and her Patriarch Partners acquired MDHI in 2005.

The product line today includes the twin-engine Model 900/902 MD Explorer and single-engine MD 520N and 600N helicopters, all with the NOTAR – no tail rotor – anti-torque system, and the MD 500E, 530F, 530G and 540 helicopters with two-bladed or quiet four-bladed tail rotors.

Throughout the corporate evolution, the light helicopters continued to evolve for airborne law enforcement, helicopter emergency medical service and other commercial, government and military operators with different equipment requirements. US Army AH-6/MH-6 'Little Birds' qualified for a range of weapons and performance enhancements that provide the basis for the Boeing-integrated AH-6i being delivered to Saudi Arabia.

MDHI meanwhile sold MD 500Es to El Salvador and MD 530Fs to Saudi Arabia under US Army Non-Standard Rotary Wing contracts. It recently delivered a commercial MD530F to the Las Vegas Metropolitan Police Department with a Stark POP300 Electro-Optical/Infrared (EO/IR] payload, Nightsun searchlight and Garmin glass cockpit. "We have a production line where we build the baseline aircraft with a Type Certificate," says Nichols. "Our completions delivery center modifies aircraft to requirements set by the customer. A unique display or EO/IR ball [for example] – those things are covered by STCs. We rework the aircraft in the completions delivery center with an options package with the paperwork already there," he said. Some modifications are FAA-Minor, others are FAA-Major. Military modifications to support an Airworthiness Release are also accomplished in the completions delivery center.

FAA AND ARMY CERTIFICATIONS

"Every certification program we do has to have a certification plan for an FAA-Major. We go through the same internal process even it's a Minor," says Nichols. The MD 530F with 650shp Rolls Royce Model 250-C30 turboshaft, five-blade main rotor and two-blade tail rotor was type-certified in 1985 and continues to sell with Supplemental Type Certificate modifications. "Usually the level of mods are not such that you're rewiring the helicopter and adding weapons and

TOP: **MDHI used the Armed MD 530F test helicopter to qualify the Cayuse Warrior weapons sight and rockets in live fire tests at the Mile High Resources range earlier this year (MDHI)**

ABOVE: **MDHI also flight tests the MD 530G at Falcon Field, Mesa Arizona**

"ANYTIME YOU'RE PUTTING ARMAMENT ON A HELICOPTER, EVERYONE'S PULSE GOES UP A LITTLE"

different components that are new to the FAA STC paperwork."

MDHI has built an in-house testing capability to support STC and Airworthiness Release programs. The number of people involved varies, according to testing requirements. Typical flight teams and test working groups have more than a dozen individuals from key disciplines. Nichols notes, "We do have our FAA-approved pilots." He explained they are used in experimental test roles and when required by the Army MDHI uses military test pilots. Nichols adds, "We have FAA DER [designated engineering representative]-qualified pilots who come in when it's an FAA-Major effort."

"We have a dedicated engineering test flight team," says Schultz. "They're responsible for the planning, moding [modifying] and de-moding [removal of modifications] of the aircraft, as well as the testing." The team also does instrumentation and installation procedures needed for special equipment for modifications and testing such as comprehensive instrument suites, integrated accelerometers for vibrations, pressure taps/transducers for air pressure and air data, strain gauges for loads, air data swivel probes for yaw and angle of attack measurements, and thermocouples for temperatures.

Blast pressure measurements on the Armed F were measured by pressure transducers attached to the fuselage above and below the waterline to measure the launch impact on the Cayuse Warrior structure and pilot.

Test criteria for rockets and missiles is provided by the Joint Attack Munition Systems project office within the US Army Program Executive Office, Missiles and Space Mission. Camera imagery, intervalometer recordings and payload-specific data are collected during weapons testing by standalone recorders.

So far MDHI has had no need for telemetry capability and records all test data on the test aircraft. Testers use data acquisition units from several vendors, and the instrument kits capture all aircraft states – position, altitude, attitude, heading, velocity and acceleration – plus flight-specific data such as airframe strain measurements, airframe and dynamic component accelerations and vibrations, and weapons blast or airstream pressures.

CHANGING STANDARDS

Despite the volumes of past MD500-series data, MDHI has to validate and recreate much of the data for the Armed F Airworthiness Release. Nichols explains, "There are always challenges to the data that's out there from the past. What were they using as a baseline? Those standards have also changed. A simple example is rocket gas ingestion. Because the rocket motors have changed based on safety, you have to redo the test to get accurate, modern data."

The MD 530G fired guided and unguided munitions at Yuma Proving Ground in July 2014, providing current data for a company qualification and future AWR. MDHI has offered the 530G with the WESCAM MX10 laser-designating EO/IR payload, Raytheon TALON laser guided rocket, and MOOG stores management system. Details of current testing are proprietary, but the MD 530G test effort includes flow measurements taken from a new internal auxiliary fuel cell integrated to extend range.

ABOVE: Afghan MD 530Fs operate at high density altitudes – MDHI is testing anti-torque enhancements for improved directional control at high altitude

The baseline MD 530F designed for high-hot operations has a 650shp engine and longer main and tail rotor blades than those of the MD 500E, and exceeded the original customer requirements. MDHI is nevertheless testing performance improvements applicable to the Cayuse Warrior. The company flew an MD 540F Armed Aerial Scout (AAS) demonstrator in 2012 with a six-bladed main rotor and 715shp M250-C47 engine to meet the range and high-altitude requirements of the canceled US Army AAS competition. The US Army Special Operations Command operates the AH-6M (based on the MD-500E) with six-blade main and four-blade tail rotors. The five-blade MD 530F and 530G also share the common airframe, and both can benefit from tail rotor and other dynamic improvements provided to other models from MDHI.

Details of the MD 530F enhancements to the anti-torque capabilities on the helicopter remain undisclosed, but current testing aims to improve directional control capabilities at heavier weights and higher density altitudes. Flight testing will measure directional control, vibration, height-velocity performance, low-speed controllability, and handling qualities at sea level, 7,000ft and 12,000ft density altitudes. The test program will also include a flight strain survey. Company development testing is due for completion in 2016, and the anti-torque enhancement aims at both military qualification as an option for current MDHI military products and future FAA certification for heavier civil helicopters. ∎

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

Proving the P-8A

Superficially a 737, the P-8A Poseidon aircraft has required an extensive testing program due to the vast changes required to meet its military mission profile

BY NIGEL PITTAWAY

A derivative of the Next-Generation 737-800, the P-8A Poseidon is designed for long-range anti-submarine warfare; anti-surface warfare; and intelligence, surveillance and reconnaissance missions

Although based on the commercial Boeing 737-800 fuselage, with the addition of 737-900ER (Extended Range) wings, the Poseidon P-8A Multi-Mission Aircraft (MMA) is considerably different from a structural standpoint. As a result, its development has required a dedicated structural and fatigue testing regime, designed to ensure the aircraft will achieve its planned life of 25,000 flight hours.

As part of the P-8 System Development and Demonstration (SDD) effort, Boeing and the US Navy are responsible for designing, engineering, building and proving the viability of the aircraft.

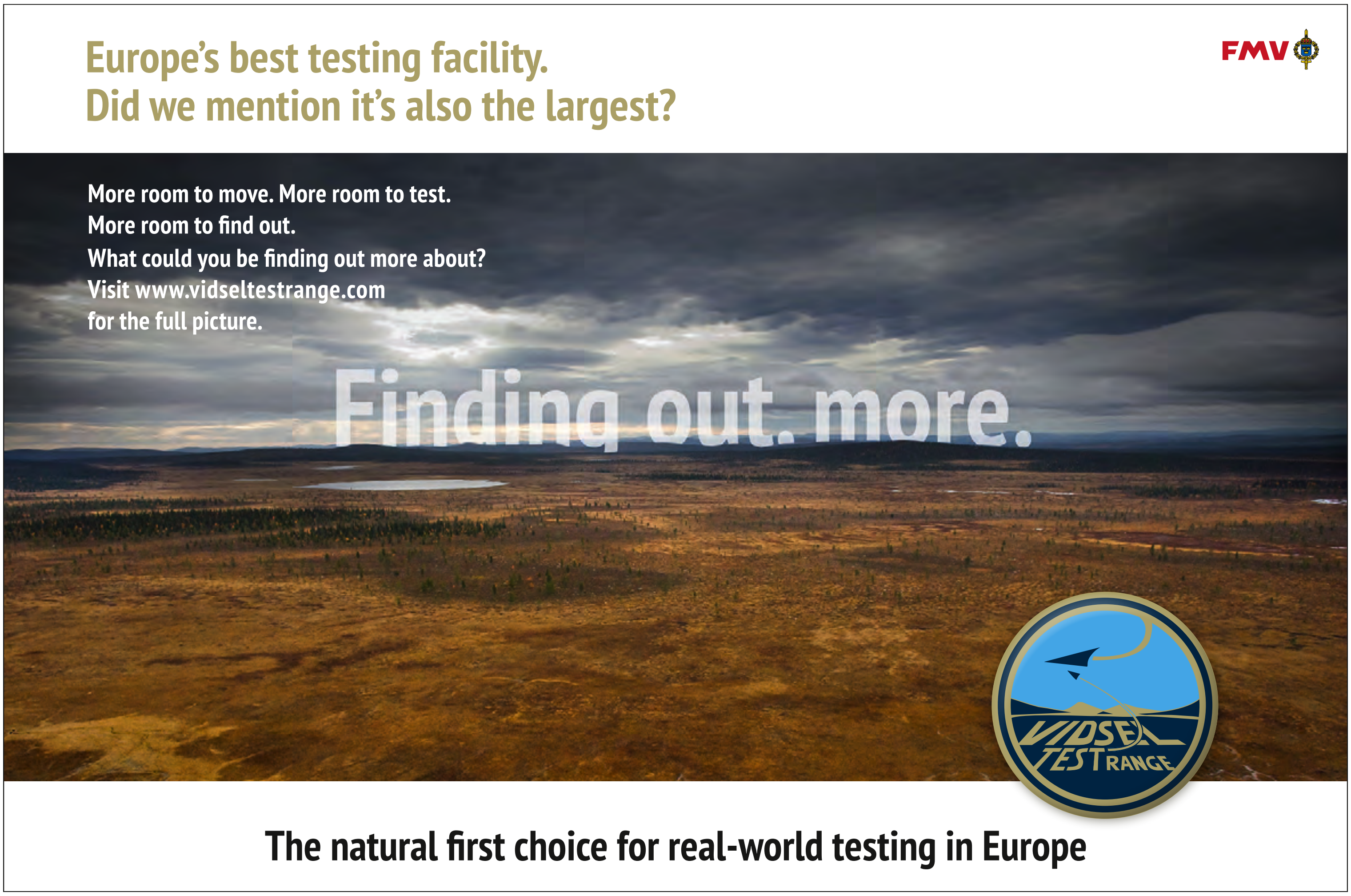
To this end, the structural and fatigue testing program is intended to verify that the aircraft will perform as predicted. As part of the SDD program, two non-flying test aircraft (one each for static and fatigue testing) and six complete aircraft for flight testing have been produced.

STATIC & FATIGUE TESTING

Although the commercial 737 from which the P-8 was derived is commonly operated in a benign flight regime where, for the comfort of passengers and crew, bad weather and turbulence are avoided as much as possible, the Poseidon's mission profile requires it to fly in all weather and at a range of altitudes.

The P-8 is a long-range anti-submarine warfare, anti-surface warfare, intelligence, surveillance and reconnaissance (ISR) aircraft and is therefore required to fly a wide range of flight profiles to fulfill its mission requirements, with several profiles possible during each typical eight-hour sortie.

The commercial product will typically see one pressurization cycle per flight as it climbs to cruise altitude and remains there until top of descent. However, the Poseidon may be required to climb and descend several times during a typical mission. This means not only more pressurization cycles per flight hour than the airliner from which it is derived, but also that the airframe will typically spend more time at lower altitudes. This leads to a greater exposure to turbulence and prolonged operations during icing conditions. The P-8A's fuselage was therefore designed to accommodate the different loads and stresses specific to the operational mission profile, and differs substantially from the baseline 737-800.



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> **"THE FATIGUE TEST WAS DESIGNED TO REPLICATE STRESS ASSOCIATED WITH EACH MISSION SET"**

As part of the designed mission profile, the Poseidon is also required to fly at bank angles of up to 60º and must be capable of tolerating g loadings up to twice those of the basic 737 design.

Furthermore, the Poseidon is designed to carry weapons both internally and externally. Therefore the structural changes to accommodate them, and the affect the weapons will have on flight performance and fatigue, have been taken into consideration.

The wings have also been considerably strengthened and are structurally different to those found on the commercial 737-900ER, with more internal ribs and stringers.

A unique testing regime was therefore required to ensure that the P-8A can stand up to the mission requirements, and to account for differences between its structure and that of a 737.

"The loads that the aircraft is expected to encounter during each of these missions were analytically determined, and the fatigue test was designed to replicate stress associated with each mission set," explains Captain Scott Dillon, the US Navy's Maritime Patrol and Reconnaissance Aircraft (PMA-290) program manager.

"Fatigue testing leverages methodology that Boeing employs to validate other military and commercial platforms, but it is extensively tailored to P-8A's unique mission profile while also following (US) Department of Defense standards."

A UNIQUE STRUCTURE

To accommodate the mission set, the Poseidon's fuselage structure has additional stringers and a thicker skin – up to double that of a commercial 737 in some places.

The fuselage structure aft of the wing cut-out (section 47) is also strengthened around a further cut-out for the internal weapons bay; the 'ceiling' of the bay itself is stressed for the carriage of five weapons (Mk 54 torpedoes or mines). Each hard-point is stressed for a weight of up to 1,450 lb (657kg).

There is provision for a further two hard-points (for external weapons carriage) on the aircraft centerline, forward of the wing, and these are also stressed to carry 1,450 lb of weapons. Although this option has not been taken up by the US Navy, Boeing has factored its potential into the baseline stress testing.

The wing has been structurally strengthened to accommodate wing stores and pylons (two of which can be carried beneath each wing) and stressed for weapons up to 3,000 lb (1,360kg) each. The P-8A also has raked wing tips, which Boeing says provides the same aerodynamic efficiencies as the blended winglets of a commercial 737, but are shaped differently to accommodate the Poseidon-unique de-icing system, which runs along the leading edge from the wing root right out to the wing tip.

ABOVE AND TOP: **Weapons loading to weapons bay and underwing hard-points – the offensive capability of the P-8A required a structural test regime to ensure performance**

2
number of static and fatigue specimens

25,000
hours – design fatigue life of the P-8A

50,000
hours – duration of fatigue testing carried out so far (two lifetimes)

STRESS AND FATIGUE TESTING

The US$3.89bn SDD contract awarded in June 2014 included the construction of three flight test aircraft (later expanded to six), one full-scale static test airframe (designated S1) and one full-scale fatigue test airframe (S2).

S1 was used to determine how well the P-8 would tolerate stress, and was installed in a test rig at Boeing's facility in Renton, Seattle, Washington, USA after completion. Testing was completed in January 2011, during which time the wings were successfully taken up to 150% of the design load to meet the US Navy mission requirement.

"The fatigue testing completed on S1 factored the external weapons and weapons pylons, and the test profile closely replicated the stress and loads the aircraft is designed to encounter during real operations," Captain Dillon says.

The fatigue test airframe (S2) was initially used to demonstrate that the P-8A was capable of achieving its design lifetime of 25,000 flight hours,

ABOVE: The first P-8A Poseidon test aircraft takes off from Boeing's facility in Seattle, Washington, USA, June 24, 2011

which has also been successfully completed. According to Boeing, this testing has now proved the aircraft is able to meet its design requirements during a first lifetime of testing.

The 25,000-hour airframe design life was set to ensure that fleet aircraft can remain in service for a minimum of 25 years without requiring major service life extension efforts

Boeing and the US Navy have recently completed a second lifetime of testing (50,000 flight hours) on S2 and are currently assessing the results. The data will provide further insight into the aircraft service life and will be used to support the aircraft into the future.

"Structural testing is complete and has not resulted in any significant airframe modifications. Fatigue testing is still ongoing and is also not expected to result in any future modifications," Captain Dillon adds.

"When complete, the results will be used to refine P-8A inspection, maintenance and localized component repair procedures."

EXPORT AIRCRAFT

So far two other countries have purchased the Poseidon. The Indian Navy ordered eight P-8I aircraft in 2009 and is currently in the final stages of negotiation to exercise options it holds on a further four. Australia selected the aircraft as its future maritime surveillance aircraft in 2014 for deliveries beginning in 2017, and also holds options on a further four aircraft.

Australia's Poseidons will be identical to US Navy aircraft; currently, India's P-8Is differ only in the installation of a Magnetic Anomaly Detector (MAD) in the tailcone. The MAD provision was a feature of the baseline P-8 design but subsequently deleted by the US Navy; the configuration has therefore been taken into consideration during testing. India may also deviate from the use of US baseline weapons in the future, which could possibly require additional carriage and release trials, but for the moment the external weapons are common between the P-8A and P-8I.

At the present time, therefore, no export-specific testing has been required. "Boeing completed the testing protocol necessary to make an airworthiness recommendation to the Indian certification authority," James Detwiler, Boeing P-8 sales and marketing director, notes.

FURTHER TESTING

Following the successful conclusion of the stress-testing program, aircraft S1 was disassembled and transported to the Naval Air Warfare Center Weapons Division at China Lake, where it was used for live-fire testing.

> "BOEING AND THE US NAVY HAVE COMPLETED A SECOND LIFETIME OF TESTING (50,000 FLIGHT HOURS) ON S2 AND ARE ASSESSING THE RESULTS"

The testing, conducted during 2012 and 2013, verified the damage tolerance of the aircraft and satisfied the US Navy's test and evaluation requirements.

During 2013, Boeing was awarded a US$138m contract to conduct additional fatigue testing of the P-8A airframe to examine the possible effects of the carriage of Raytheon's Advanced Aerial Sensor (AAS).

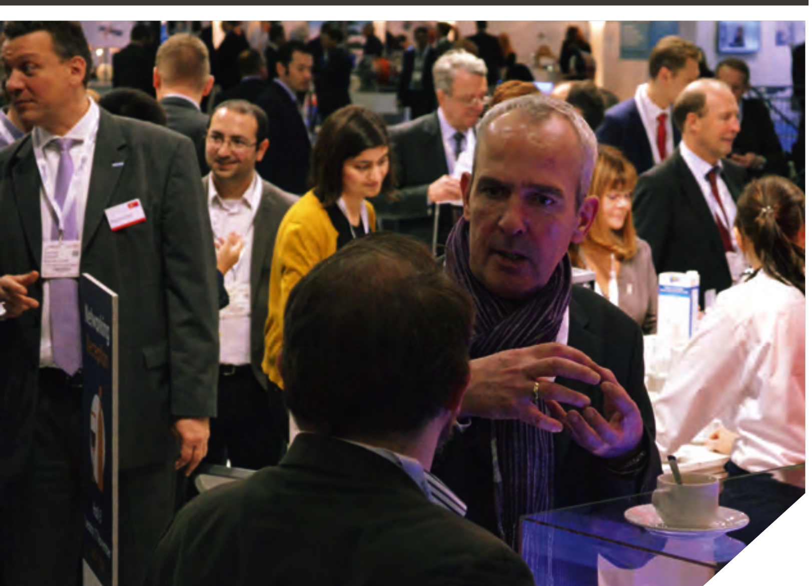
The AAS is an Airborne Electronically Scanned Array (AESA) radar that can be installed under the forward fuselage of the P-8A and will possibly become part of the US Navy's incremental upgrade roadmap for the Poseidon.

One flight test aircraft has been noted flying from Boeing Field in Seattle with the AAS installation. Furthermore, initial stress testing had reportedly been carried out on S1 prior to its relocation to California for the live-fire testing.

Further fatigue testing is now underway using S2, and will determine what the longer-term impact of AAS installation will have on the US Navy fleet. ▮

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

ABOVE: P-8A fatigue test article (S1), pictured at Boeing's Renton, Washington, USA facility in 2009



PORTABLE ACOUSTIC CAMERA

Noise source identification tool displays color-coded sound maps in 20 seconds

For acoustic measurements in the cabins and cargo bays of aircraft, the time available for performing acoustical tests can be very short – during a test flight, or a snatched opportunity on the ground. And the possibility of repeating a test can be very unlikely, due to the expense of flight tests and the tight schedules involved. So acoustic tests such as noise source location need to be quick and thorough. Being able to use one tool to make rapid, reliable acoustic measurements over the full audible frequency range can help fit acoustic testing into packed aircraft test flight schedules.

The PULSE Reflex Acoustic Camera from Brüel & Kjær provides reliable and accurate measurements that can be verified on-site immediately, so the results of troubleshooting are well documented in the form of recordings (audio and video) or screendumps, which can be handed to the design team upon landing.

The acoustic camera gives an instant sound map of whatever its user points at. Mounted on the hand-held microphone array is a tablet that displays the sound map, laid over a real-time video of the target. Color-coded noise contours show the strength of the sound, from which the user can easily determine the sound's source – from the brightest contours. Good maps allow reliable ranking of noise sources in order of importance.

Beyond the intuitive interface, speed and simplicity are key to the whole product, which has been designed around the goal of getting it up and running in 20 seconds for rapid troubleshooting. This speed objective has permeated the development of the hardware and software, and even the box that the battery-powered kit comes in. This approach ensures minimal training is required to learn to use the acoustic camera.

Because the acoustic camera displays and analyzes noise in real time, it can map moving objects. While streaming sound information to the tablet screen, a user can walk and move around with it. When they find a noisy area of interest, a built-in camera can take a screenshot or video to refer to later and more easily explain the measurements.

As well as real-time streaming, the acoustic camera can record the data and video, by pressing a button on the microphone array. This is typically done when the user wants more in-depth analysis of the sound than just a rapid noise source identification. Because the camera streams data to a PC at the same time as the tablet, the data is recorded directly to the PC's hard disk.

After measurements have been recorded, post-recording analysis on the time data is done using the PULSE Reflex software. The acoustic camera runs inside this software platform, making data transfer and interpretation seamless. In PULSE Reflex, the user interface is shared across applications, making use as intuitive as possible.

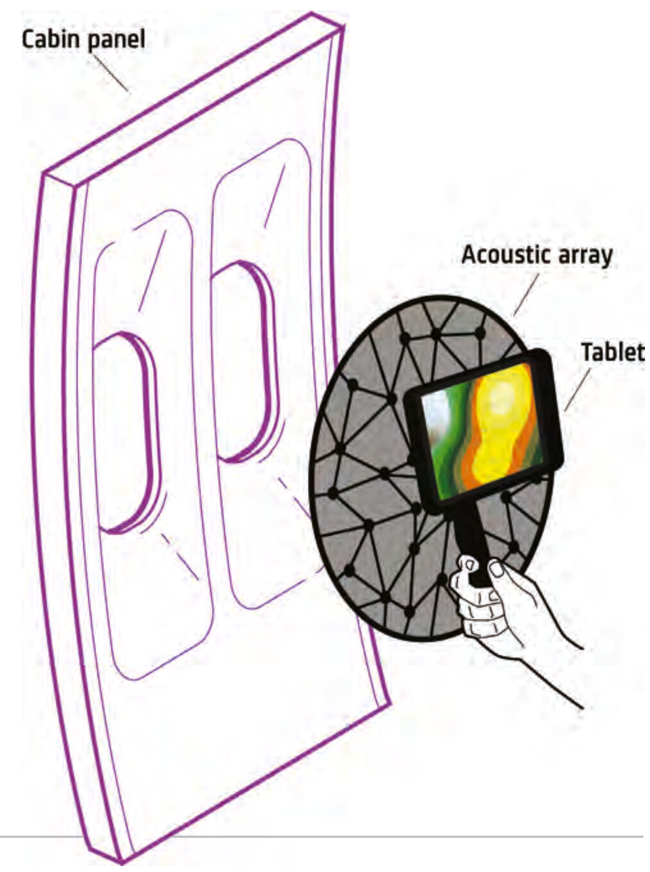
To analyze the data, the software includes tools allowing users to adjust aspects of the sound such as the frequency range displayed, helping to narrow the focus of the problem-solving efforts, to pinpoint specific problems.

Versatility is key to the acoustic camera's utility. Its relatively small diameter of 35cm makes confined spaces – such as small areas of aircraft cabins – accessible. For measurements from further away, a removable reflective plate on the array quickly optimizes it. Furthermore, the ability to incorporate reference signals such as tachometer information enables clear and easy correlation with noise sources, such as the engine's specific position.

To ensure right-first-time data capture, the acoustic camera has built-in measurement safety features such as automatic cable-break detection that clearly indicates any issues through a large LED for each measurement channel. Automatic input ranging using dual DSPs removes the need for manual input, reducing setup procedures and avoiding measurement errors from over- and under-range signals.

The acoustic camera provides good spatial resolution over a wide frequency range by combining beam-forming and acoustical holography calculations, which means improved noise source identification capability.

Overall, with the PULSE Reflex Acoustic Camera, engineers and technicians get a complete noise source identification kit, from a single, global supplier. The kit has been conceived and optimized for deployment that is as rapid as possible by a company that has long experience in acoustics, and has been involved with array-based noise source identification since the inception of the discipline in 1986. Consequently, there is an extensive suite of techniques, software and hardware available from Brüel & Kjær, which offers a shared user interface and database from a single, global supplier. ∎



Brüel & Kjær's acoustic camera is a complete kit for mapping sound emissions in seconds

MIMO QUALIFICATION TESTING

Multiple-input multiple-output testing ensures each mechanical interface point receives the required amount of vibration

Wing slats are components which have an essential role in aircraft aerodynamics. Located at the front of the wing, they give the aircraft the necessary energy to take off and land and in flight they protect the airplane from bird strike. Hot air de-icing systems are fitted which help prevent ice accretion on the wing leading edge.

In a standard slat design, the wing anti-icing system (WAIS) consists of a pneumatic system with a number of piccolo tubes and hoses that run throughout the span of the slat, in-between its ribs. Hot air blows through the small holes along the piccolo tubes to prevent ice accretion. To certify the system, the WAIS must undergo thorough qualification tests as per the DO-160 standard – the Environmental Conditions and Test Procedures for Airborne Equipment. These ensure the performance characteristics of the equipment remain within specification no matter the environmental conditions (humidity, electromagnetic compatibility, vibration, etc).

VIBRATION TEST SETUP

Vibration testing is a critical part of the structural qualification. This checks the functional performance and structural integrity of the A/C system when subjected to normal and unusual vibrations. Such tests must be carried out to study the reaction of various parts of the anti-icing system (AIS). The standard says vibration levels are tested where the AIS is attached to the wing ribs. This is not an easy task, as the anti-icing system is big and runs the entire wingspan, making it a very long, slender body and difficult to measure accurately.

Each part of the system is over 3m long and together they make a very lightweight structure. Traditional single-shaker test setups with a slip-table able to accommodate a long object are rare and expensive. More challenging is obtaining uniform excitations at the attachment points, because of structural resonances of large slip-tables. While accepted by most standards, single-shaker setups require that the average of multiple control accelerometers matches the test profile. This methodology may lead to large differences between the local vibration levels and the average control acceleration.

The Certification and Testing Facilities Center of SONACA found a simpler test solution. With Siemens PLM Software, it applied multiple-input multiple-output (MIMO) technology to test the system, making sure that each excitation point is properly excited. MIMO brings the advantage of independent control of acceleration targets at each mechanical interface of the leading edge. Thus, each attachment point was subjected to the required amount of vibration.

TESTING PROCEDURE

Tests were run on three piccolo tubes. Each axis was subjected to: shock, low-level sine, random performance, three hours of random endurance, high-level sine fan blade off, sine windmilling and sine low-level test. Each tube was equipped with 15 strain gauges and PCB Piezotronics accelerometers. The gauges (in red) were placed on the most critical areas observed during the three axes excitation as per LMS Samtech Samcef finite element method analysis from Siemens PLM Software. The accelerometers (below in blue) were placed to capture mode shapes and first bending modes.

Five Modal Shop, Inc shaker systems were placed at each mechanical interface with the slat, and one control accelerometer was fixed on the support tooling. The supports and clamps that were used to fix the hoses reproduced a typical A/C installation, including silicone rings between the slat and its support. The test also involved an LMS SCADAS Mobile controller with 32 input channels and five outputs for generating the drive signal.

MIMO VS SISO AVERAGE RANDOM RESULTS

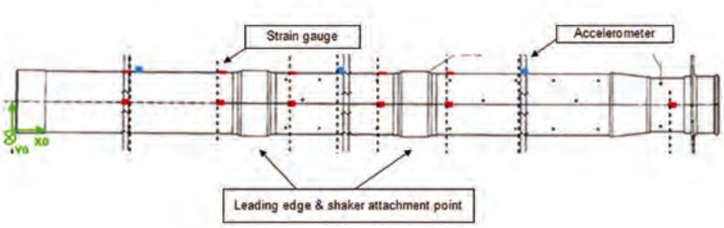
The results of all tests show that the five shakers' control target spectra were stable and remained within the limits specified by the DO160 stand. No significant differences were recorded in a comparison between the linear average PSD (power spectral density) of the five control target spectra during the MIMO random with the control PSD using a single-shaker setup (SISO).

Although not yet standardized in the civil aerospace industry, MIMO setups have clear advantages to offer when applying forces to large structures.

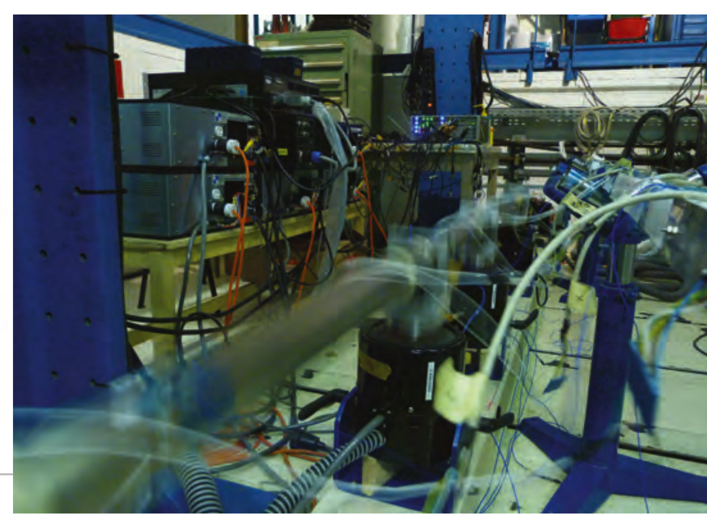
Results have shown that this MIMO control implementation enables critical tests to be carried out while maintaining the important safety features of root-mean-square (RMS) and response limiting.

Moreover, this specific setup allowed for on-site testing which facilitated additional inspection work and reduced travel costs for the team and equipment which would otherwise be engendered.

BELOW: **Strain gauges (red) were positioned on the most critical areas observed during the three-axes excitation. Accelerometers (blue) captured mode shapes and first bending modes**



RIGHT: **A piccolo tube being tested on a five-shaker system**



SMART CABLES FOR AVIONICS

USB interfaces with built-in hardware, firmware and processing resources combined with off-the-shelf computing power offer game-changing solutions for testing avionics data

With more electronic avionics equipment being integrated into almost any type of aircraft (fixed and rotary wing), demand exists for portable test equipment for on-aircraft testing and troubleshooting. Dedicated handheld devices displaying avionics bus data in basic formats such as simple binary or hex view have been around for many years. In today's situation, we have a game changer, with the availability of more powerful portable platforms such as tablets and smartpads offering new capabilities and endless possibilities for portable test equipment implementations from both the technical and the commercial point of view.

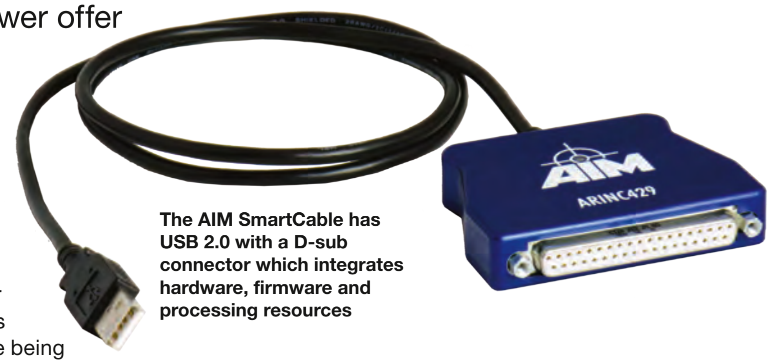
A wide range of portable computing platforms are available as commercial–off-the-shelf (COTS) devices that theoretically can cover almost every avionics testing application, from the laboratory environment up to rugged use in the hangar, or even for on-aircraft testing.

Testing avionics databuses and networks, which typically interface to data communication standards like ARINC429 and MIL-STD1553, are not readily supported off the shelf by such computing platforms.

Common data connection interfaces for most of these computing platforms is Ethernet (wired or wireless implementations) and USB. Wireless Ethernet is attractive from a user handling perspective, primarily because it requires no cabling for communication between the computing platform and the interface for the tested device. However, the interface device still needs to be powered, raising a further issue as to how to provide power for the application or user case. For larger avionics testing solutions, Ethernet is definitely a good choice. It handles the concern of computing platform obsolescence by keeping the Ethernet-based avionics interface hardware investments in place and only replacing the computing platform.

On a smaller scale, by using highly portable testing solutions, a common off-the-shelf USB interface on COTS platforms is a good candidate worth examining more closely.

USB interfaces can deliver power so the interface hardware can be connected via a single cable for powering and controlling the data interface. Additionally, USB is an established standard and has been in use for many years. Even today, we see the USB interface being updated and migrated to the newer COTS portable computing platforms.



The AIM SmartCable has USB 2.0 with a D-sub connector which integrates hardware, firmware and processing resources

Obsolescence handling of platforms is made easier by more dedicated avionics databus interface hardware being USB based. Both USB 2.0 and the higher data-rate USB 3.0 are typically implemented in such platforms with the advantage of having maximum flexibility for the user and application.

From a data rate perspective, USB 2.0 is still suitable to handle the ARINC429 and MIL-STD-1553 standards. It also has lower power requirements for its interface hardware, the benefit being a saving of valuable battery power of the hosting platform, providing longer operational time without requiring an external power supply or a battery recharge.

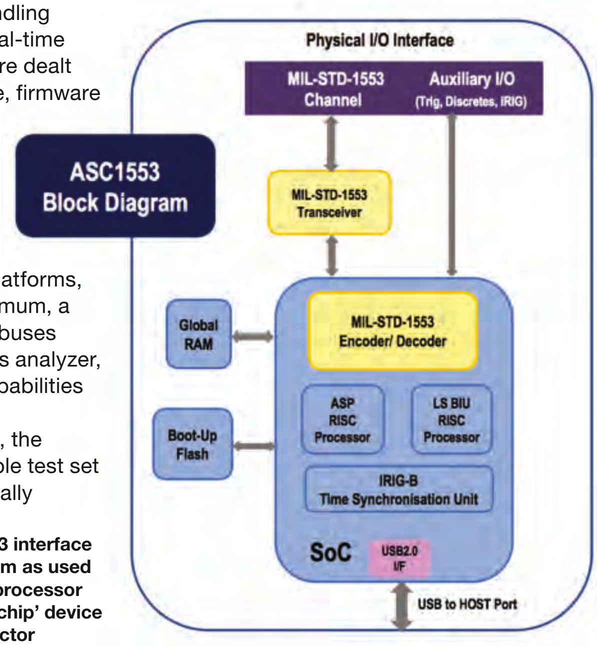
The AIM SmartCable family (ASC429 and ASC1553) has been designed to offer USB-based interface solutions to operate on any single USB 2.0 (or higher) port. This provides maximum flexibility for the connection, especially for portable computing platforms. A low-power hardware design has driven the current solution for a half-pocket sized interface (75mm wide, 55mm long, 15mm high) for ARINC429 and MIL-STD1553 test, simulation and monitoring applications.

Any concerns with respect to handling avionics databus protocol-related real-time capabilities over the USB interface are dealt with by having the required hardware, firmware and processing resources directly integrated within the D-sub connector housing. Additional potential is also offered with the use of a dual processor System-On-Chip device (SOC).

Working with COTS computing platforms, offering USB 2.0 capability as a minimum, a solution for interfacing avionics databases now offers the capability for a full bus analyzer, troubleshooting and data loading capabilities with minimum size and weight.

With flexible application software, the essential building blocks for a portable test set are now available and can be principally implemented using COTS hardware and software. Customization of software and hardware can address dedicated user cases as well as differing operator skill levels. At the hardware level, the typical 'A-Type' USB connector can be easily replaced with a more robust circular connector, which can mate with corresponding tablet computing platforms. On the software side, the COTS software customization capabilities, such as the implementation of application-specific Graphical User Interfaces (GUIs), allows flexible adaptation to the end user's needs and applications.

AIM supplies COTS hardware and software solutions for avionics databus, network interfacing, testing, simulation and data loading. It offers such building blocks in the form of the ASC429 and ASC1553 AIM SmartCables together with the PBA.pro software and suitable third-party computing platforms to provide smart and highly portable testing solutions. ∎



The ASC1553 interface block diagram as used by the dual processor 'system-on-chip' device in the connector

HIGH-SPEED CAMERA FOR SEVERE CONDITIONS

AOS high-speed cameras have a reputation and proven track record for reliable functionality under even the most severe conditions, such as those experienced in real-world military tests. The cameras are ideal for mounting inside or outside of the aircraft and are able to record multiple sequences, store data to the built-in non-volatile memory, and provide data for motion analysis in the lab.

Q-MIZE EM offers a built-in video interface for connecting the camera to the aircraft telemetry system, giving live image feed to the ground.

AOS cameras are designed to MIL810 standards and are built for the challenges of inflight image data recording. All cameras are available with different MIL-spec connectors for easy integration into the wiring of existing aircraft.

The cameras comply with GigE Vision standards and meet the new IRIG ANCS communication standard. Q-MIZE EM records in standard speed ranges and in high-speed camera mode.

Data formats include native image formats and storage under the IRIG106 – chapter 10 standard.

AOS provides special enclosure for the camera, specific software functions, and the extension of functionality vital for the test setup. AOS supports these solutions over their full lifetime.

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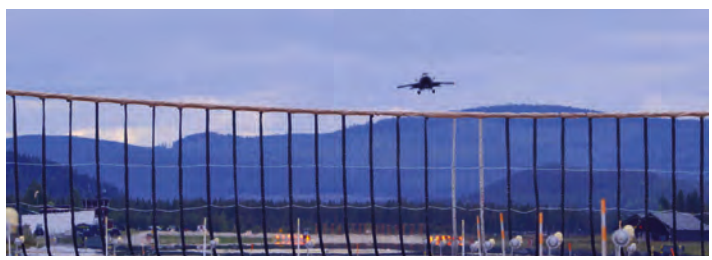
UAV TEST RANGE IN SWEDEN



The development in the UAV branch (in this context meaning advanced and large UAVs designed to carry out high risk missions in a hostile anti-access airspace) continues to progress. Two major European UAV demonstrator programs, Barracuda from Airbus and Neuron from Dassault, have both reached the system development and capability demonstration phase. This step includes full-scale flight trials and the use of complex test and evaluation (T&E) scenarios. T&E with advanced UAV platforms are complex tasks requiring: vast volumes of restricted air and ground space; well-equipped and heavily instrumented test ranges; and personnel who are highly skilled and well-trained.

The Vidsel Test Range in the far north of Sweden is operated by the Swedish Defence Materiel Administration (FMV) and possesses all the required capabilities. It has 24,000km² restricted (overland) airspace and 3,300km² restricted ground space and is fully instrumented with tracking radars, theodolites, flight termination and telemetry systems. The varied terrain and abundance of ground and aerial targets at Vidsel enables the development of realistic test and evaluation and capability scenarios.

The Vidsel Test Range is operated by experienced and flexible personnel, which gives it all the means necessary to host and conduct advanced UAV flight testing at the leading edge of technological developments.The capabilities and expertise of the Vidsel Test Range were fully used when the high-profile Barracuda and Neuron UAV programs were deployed to Sweden for two intense T&E periods. The test and evaluation demonstrations performed included an array of different mission profiles and proved the system capabilities at the range.

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HYDRAULIC TEST EQUIPMENT

New developments demand new specific test equipment. To keep pace with the development of new aircraft types, engineers in the testing industry always have to be one step ahead. With the new E-JET E2, Test-Fuchs engineers were selected to design multifunctional test equipment for the aircraft's hydraulic system. The result was the delivery of equipment that automatically performs pressure tests with a hydraulic, compressed air or nitrogen medium; and in addition, flushes, cleans, fills, empties and dries the aircraft's hydraulic system.

To manage all these tasks, the new test equipment consists of a compact suit of different functional components. Firstly, there is a hydraulic power unit that supplies the required hydraulic pressure and flow for hydraulic tests (4,500psi at a maximum of 25 US gal/min). This is linked to a special hydraulic distribution system, capable of servicing all of the aircraft's hydraulic circuits, a challenging task for engineers to develop, since the equipment had to be an 'all-in-one' solution, providing mobility, flexibility and future-proofing. The next component is the human-machine interface (HMI), which enables operation of the test equipment, including fully automatic tests. The final component of the test equipment is an integrated HIAC PODS, which performs an online particle measurement of hydraulic fluid, while in operation. This speeds up the time required for particle evaluation by automatically sending the measurement data to the HMI, and removing the need for laboratory analysis.

Apart from the fully automated test operation, the customer enjoys other features of the test equipment, such as a compressed air filter that cleans and dries the air, and easy access for maintenance tasks. Calibration or maintenance tasks are performed by authorized personnel only, to avoid errors in a manual mode. As a very compact and mobile test system, it can be easily transported and positioned at the operator's convenience, meaning it is also fit for future aircraft developments.

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T-34C farewell

The analog-instrumented chase aircraft is being replaced by a model with digital test instruments

BY MICHAEL JONES

The venerable T-34C turboprop chase aircraft has flown its last mission for the US Army, at the Redstone Test Center (RTC) in Alabama, after 35 years of service. Three of the aircraft had been used at the RTC to support test flights and record supporting data. Their role has been fully taken on by the more capable T-6D Texan II.

The small two-seater T-34 was developed from a Beechcraft Model 35 Bonanza, which was the brainchild of Walter Beech. His company developed the aircraft privately in the late 1940s, a time when the US military had no budget for trainer aircraft. A conservative military in aeronautical terms meant the T-34 was developed without the distinctive V-tail of the civilian Beech Bonanzas. Other changes to convert the airframe to training duties included removing a four-passenger cabin and replacing it with a narrower two-seater version and bubble canopy, which gave greater visibility and stability. The T-34 series shares the same basic wing planform and landing gear as the civilian series of distinctive Beechcraft Bonanza general aviation aircraft.

The US Air Force was the first to put the piston-engine training aircraft (T-34A) into service, in 1953, and the US Navy followed in 1955 with the T-34B. Production continued until October 1956 and then halted until 1975 when a Pratt & Whitney Canada PT6A turboprop version, the T-34C, was introduced for the US Navy. The last of the T-34Cs rolled off the production line in 1990. About 100 remain in US goverment service.

The RTC says that the testing support mission of these small aircraft is 'pace and chase'. Gathering data on these missions is called 'pace' because the test article and pace aircraft are flown close to each other in order to gather airspeed and altitude data. An 'area chase' mission uses the T-34C (now T-6D) to assist the test aircraft, if needed, as they communicate with air traffic control.

A 'safety chase' is a task where the aircraft is used to observe external modifications to the test articles and assist in emergency situations.

'Photo chases' provide inflight photo documentation of test flights and missions.

There are key differences between the T-34C and the T-6D. For example, the T-34C has analog instrumentation (for data and flight), and the T-6D is all digital. Plus, the T-6D has a pressurized cabin, meaning that it can fly to altitudes of 18,000-20,000ft.

The T-34Cs retired from the RTC will continue in service with NASA. One aircraft went to the NASA Glenn Research Center in Ohio; the other two were flown to the NASA Armstrong Flight Research Center at Edwards Air Force Base in California.

NASA uses the T-34Cs for photography and video data collection flights, and also for safety chase duties. At Armstrong, the T-34C's role is chasing remotely piloted unmanned air vehicles, which fly more slowly than NASA's F-18 mission support aircraft.

The replacement aircraft now built by Textron Aviation, the T-6D, has been in production since late 2001. Based on the Pilatus PC-9, the T-6D features major modifications made to fulfil the requirements of a Joint Primary Aircraft Training System (JPATS). So extensive were the changes that it is reported that the T-6D represents a completely new aircraft and is heavier by 1,100 lb – or 22% – than the PC-9. ▮

T-34C STATS

Crew: Two

Length: 28ft 8.5in (8.75m)

Wingspan: 33ft 3in (10.16m)

Wing area: 179.6ft² (16.69m²)

Empty weight: 2,960 lb (1,342kg)

Max. take-off weight: 4,300 lb (1,950kg)

Turboprop: 1 x Pratt & Whitney Canada PT6A-25 – nominally 715shp (533kW) operated de-rated at 400shp (298kW)

Cruise speed: 214kts (396km/h) max. cruise at 17,000ft (5,180m)

Stall speed: 53kts (98km/h) flaps down, power off

Range: 708 nautical miles (1,311km) at 180kts (333km/h)

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

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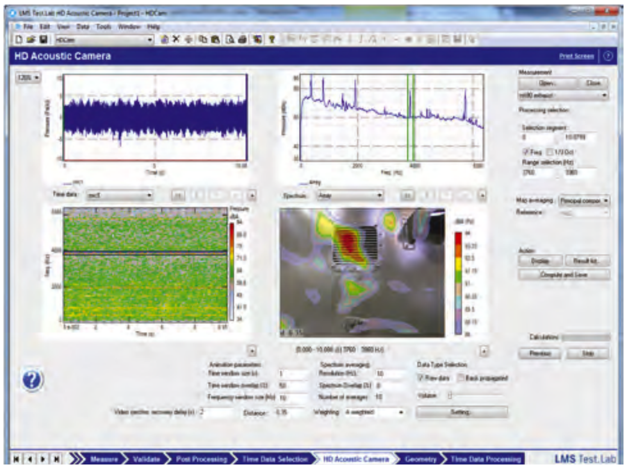

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