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AEROSPACE TESTING INTERNATIONAL

NOVEMBER/DECEMBER 2012

CSeries

How Bombardier's revolutionary approach to systems testing is keeping it one step ahead in the flight test game

NDT breakthrough

A mobile inspection system combining active thermography with phased-array ultrasound enters service with the German Air Force

Live and learn

Remote controlling a 727 nose-first into the Mexican desert created a huge impact in more ways than one: the groundbreaking experiment revealed who would die – and who could survive

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20


14


40


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This foreword was intending to go into a little detail regarding the Chinese aerospace test industry (see news story on page 7). However, that has 'stalled' (maybe next issue). Just a couple of days before publication I was sent an email by Bob Moreau, chairman of the Society of Experimental Test Pilots SETP EASA (European Air Safety Agency Committee). The committee was formed to gather information regarding the imposition of test pilot licensing requirements by EASA, to inform and help its membership deal with the regulatory world. Moreau says he is keen to send his message across to the aerospace test industry.

As editor, I have abridged the letter sent to me, and chosen some salient points. Within his statement, Moreau makes his mark: "The Society of Experimental Test Pilots was asked by a European test pilot for an opinion on the EASA Notices of Proposed Amendment (NPAs) concerning flight testing. The 'amendments' were obtained, and discussions were had with a variety of concerned participants. The source of the NPA's is a proposal that helps flight test pilots work in various countries across the European Union, despite having flight crew licenses granted by their respective national airworthiness authorities.

Moreau is straightforward, "As an example, a British test pilot for AgustaWestland would have a pilot certificate granted by the British CAA, valid for flights within the UK. An Italian test pilot, also working for AgustaWestland in Italy, would have a pilot certificate granted by the Italian ENAC, valid for flights within Italy. Due to the way in which the Italian ENAC structures its certificates, this pilot certificate would also have an endorsement for flight test operations, whereas the British CAA certificate would not. As a result, the British pilot may or may not be able to work on his company's project, depending on where the aircraft was registered. Similarly, the Italian pilot's credentials may not be recognized in the UK.

"EASA is most closely linked with EPNER. Empire TPS and National Test Pilot Schools are commercial ventures and would potentially see business opportunities in being evaluated and approved by EASA. However, US Navy Test Pilot School and US AFTPS are military test pilot schools that are funded for the purpose of military requirements, and have little to none of their curriculum oriented toward civil aircraft certification. Finally, EASA is funded through user fees. It is assumed that an EASA audit and evaluation of a school's curriculum would require the school being assessed to pay a user fee for the privilege of an EASA approval. In the case of the US military test pilot schools, since civil aircraft certification is not in their mission statement and in fact may be interpreted as conflicting with the career or retention requirements of their students, this user fee could prevent the evaluation. Without an evaluation, graduates of that school would not be recognized as having completed the EASA-required course of instruction," Moreau states.

The number one issue for SETP is the source of entry-level test pilot credentials to operate as a test pilot (or flight test engineer). Formal test pilot schools are not the only path to becoming a test pilot. The knowledge and skill necessary to perform as a professional test pilot are critical, but can and should be obtained from a variety of methods. Formal test pilot schools are excellent sources, but not the only available way to obtain this knowledge, expertise, and experience.

The Society's *Pilot's Handbook for Critical and Exploratory Flight Testing* is a good starting point for pilots. Moreau concludes, "While graduation from a formal test pilot school is one path to satisfy the entry level into the test pilot profession, there is no substitute for experience. Category '3 and 4' flight test pilots (production and engineering evaluations) must be allowed to accumulate experience under the mentoring of Category '1 and 2' test pilots. Aircraft manufacturers must be allowed and encouraged to train qualified pilots (appropriate license and scientific/engineering degree required), and that training should be formalized and documented," says Moreau.

Again this is all an opinion, but is from someone who has much clout and it is worth sharing in this forum. I have myself have written a book using amazing anecdotes form test pilots, and I have noticed many areas where test skills do not reflect the necessary education.

Christopher Hounsfield, editor

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COVER IMAGE: Boeing 727 test crash (image courtesy Discovery)

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Felix – the high jump trial to beat all trials

For nine minutes and nine seconds on October 14, 2012 the world held its breath. With millions of people watching live on the internet and tens of millions viewing on television, Austrian sky diver Felix Baumgartner single-handedly created a new sport – space-jumping.

At the post-jump press conference Baumgartner recalled, "When you are standing on top of the world, you don't think of records anymore; all you think is that you want to come back alive. In normal skydiving you can feel the air to maneuver yourself, but in the suit with pressure at 3.5 lb/in², it's like swimming without touching the water."

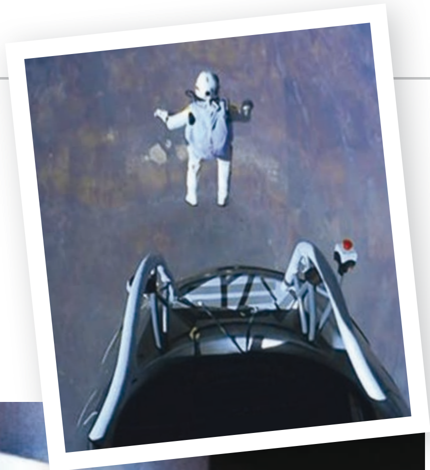
His 39,045m (128,100ft) jump from the edge of space broke a raft of records and turned the Austrian into a global celebrity. The iconic image of Baumgartner stepping off his capsule dressed in a spacesuit served to confirm his fearlessness but behind the scenes cutting-edge science and advanced testing developed the hardware to make the record-breaking jump possible.

As no-one had taken a balloon up or made a sound barrier-breaking freefall jump from such a height before, Baumgartner's Red

TEST FACTS

Preliminary results from the Red Bull Stratos Mission
(These achievements may change as data is further analyzed)

- **Altitude at which Felix Baumgartner stepped off the capsule:** 39,045m/128,100ft
- **Fastest speed achieved during freefall:** 1,342.8km/h / 833.9mph (Mach 1.24)
- **Time elapse before reaching speed of sound during freefall:** 33 seconds
- **Vertical distance of freefall:** 36,529m/119,846ft
- **Total time spent in freefall:** 4 minutes 22 seconds
- **Chute pulled:** 5,300ft above the ground
- **Total time from the moment he jumped to landing:** 9 minutes 9 seconds
- **Distance between launch and landing positions:** 70.5km/43.8 miles
- **Records achieved (awaiting certification):**
  - **First human to break the speed of sound in freefall without mechanical intervention**
  - **Freefall from the highest altitude**
  - **Longest vertical distance in freefall**
  - **Highest manned balloon flight**
  - **Source: Red Bull Stratos**



Bull Stratos team had to develop new systems and hardware to make the jump happen. On top of generating an unprecedented amount of publicity for his sponsor, Baumgartner said he hoped to gather information on the feasibility of high-altitude bailouts that will be useful to the budding commercial space-flight industry.

Dr Jonathan Clark, medical director of the project, said, "Never before has anyone reached the speed of sound without being in an aircraft. Red Bull Stratos is testing new equipment and developing the procedures for inhabiting such high altitudes as well as enduring such extreme acceleration. The aim is to improve the safety for space professionals as well as potential space tourists."

According to the team, "Red Bull Stratos aimed to provide information that will further the progression of aerospace safety". The key benefits for the science community including aiding the development of a new generation of spacesuits – including enhanced mobility and visual clarity – and other systems to lead toward passenger/crew exit from space. The project also aimed to help develop protocols for exposure to high altitude/high acceleration, and to provide real-life data on the effects on the human body of supersonic acceleration and deceleration, including development of the latest innovations in parachute systems.

THE BUILD-UP

The build-up for Baumgartner's jump involved more than two years of design and development and then the testing of his capsule, balloon, spacesuit and the systems to coordinate the jump.

At each step, rigorous evaluation of technical, scientific and medical data ensured that the project was on a sound footing and that Baumgartner was not taking unnecessary risks. The integrity of the pressurised capsule that took Baumgartner up into high atmosphere was verified in an altitude chamber at Brooks City Base in San Antonio, Texas. Baumgartner and his capsule underwent decompression to simulate the descent in the frigid temperatures and near-vacuum of the upper stratosphere before he underwent stratospheric tests in a specially modified Skyvan aircraft in March and July 2012. At above approximately 62,000ft (18,900m) the pressure is so low that liquids in the body will turn to vapor – bubbling and boiling. To avoid serious medical consequences to Baumgartner, during the tests the team had only seconds to 'dump' the chamber and return it to a normal environment.

Felix's pressurised capsule was designed, built and tested by the US company Sage Cheshire Aerospace, Inc. It featured a remote triggering system to release the capsule from the balloon to allow it to return safely to earth after the jump. A major innovation was the suite of cameras and other instruments fitted on the capsule and on Baumgartner's spacesuit that enabled real-time monitoring of the jump. "This complex camera system was vital to enable mission control to monitor Felix's physical condition, to document the mission's progress in real time and for future review", said one of the mission's planners.

IN THE PICTURE

The capsule was equipped with nine high-definition cameras, three digital cinematography cameras and three high-resolution digital still cameras. On Baumgartner's pressure suit, he wore five small high-definition video cameras – two on each thigh and one on his chest pack. To receive the live signals, a dedicated radio communications system had to be set up, including both fixed and mobile units in a range of 200 miles around the launch and recovery site at Roswell in New Mexico. "We have a great scientific team, and we're working to compile all of the scientific data," said Dr Jonathan Clark, the team medical director. "Felix had a monitoring system that will help to break incredible new ground."

According to Art Thompson, the project technical director, the monitoring information came into its own when Baumgartner started to tumble during his jump and it seemed as if he might spin out of control. "As a tumble ramps up in speed, it gets more and more difficult to stop," recalled Thompson. "We're glad Felix was able to get it under control. You could see a beautiful step-off, and then he went into a tumble. We have the accelerometer information – all that data will be analyzed. You can see that his flight path was controlled, he got into the Delta position, and so on, and that tells us about high-altitude egress, transitioning through Mach and back. Felix provided that, and he did an outstanding job as a test pilot."

Royal Artillery UAV operations criticized by UK air safety authority

THE INCIDENT

During the landing the crew selected the wrong runway to land the air vehicle on, made mistakes programming the automatic landing system, did not follow air traffic control procedures and displayed poor airmanship, said the report. As a result the air vehicle hit a hanger during its final approach and broke into several parts. No one was injured in the incident.

The UK's Royal Artillery unmanned aerial vehicle (UAV) operating procedures have been heavily criticized in a report by the UK Military Airworthiness Authority (MAA) into the crash of an Elbit Systems Hermes 450 at Camp Bastion airfield in Afghanistan October 2011.

The hard-hitting service inquiry by the MAA made more than 68 recommendations to improve flight safety and testing of Royal Artillery UAV operations, including many that propose outside supervision of training and of the routine work of Royal Artillery UAV flight crews.

This includes 'outside assurance of Hermes 450 flying' by an organization independent of the Royal Artillery, according to the inquiry report published on September 26, 2012 by the UK Ministry of Defence. It recommended that an outside study be commissioned by the UK Joint Helicopter Command to map how the 'risks' identified in the inquiry will impact on the Thales Watchkeeper when it eventually goes through operational test and evaluation before it enters service with the Royal Artillery.

The previously undisclosed accident occurred at Camp Bastion's main airfield after the Hermes crew of 57 Battery of 32 Regiment Royal Artillery ordered the air vehicle to return to base after its engine started to overheat.

Plastic deposits in the oil pipes reacted with engine oil to create a build-up of oil residue in a pipe. This starved the engine of oil, causing the accident, concluded the inquiry. The report recommended that the pipes be changed.

The inquiry identified 13 contributing factors that made the accident more likely to happen. These centred on the Royal Artillery's Hermes 450 training system, the selection procedures for UAV pilots, development of airmanship and captaincy skills, as well as the experience and knowledge of supervisors.

The inquiry described the rapid introduction of the Hermes 450 under urgent operational requirement (UOR) funding processes as 'an outstanding success' and said it had 'saved lives'. However, the inquiry criticized the army 'chain of command' for not acting on the findings of an inquiry into an earlier Hermes 450 accident in May 2011, which identified many similar problems.

It concluded that the current army UAV regiment structures and procedures were unsatisfactory' as the "Watchkeeper era beckons" and said "the finding [of the inquiry] may be interpreted as pointing to an organization pushing the limits of their organic air competence".

The report warned that, if action was not taken, there was 'significant risk that these factors could be transferred to the Watchkeeper program'.

A Ministry of Defence spokeswoman said on October 4, 2012 that the MoD was "working to implement the report's recommendations".

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Chinese fighter yet to start flight trails

LOW ON THE RADAR

The J-31 has clearly been designed for a low radar signature (RCS), at least in the front sector. However, it has a two-piece cockpit – a structural feature that increases frontal RCS. It is assumed that the Shen Fei will be equipped with an active electronically scanned array (AESA) radar, but its upswept nose and relatively small radome area reduces the size – and therefore the performance – of any AESA antenna that will be fitted.

The posting of images of the latest Chinese jet fighter on the internet in September 2012 revealed that the Asian superpower is moving fast to field a new combat aircraft featuring advanced 'stealth' or low observable capabilities.

China's Shenyang Aircraft Corporation (SAC) rolled out its prototype advanced fighter design, named the Shen Fei (Falcon Eagle) and it appeared to be designated J-31 because of markings on its tail.

The aircraft emerged from the main SAC factory site over September 15-16, just as US Secretary of Defense Leon Panetta arrived in Beijing for an official visit. Several 'China watchers' declared this was an attempt to upstage the American's tour.

The Chinese government, military or the company have not provided any official information about the aircraft but interpretation of the images has provided several clues about its heritage and technical specifications.

The Shen Fei name is carried prominently on the aircraft's tail alongside a large bird of prey logo and the serial '31001' is painted in bold white digits on the nose, leading to speculation that its designation is J-31 (following the precedent of the J-20 combat aircraft). Unlike the J-20, the J-31 does not have any form of official People's Liberation Army Air Force insignia, leading to speculations that it is a company's private venture, rather than being built to a Chinese military requirement.

From the images it is clear that the Shen Fei bears a startling appearance to the Lockheed Martin F-22 and F-35 aircraft, which apparently confirms persistent reports that Chinese espionage accessed many of these aircraft's classified design details. The twin-tailed, twin-engined aircraft has two ventral weapons bays sized to carry two PL-12 (SD-10) air-to-air missiles in each bay. Seemingly well-informed computer generated images (CGI) on the Chinese internet show the aircraft with eight additional underwing hardpoints.

Initial analysis suggests 31001 is fitted with two Russian-built Klimov RD-93 turbofans, which are non-thrust-vectoring engines in the 19,000 lb thrust class. The engines on 31001 do not seem to be properly installed: the pronounced gap between them and the surrounding structure suggests it is not a flight-worthy configuration and that flight testing has yet to begin.

In late June 2012 the first signs of the Shen Fei emerged when a partially dismantled airframe was driven in a highly visible, almost processional, road convoy from Shenyang to the China Flight Test Establishment (CFTE) at Xian-Yanglian. Widely photographed and filmed throughout its journey, it was assessed to be a static test airframe.

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RAF pilots get smart specs to defeat laser threats

PILOT DANGER

In October 2012 a teenager was arrested in Somerset, UK, on suspicion of endangering a police helicopter by temporarily blinding its pilot and reinforcing the fears of military chiefs that crews of their helicopters and jets could be put at risk in war zones.

A British judge has warned that anyone who shines laser pens at aircraft could go to jail. He made his comment as he handed down a six-month suspended jail term in Belfast, after a man was found guilty of shining a green laser at the pilot of a police helicopter flying in the area in 2010.

British pilots could soon be protected by new 'smart glasses' that stop them being dazzled by lasers as they come in to land or carry out high-risk maneuvers.

Fears that insurgents could use a US$10 laser pen bought over the internet to bring down a US$79 million helicopter loaded with dozens of troops in Afghanistan have prompted scientists at Britain's Defence Science and Technology Laboratory (DSTL) to begin testing new technology to counter this growing threat.

Up to now laser eye protection devices have been able to defeat only a single type of laser but the new glasses developed by Glasgow high-tech firm Thin Film Solutions are able to simultaneously counter multiple laser threats, making them dramatically more effective.

Dr Craig Williamson, principal scientist at DSTL's research center at Porton Down in Wiltshire, said, "There are an increasing number of incidents of inexpensive lasers being used to distract pilots, so we have been researching advanced technologies to mitigate this hazardous and potentially lethal distraction."

Unlike conventional laser protection, which filters out and blocks just one wavelength from the color spectrum, the prototype glasses can filter out a range of different laser wavelengths, allowing greater operational benefits and flexibility for pilots, he said. This is achieved by a attaching a layer of polycarbonate with a special absorbing optical dye and then bonding it to a thin glass lens, which has a special coating capable of reflecting certain wavelengths.

The project work on the glasses is a good example of how funding from the UK's Defence Equipment & Support (DE&S) organization's equipment program can be used to evaluate technology and assess it for potential benefits and uses, said Dr Williamson.

Pete Douglass of DE&S said, "With funding from the equipment programme we were able to ask DSTL to evaluate these new glasses against older, more conventional filters in order to understand the development needs before they would be ready for service," he said. In the case of the glasses, the research highlighted some clear strengths, while also showing some weaknesses of the technology, which we are now addressing with future research."

The work on the glasses has also benefited from an established partnership between DSTL and the USAF, with testing having taken place in May of this year. Dr Williamson said, "the bilateral work at the United States Air Force Tri-Service Research Laboratory in San Antonio proved to be invaluable. The results from this human performance testing on spatial detection and color perception have set the benchmark for future work, and we're hoping that further bilateral funding will be available to research the next generation of eye protection in the coming years."

Further testing is to be conducted later this year, including optical performance and environmental testing by DSTL, and laser dazzle and performance testing at QinetiQ.

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Droning on

A professor of aeronautics and astronautics at Massachusetts Institute of Technology (MIT) has conducted a study into UAV operator fatigue and discusses how to beat pilot boredom

BY JENNIFER CHU

ABOVE: MQ-1 Predator UAV as used in aggressive military operations

ABOVE INSET: Drone operators at work (US Department of Defense)

On the surface, operating a military drone looks a lot like playing a video game: operators sit at workstations, manipulating joysticks to remotely adjust a drone's pitch and elevation, while grainy images from the vehicle's camera project onto a computer screen. An operator can issue a command to fire if an image reveals a hostile target, but such adrenaline-charged moments are few and far between.

Instead, a drone operator, often a seasoned fighter pilot, spends most of his shift watching and waiting, as automated systems keep the vehicle running. Such shifts can last up to 12 hours, as is the case for operators of the MQ-1 Predator, a missile-loaded UAV used by the US Air Force for surveillance and combat.

"You might park a UAV over a house, waiting for someone to go in or come out, and that's where the boredom arises," says Mary Cummings, associate professor of aeronautics and astronautics at Massachusetts Institute of Technology (MIT) and leader of the test study. Cummings says such unstimulating work environments can impair performance, making it difficult for an operator to jump into action in the rare instances when human input is needed. She and researchers at MIT are testing how pilots and operators interact with automated aerospace systems, and are looking for ways to improve UAV performance.

In a study, Cummings's team found that operators working with UAV simulations were less bored, and performed better, with a little distraction. While the study's top performer spent the majority of time concentrating on the simulation, the participants with the next-highest scores performed almost as well, even though they were distracted nearly one-third of the time.

The test program findings suggest that distractions may help avoid boredom, keeping people alert during otherwise-tedious downtimes. "We know that pilots aren't always looking out of the window, and we know that people don't always pay attention in whatever they're doing," Cummings says. "The question is: can you get people to pay enough attention, at the right time, to keep the system performing at a high degree?"

KEEPING BOREDOM AT BAY

An experiment in which participants interacted with a UAV simulation in four-hour shifts was set up. During the simulation, subjects monitored the activity of four UAVs, and created 'search tasks', or areas in the terrain for UAVs to investigate. For hostile targets, subjects issued a command for a UAV to fire, destroying a target and earning points in the simulation. The researchers video-taped each participant throughout the experiment, noting when an operator was engaged with the system, and when he or she was distracted during the tests and facing away from the computer screen.

The person with the highest score overall was the one who paid the most attention to the simulation. "That's the person we'd like to clone for a boring, low-workload environment," Cummings says, but such a work ethic may not be the norm among most operators. Cummings and her colleagues found that the next-best performers, who scored almost as high, were distracted 30% of the time, either checking their cellphones, reading a book, or getting up to eat.

The team also found that while the simulation only required human input 5% of the time, most people "made themselves busy" in the simulation for 11% of the time, an indication that participants wanted more to do, to keep from getting bored.

PERSONALITY COMPLEX

Cummings says personality may also be a consideration in hiring UAV operators. In the same experiment, she asked participants to fill out a personality survey that ranked them in five categories: extroversion, agreeableness, conscientiousness, neuroticism, and openness to experience. "You could have a Catch-22," Cummings says. "If you're high on conscientiousness, you might be good at watching a nuclear reactor, but whether these same people would be effective in certain military settings is unclear."

Cummings's group is continuing to run test experiments to tease out conditions that may improve performance and discourage boredom. For example, periodic alerts may redirect an operator's attention. The group is also looking into shift duration, and the optimal period for operator productivity."

Jennifer Chu is a technical and news writer for Massachusetts Institute of Technology


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GARNET RIDGWAY

Does size matter?

Two former colleagues from the Flight Science and Technology group at the University of Liverpool discuss how marketing and sponsorship can seriously affect test and development programs. Go big, or stay small?

SOPHIE ROBINSON

To make an impact in aerospace testing, size doesn't matter. A simple proof-of-concept testing exercise can punch well above its weight in terms of attention from the media and customers.

For example, a demonstration earlier this year caused the generation of the headline: "Flying robots build a 6m tower." This consisted of a fleet of quadrotor UAVs lifting polystyrene blocks into locations predefined by the design blueprint. To add to the dramatic effect, the tower took the form of an elegant white obelisk designed by a team of German architects, and construction took place in a room full of onlookers. This highlights a key benefit of small-scale aerospace testing: it can be simple and inexpensive but still draw a crowd.

The UK-based Bloodhound Supersonic Car (SSC) project recently undertook the first test firing of its main rocket motor, designed to propel the car to speeds in excess of 1,000mph. Although spectacular, the test was not large in scale by aerospace standards. However, every opportunity was taken to publicize the event and to provide media exposure for the project partners – their logos were actually emblazoned on the test rig. The event was streamed live over the internet, with headlines screaming: "Largest rocket fired in the UK for 20 years."

The key lesson here is that the public still take an interest in aerospace tests when given the chance. Admittedly the Bloodhound SSC project aims specifically to raise awareness of science and engineering, but perhaps the concept could be transferred to other areas of the aerospace world. A live webcam broadcast from the cockpit of the Airbus A350 during its first flight? Commercial confidentiality issues aside, it would provide the media with an event to get behind at almost no expense to the company – and media attention sells aircraft.

In closing, an example of the smallest possible scale of aerospace testing. Bad Piggies, the latest offering from Rovio (makers of the highly addictive smartphone app Angry Birds) challenges users to build machines from a set of standard components in order to transport a cartoon pig across various obstacles. It may sound like child's play, but fundamental concepts of lift and drag are faithfully modeled to give a hugely demanding experience (including the need to build and pilot a rocket-powered compound helicopter!). If more evidence is needed to show that the public are interested in small-scale aerospace testing, consider the number of downloads for this simple piece of software: 10 million and counting. Aerospace PR departments, take note! ∎

Garnet Ridgway has a PhD from the University of Liverpool. He has designed cockpit instruments for Airbus, and is currently a senior engineer at a leading UK-based defense company

A recent example of size that matters is the Red Bull Stratos project, which saw Austrian daredevil Felix Baumgartner freefall from over 24 miles above the earth. Felix broke world records for the highest manned balloon flight and the highest freefall (from 128,100ft), as well as becoming the first man to break the sound barrier without mechanical assistance (reaching a speed of 833.9mph, or Mach 1.24). The jump was streamed live online and smashed YouTube's record for a live-view event: over eight million people tuned in to share in Baumgartner's stratospheric dive.

The event demonstrates the overwhelming power of large-scale testing to attract attention to a product or brand. Red Bull hasn't revealed how much the jump cost to stage (it's rumored to have been around US$65 million), but it is projected to recoup sales of a similar magnitude. If events like this don't have any obvious financial benefits, why do companies invest such large amounts of money in what could be described as grandiose marketing exercises? Simply for prestige.

Companies invest millions of dollars annually to enhance the prestige of their brand. In the past year Red Bull invested over US$320 million in its Formula 1 operation for this very reason. So why not combine testing and marketing and capture the imaginations of prospective customers in the same way the Stratos event did? Smaller events simply do not have the same potential for return; you really do get what you pay for!

Airshows serve a similar purpose, serving as a forum for test and demonstration of new aircraft, while simultaneously being an ideal marketing exercise for the companies involved. Going 'big' is standard practice for these types of events, with companies wining and dining prospective customers, even in the current economic climate. So prominent is this culture that it led to the Defense Analysis newsletter publishing a wine review as part of its write-up of the 2011 Paris Airshow (MBDA's wine choices were 'kooky' but 'quaffable' and Thales served a delicious Burgundy, if you were wondering). By the end of the event, Airbus had sold more than 500 new A320s, netting the company several billion dollars.

Ostentatious testing programs can, and still do, serve a purpose in modern engineering, whether they are purporting to advance the understanding of the human body at high altitude, or just elevating a brand. ∎

Sophie Robinson has a PhD from the University of Liverpool and currently heads up its Flight Science and Technology research group, based within the Centre for Engineering Dynamics. In the course of her research, Sophie regularly works with test pilots

Time for CIASTA

Bombardier's CSeries program may be suffering delays, but the manufacturer's revolutionary approach to systems testing is keeping it one step ahead in the flight test game

BY PAUL E. EDEN

At the Farnborough International Airshow in July 2012, Mike Arcamone, president of Bombardier Commercial Aircraft, told the author that he expected the first flight of the new CSeries single-aisle airliner "in the New Year". The inference is that though the company continued to make noises about having the aircraft in the air before the end of 2012, consideration was already being given for a first flight slip into 2013.

Of course delays in new aircraft programs are nothing unusual, especially when the airframer is bringing a new airframe and engine combination to market. The media delights in every problem, but few remember that Boeing, for example, first flew the 707 in 1954, then had to take it away and redesign it because it was too narrow for the six-abreast seating the airlines desired. It recovered from the resulting four-year delay, but not without having lost almost all its advantage over Douglas and the DC-8.

On November 7, 2012, Bombardier announced a nominal six-month delay to the maiden flight of FTV-1, the first CS100 flight test vehicle, to June 2013. Without pointing fingers, the Canadian manufacturer stated that supplier issues were the cause of the slip, which will result in the first CS100 customer delivery around June 2014. The larger CS300, subject to the majority of orders, should still reach its first customer on schedule late that same year.

CIASTA SYSTEM

While manufacturing delays are, perhaps, inevitable, today's aircraft builders have a major advantage over a 1950s-era Boeing; a great deal of their test work can be conducted off-airframe, with detailed, flight-critical analysis taking place on laboratory rigs. For many years the 'iron bird' has been an important component in the test process. Varying in scale from a bench rig using actual aircraft systems to manipulate generic flight controls and other items, right up to a non-flying airframe, the iron-bird concept has never been exploited so thoroughly as with the CSeries.

Bombardier's primary CSeries test rig has been set up at its Mirabel plant, as the Complete Integrated Aircraft Systems Test Area (CIASTA). Combining various test rigs and laboratories, CIASTA is in effect a virtual aircraft that can be flown by a regular flight crew and, ultimately, populated by regular 'passengers'.

Occupying a 5,760m² (62,000ft²) facility, CIASTA houses and combines the Integrated Systems Test and Certification Rig (ISTCR), Engineering Simulator (ESIM), Systems Integration Test Stand (SITS), Flight Controls Integration Lab (FCIL) and Environmental Cabin Systems (ECS) rig. Both the SITS and the FCIL were initially commissioned off-site, Rockwell Collins bringing the SITS into operation at its own facility, while Parker Hannifin did the same with the FCIL.

Individual equipment items from Bombardier's suppliers are integrated into the whole, so that CAE, Goodrich Actuation Systems, Hamilton Sundstrand, Honeywell, Liebherr-Aerospace, Parker Hannifin, Pratt & Whitney, Rockwell Collins, and others all have a CIASTA part to play. Furthermore so do their engineers, since all these suppliers have personnel stationed on-site, alongside their Bombardier colleagues.

Rob Dewar, vice president and general manager of the CSeries program, explains that CIASTA will include a representative passenger cabin, with environmental control, although the possibilities for testing pressurization in the rig are limited for safety's sake. The cabin will have water and waste services, however, as well as trialing the innovative seating arrangements that Bombardier is introducing.

From the passenger perspective, Bombardier has to get its in-flight entertainment and connectivity offering right and although CIASTA features both, this is one area where only a flying aircraft will do; several key functions, including satellite capture rate, must be tested throughout the flight test envelope and cannot be fully analyzed on the ground. According to Dewar, full IFE function will be assessed on a dedicated flight test vehicle, FTV-5, while the ECS will enable airline cabin staff to test IFE operator functionality and component utility.

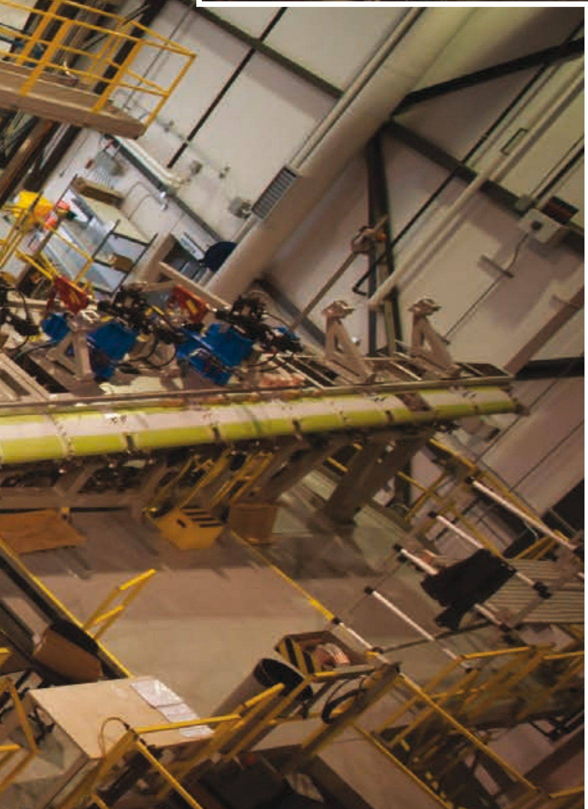
CUSTOMER SATISFACTION

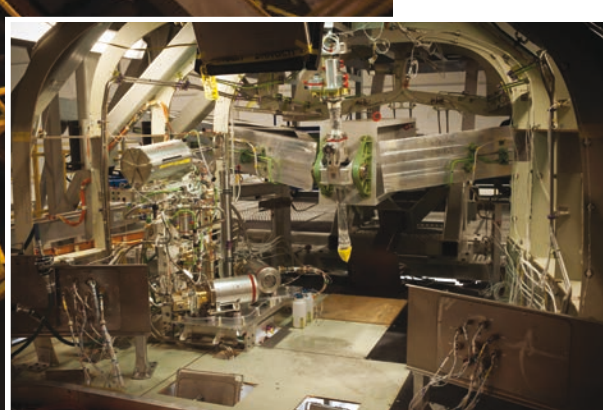
CIASTA is a vital tool in offloading tasks from flight testing and though it allows Bombardier to maintain momentum even as its airframe is delayed, the company is also looking to the rig to identify the potential for

"IN A FIRST FOR THE INDUSTRY, EVERY MAJOR SYSTEM AND PIECE OF SOFTWARE INCORPORATED INTO CIASTA IS PRODUCTION STANDARD"

CSERIES PROGRAM MILESTONES

JULY 2008	MARCH 2010	MARCH 2010	MAY 2012
Program launch	First test article – Shenyang produced fuselage barrel – delivered to Saint-Laurent	Demonstrator wing testing began in Belfast	CIASTA hydraulic system commissioned





ABOVE: The hydraulic test rig sits within 'the system of systems' that comprise CIASTA

LEFT: The ISTCR component of Aircraft 0, or CIASTA, back in May 2012, before it had been formally commissioned

BELOW: The hydraulic system test rig sits within the system of systems that comprise CIASTA

longer-term maturity issues. In a first for the industry, every major system and piece of software incorporated into CIASTA is production standard, helping the manufacturer mitigate risk ahead of first flight.

Talking about Bombardier's wider aspirations for CIASTA and its implications for the CSeries at service entry, Dewar notes: "We've committed to delivering a product that meets the expectations of our customers out of the box. To do that we do simulation and global systems testing, but to make a step improvement we've committed to having a complete system fully integrated on the ground. Basically it's a cabin and other systems, using full production parts."

Aircraft 0's electrical system was commissioned early in 2012, with the hydraulics coming on stream during May. "This was an important milestone," says Dewar, "enabling the operation of the actuation systems for the aircraft's flight control surfaces, thrust reversers, and landing gear."

CIASTA's ISTCR was then commissioned and 'flown' for the first time on August 22, 2012. "The interior will be commissioned by the end of the year," Dewar says, "with testing continuing for about 12 months. We'll have passengers in the cabin early in 2013. Airlines will also be sending their crews in for a big shakedown, making sure that everything we've designed and built is working and that the reliability and functionality of this system is working."

TEST PROCEDURES

The level of importance Bombardier attaches to CIASTA is evident when Dewar refers to the rig as Aircraft 0. But function and maturity testing aside, does CIASTA provide a deeper understanding of CSeries systems in a less than perfect, real-world operating environment? Can it be influenced by outside sources, with engineers introducing failures, for example? And, on the other hand, can it be influenced to improve the efficiency of particular subsystems while it is running?

On all counts, Dewar's response is affirmative: "We primarily use CIASTA to validate system integration from both a software and a hardware perspective, thereby enabling us to substantially increase the maturity of the systems prior to first flight and entry into service.

"We can definitely introduce failure cases on CIASTA. This is necessary in order to validate the interaction between various systems under certain conditions. During the testing phase we continue to build maturity and optimize all the systems. And, in addition to the CIASTA/Aircraft 0 and CAST vehicles, there are about 200 suppliers' testing rigs commissioned, or being commissioned, for data collection and analysis for the testing phase."

THE CAST

The CAST (complete airframe static test) vehicle was assembled at Bombardier's Saint-Laurent, Quebec, Experimental Test Facility during the autumn. The assembly work had been tested extensively on a full-size wooden mock-up, where engineers were able to test fit and refit mocked-up components, identifying problems before working with production-standard parts.

The CAST vehicle has key static test functions, as well as a crucial role to play in the certification program. Given the aircraft's advanced aluminum-lithium fuselage construction and large composite sections – including the wings and aft pressure bulkhead – and, perhaps, the fact that fuselage sections are being supplied from manufacturers as far apart as Northern Ireland and China, CSeries static testing carries considerable weight. Early reports are that assembly was seamless, although some commentators note that Bombardier has struggled with Shenyang's center fuselage and wing box components and, indeed, some work has been temporarily moved from China to Belfast.

The CAST airframe will be subjected to a series of tests where 'load cases' will be applied, simulating sets of stresses that the operational aircraft is likely to encounter in particular scenarios through all phases of flight, as well as on the ground. Multiple strain gauges mounted around the static test vehicle collect data on as many as 8,000 parameters for careful

AUGUST 2012	JUNE 2013	JUNE 2014	LATE 2014
ISTCR initial 'flight'	Revised projection for first airborne flight	Projected CS100 entry into service date	Projected CS300 entry into service date

real-time monitoring, as well as subsequent analysis.

By mid-October 2012, with CAST assembly entering its final stages, major components for FTV-1 (construction number 50001) coming together and CIASTA returning test data, Dewar was delighted to be able to sum up: "The CAST, FTV-1, and Aircraft 0 are all key elements in the testing and development of the CSeries aircraft and we are delighted with the progress on each of these three test platforms."

Speaking about the aircraft's carbon-fibre wings, he explained that they had already been through a vigorous structural test process even before being assembled to the CAST fuselage: "Subsequent to the extensive research and test program at Bombardier Aerospace Belfast, which was used to optimize the final production design for weight and performance for the wings, the CAST will be used to confirm their static strength along with that of the other components of the airframe."

In fact Belfast began testing a demonstrator wing early in 2010. An extensive program of test and evaluation had already examined individual wing components, before a full-size pre-production demonstrator wing, produced using Bombardier's unique Resin Fusion Transfer Infusion process, was commissioned.

Although extending to just 75% of the span of the production wing, the demonstrator replicated the outer-wing to center-wing box joint, as well as its assembly to the center fuselage. It also featured a simulated undercarriage leg and engine pylon, with the whole test piece mounted in a specially designed rig for the application of controlled loadings. Representing a major investment, the demonstrator and associated rigorous testing program provided real test data, which enabled optimization of the final CSeries wing design.

Describing the level of functionality reached by CIASTA by the second week of November 2012, Dewar was able to reveal: "The ISTCR comprises all key systems on the aircraft with the exception of systems that could not be installed for safety reasons; running engines with actual fuel circulating in the fuel system, for example, could create some real safety constraints. Instead, in the case of the engine, though it is being tested by Pratt & Whitney, we do have an actual engine gearbox to replicate the power generated by the engine for powering other systems.

We also have a complete cabin interior and environmental control system rig, which will be used primarily for air flow control and balancing. This will help test our cabin management system.

"The strategy is that by testing early and up front, we can substantially increase the maturity of the interior systems to provide exceptional experience to our customers at entry into service. We collect data in real time and we also use this data for 'post-flight' analysis. The results from Aircraft 0 so far are as expected. The feedback being collected from all the test sites – ours and those of our suppliers – is very positive and we're making solid progress, having already met a number of key milestones, with CIASTA running 20 hours a day, seven days a week." ∎

Paul E. Eden is a UK-based writer for Aerospace Testing International *and also a specialist freelance writer and editor in the aviation industry*

BELOW: With the fuselage of the CAST airframe completed during September 2012, assembly work, including adding the wings, continued into October

Total impact

Aerospace Testing International has an exclusive look behind the scenes of one of the most important test experiments in recent decades – the crash into the Mexican desert of a remotely controlled Boeing 727

BY LELAND C. SHANLE JR

A unique and highly successful four-year flight-test program closed in April 2012. It was designed to verify the industry-standard component-based testing and its application to passenger survivability, and to validate external control of an airline-sized aircraft for future application. A project executed by a small team with a tight budget is nothing new; however being sponsored by television is, and it is only now that we can write about it.

The task was to use an instrumented, full-sized airliner drone and fly it on a specific profile to impact, achieving three passenger survivability zones (fatal/catastrophic/walk-away) while evaluating component-based testing and the drone system. Further requirements were that there would be no fire and that it would all be captured on film. It was a Category D flight test with a huge added distraction – television.

The first priority had to be getting the core team together; external 'distractions' would also have to be factored in. Broken Wing was built around a core of five members. I first called Dave Kennedy, SETP (Society of Experimental Test Pilots) and together we picked Morris 'Barney' Barnet to design and install our drone system, Bill Warlick (SETP) to write the test plan and finally Forrest Murray (producer) to handle any distractions. The team would have a very fulfilling and interesting four years together.

THE FIRST TEST TASK

Broken Wing first had to evaluate the task within a very tight budget of less than US$900,000. It would be a finite amount with no possibility of cost overruns. The drone system would have to be off the shelf as much as possible. For the profile we would have to configure the aircraft for landing. For safety and to get regulatory approval we would have to limit the time of No Onboard Live Operator (NOLO) flight to an absolute minimum. The solution was to keep the crew on board and have them bail out on the range at the minimum safe altitude. Next we needed an appropriate aircraft. After searching aircraft facilities from Fort Lauderdale, Florida, to Victorville, California, the

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GETTING THE MOST FROM INTENTIONALLY CRASHING A PASSENGER JET

The phone rings and I'm asked an unexpected question. Given the chance to crash a passenger jet, could I make it worthwhile? The crash would be useful from an investigation perspective, but laboratory-type experiments and tests in this real-world crash environment would be truly special.

Floor accelerations came immediately to mind. Passenger interiors are challenging and costly for the aviation industry and government regulators. The designs and certification are based on a simple but broad assumption: that a generic impact pulse reasonably represents a real survivable crash. This was a unique opportunity to test that assumption. Four years later several experiments were in place to be featured on the TV documentary *Plane Crash*.

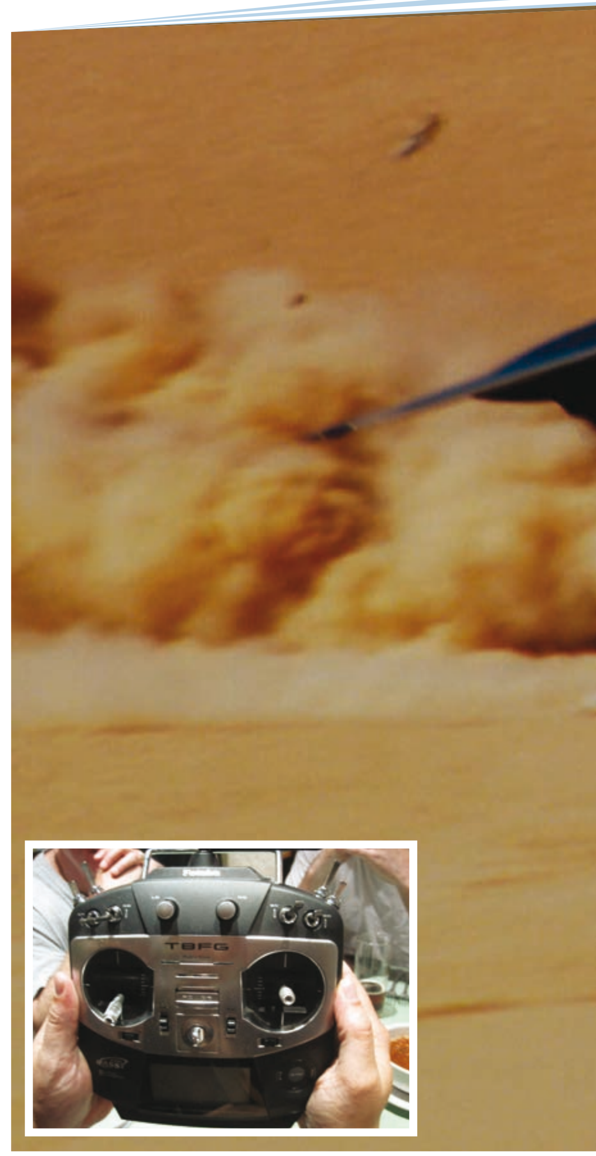
Tri-axial accelerometers were mounted on floor track in three locations to compare engineering theory with real-world survivability. Three fully instrumented Hybrid III crash-test dummies, high-speed video, and cargo floor time-displacement measurements were also included along with some low-tech sand-bag dummies and baggage placed in the overhead bins. Several options were explored for triggering, capturing, and retrieving the data. Most uncertain was the post-crash environment. Site safety and the worse-case scenario of fire suppression caused safety advisors to estimate a 3- to 12-hour delay in accessing the aircraft and our fire-proofed data-collection box.

The accelerometers were the most robust, featuring a long recording window and data retention capability after loss of power. The cameras and crash-test dummies had a higher risk of data loss and physical damage. We hoped the equipment would survive, but recognized that anything could happen.

The dramatic crash ripped the cockpit and the first several rows off the aircraft. Fortunately there were no dummies or instrumentation there due to the space needed for the remote-control mechanism. Data was collected from the intact and survivable portions of the cabin and was not of interest in areas that were clearly not survivable.

The highest crash forces and potential for severe injury occurred at the front, with moderate injury potential over the wing, and minor at the back. The generic impact pulses used to design and certify aircraft interiors appear to be appropriate. Most on board could have survived if they had been wearing a seatbelt, and many would have had only minor or no injuries. The experiments helped confirm what many don't realize: flying is a fantastically safe way to travel and most people on board will survive even if the plane crashes.

Thomas Barth, PhD is an accident investigator for the National Transportation Safety Board and previously the director of R&D for AmSafe Aviation in the USA



team decided on a Boeing 727-212 (N293AS). This model would give easy egress from the aft hatch with the door removed. The specific aircraft had been in service with Champion Air just 18 months previously. With the same cockpit and fuselage as the popular 737, it was applicable to modern aircraft and therefore the data points would transfer direct to existing fleets.

Cost considerations drove the engine selection – a Pratt+Whitney JT8D-9. There was a pending AD on the turbine section and the aircraft was not certified with the -9 variant, simply because it was an older model engine. The -17 was the normal engine on the 212 series. Certified Air Services (CAS) developed an AMOC (alternate means of compliance) and it was approved by the FAA with a limit of 20 hours of operation. After King Aerospace rehung the engines, N293AS was ferried to San Bernardino for maintenance and modification. We named her Big Flo.

A modified C-check was designed by CAS and approved by the local FSDO. While the maintenance was being performed, N293AS was instrumented for experiments and the drone package installed. The rest of the team continued down a timeline of major milestones:

- Aircraft decision point;
- Aircraft purchase and ferry;
- Maintenance and modification;
- Regulatory compliance;
- Location selection;
- Exportation/DGAC regulatory compliance (added after location decision point);
- Flight test plan;
- Ground/flight test 1;
- Flight test 2;
- The big week.

Laguna Salada, a large dry lake bed, was selected for the impact zone. Being in Mexico it would necessitate close coordination with the DGAC and the export of N293AS. This added complexity, but Broken Wing determined that Laguna Salada was the best location. It is large, flat, has excellent weather and most importantly is ringed by mountains for containment. Captain Sean McDonald and Flight Engineer Gerry Dearie were brought into the team for the initial testing. With Bill acting as first officer

ABOVE INSET: The simple remote control used by Leland C. Shanle to control the 727 from the chase plane

© Discovery Channel

they would form the QB-727 flight test crew. After exporting N293AS to Mexico the aircraft became XB-NMP.

MOVE INTO OPERATION

The flight test plan was finalized once the QB-727 was in place at Mexicali Airport and Laguna Salada was decided on as the impact zone. A standard build-up approach was employed: a series of static ground tests followed by a series of flight tests. With the QB-727 a chase plane was flown at varying distances while remotely manipulating the controls to establish the envelope. Throughout the initial system testing, Forrest kept the distraction of filming to a minimum.

One last flight test remained before hitting a very important milestone and further funding. Broken wing had to prove to the sponsors, Discovery and Channel 4 (UK); Prosieben (Germany), that we could control the QB-727 from a chase aircraft.

Designed with a multitude of backups, the system eliminated any single point of failure. Two chase aircraft with two separate controllers were backed up with a totally independent secondary control system (with its own controller) that was designed to keep the QB-727 on the range. Engines 1 and 3 were set statically in a very low power range. Only engine 2 would be manipulated; this thrust configuration would not allow the QB-727 to maintain level flight even in the event of a number 2 full throttle run away. The geographic location (circled by mountains) would act as the final failsafe.

Broken Wing's system tapped into the existing flight controls without damaging them, enabling normal flight up to engagement. Dual gain servos would provide the fidelity required to maintain the profile and put the aircraft into the 9,000 x 500ft impact zone. Redundancy would be maintained with multiple aircraft, controllers, and the 'Deep Six' back-up system already detailed. The team and system were ready.

After traveling back to Mexicali in March 2012, the team put the QB-727

ABOVE: **the first 11 rows of seats are ripped out as the nose of the airplane dips and the front of the fuselage is sheared off**

into the air and controlled it from a Cessna 337 Skymaster. Nulled perfectly, Barney's system engaged so benignly at first that neither the QB-727 crew nor the chase crew could tell that control had been transferred. A series of turns and descents were completed and the flight test was deemed a complete success.

Three data points were gathered that would affect the final event. First, the 337 was too slow; second, the effective range was less than the ground test envelope; and finally, the video targeting system was unusable. Broken Wing addressed these issues by securing a faster aircraft that would keep up with the QB-727 and fly comfortably close in for reception and visual targeting. After a detailed test report was reviewed by the sponsors the decision was made to go.

FINAL TEST PROGRAM

A month later the team journeyed again to Mexicali and was joined by the 400 members of the Dragon Fly and Discovery Production Teams. Previously we had been videoed by small film crews. The distraction was very real initially, but we had contractually maintained the last word on safety, so we felt confident that our primary objective could be met. Through out the entire program our objectives were unchanged: safety, science (hitting the profile), and capturing as much as we could on film.

Again we went with a build-up approach. The team's air force consisted of an A-23 Musketeer for range safety and weather reconnaissance. The C-337 Skymaster would be the back-up chase and test conductor, and an SF-260TP Turbo Marchetti would act as primary chase. Four jumpmasters had also been brought on board as well as a new 727 captain and desert ground crew.

Sean McDonald was moved to range safety; his intimate knowledge of all aspects was the choice for him to monitor Objective 1. His co-pilot was David Shanle. Quentin Weiskittel would pilot the C-337 with Broken Wing chief test pilot Dave Kennedy acting as test conductor and backup chase/controller. Chris Joachims and I would man the primary chase and

THE BIG QUESTION: WHY?

Why did we crash a perfectly good, albeit retired, Boeing 727 in the Sonora Desert? Was it for television ratings? Some people might say so. Investors expect a reasonable return, and without them we couldn't have put this project in the air, much less drop the QB-727 into a dusty lake bed lined with high-speed cameras. But that wasn't the motivation for our 23-person Broken Wing team – and it certainly wasn't my motivation.

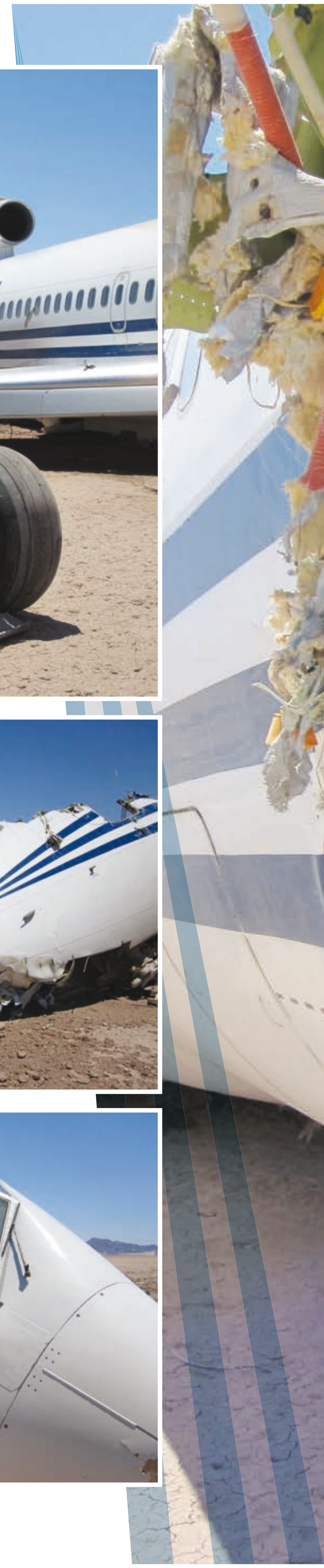
In 1996 my fiancée Susanne was one of 230 passengers and crew who died on board TWA Flight 800 when it blew up off the coast of Long Island. That Boeing 747 was dredged from the Atlantic Ocean floor and 876 pieces were reconstructed over subsequent years in a hangar in Calverton, New York. It was the USA's largest and most expensive aircraft investigation, yet no definitive answer was obtained.

Via experiments and recording equipment, crashing the QB-727 was an opportunity to put researchers on board an aircraft as it crashed. As a career airline pilot, who has seen the ultimate loss when safety fails, and felt the strain of living with the cause remaining unknown, I couldn't imagine not participating in this event once presented with the opportunity.

My greatest hope is that there will be at least one less fatality, and one less mourning survivor in the future of aviation as a result of this work. There's a catchphrase in the airlines: "Safety is no accident." In this case it was a deliberate aircraft accident performed by a team of professionals.

Mark Berry is an airline pilot and co-project leader on the 727 crash

ABOVE: A force of 12*g* was recorded in the front of the remaining cabin while, further back in the plane, the force dropped to 6*g*



control the QB-727. The new QB-727 captain was Jimbob Slocum. His skills as an experienced sky diver were needed for the final test.

The operational test plan was simple: execute an in-flight pick-up with the SF-260TP as the QB-727 rotates. Proceed as a flight of two at 6,000ft to Laguna Salada, 48 nautical miles due south. Then make a coupled practice run down to 200ft AGL over the dirt runway cut into the desert floor. Climb back to 6,000ft, egress the first officer and flight engineer on downwind in tandem harnesses with their jumpmasters.

Then turn to final approach, couple up and descend toward the impact zone. At 4,000ft Jimbob exits the cockpit, the last jumpmaster activates the Deep Six system (covered toggle) next to the rear exit and both egress the aircraft at 2,500ft AGL. Chris maintains position on the Marchetti as I guide the QB-727 down the glide slope and at 800ft go to idle on engine number two. Range safety monitors from 8,000ft while Chase 2 dives from 7,000ft to maintain a position on the right wing as backup. So simple.

BIG WEEK

Again we started with a standard build-up strategy. On day one we flew the entire profile twice, with the C-337 Skymaster acting as the QB-727 and the A-23 Musketeer as Primary Chase. As well as dusting off formation skills we had an important realization. With Chris flying formation and I controlling the QB-727, no one would be monitoring the altitude. It became critical because of a lack of visual queues over the lake bed. After debriefing, the plan was changed to have the backup chase plane join the primary in cruise formation to monitor altitude and transmit it at specific distance check points.

We continued to progress through the week: the practice jumps from the QB-727 went flawlessly, as did controlling her down to 400ft from the SF-260TP. The biggest discovery for the week was that the earlier we were over Laguna Salada the better, due to wind and thermals.

After a perfect full test run, Broken Wing was set for the final experiment. A final brief was conducted pool side with beer and pizza, and the crew retired early. Overnight a second full rehearsal was demanded by insurance monitors. The team, though not happy, complied after making it clear that it was an unnecessary risk and the aircraft had miraculously held up to that point.

We were now up against the wall; wind had cost us one day and the second full rehearsal took our slide day. By the end of the day the team and the insurance would turn into pumpkins, regardless of whether the experiment was complete.

FINAL DAY

Dave Kennedy and I discussed the fleet over coffee in the lobby of our hotel. We had visions of the QB-727 shearing a starter shaft, which would have ended it all. Flight plans were filed, crews walked, the air was still. Each time one of the aircraft rolled down the runway I checked my watch: T-00:45 the A-23 rotated on time. T-00:15 the C-337 rotated on time. I sat in the SF-260TP straining to hear all three engines of the QB-727 light off. Chris and I exchanged smiles and he cranked up the Allison of our Marchetti.

It whined to life with all gauges in the green. Out of my peripheral vision I saw our mechanic Ray Myallya start to shake his head and then slash a hand across his throat. An internal seal of the mechanical fuel pump had blown, the Marchetti was done. Forrest was watching from the tower and had the controller radio the QB-727. Dave Kennedy was on the common frequency and heard the transmission. He immediately turned north to RTB and radioed to Sean overhead, "You've got it Mac."

Sean and David dropped the A-23 down to the test conductor's altitude as Kennedy and Quentin raced back to Mexicali Airport. I climbed the steps and entered the cockpit to discuss options with Bill; there was only one. We had to try it with the C-337 as Primary Chase. Descending the steps, I looked up to see the C-337 on final. Grabbing the controllers, Chris and I ran to the turning aircraft. As Dave got out we stood silently; after four years he would be left behind. Chris ran up next to us; "Come on, we can do this!"

We rolled as fast as we could, the fuel clock was ticking and the wind would be building. Our tandem jumpers needed 15kts or less, so time was critical. The QB-727 gave us a 15-minute head start; the plan had to be modified. We would dive down on the QB-727 to get in position as she entered the range. It almost worked; at maximum power the C-337 stabilized aft in a cruise formation position, but 500ft low. Jimbob lowered his altitude and we were aboard. I flew inside the QB-727's radius of turn to maintain position.

All images on this page © Discovery Channel

On final of the practice run I turned the C-337 over to Chris and Jimbob and I began the checklist; once coupled we started down the 1,000fpm glide slope at 15 miles. In the descent we could maintain position adequately. At 400ft over the desert runway Bill radioed from the QB-727: "Are we a go?"

"We are a go!"

I immediately turned the aircraft south toward the Sea of Cortez as the QB-727 climbed to the drop altitude of 6,000ft. There was no way the anemic C-337 could stay with her. We had to get in position to dive down on her again. As we climbed we heard the transmissions "Jumpers away" and "two good canopies". With no radar or GCI we had to do a visual join up. I used an old F-4 Phantom trick and looked for the smoke of the JT8D-9s. It worked again after all these years. We dived into position and repeated the run in. Once coupled we began to slip back; Jimbob slowed the QB-727 speed by 2kts, to its minimum speed of 122kts and we stabilized. After four years and it was all decided by two knots of airspeed.

ABOVE: Since the crash was aired on television, reports have indicated a drop in front seat airliner bookings

When the SF-260TP went down we knew our accuracy would be affected. The profile had been planned and practiced at 140kts and we were almost 20kts below that. The 1,000ft high-speed camera pit was no longer feasible but I was confident we could hit the impact zone safely. We pressed on. At 4,000ft Jimbob left the cockpit and the Deep Six mode was activated; I now had irreversible control of the QB-727. At 2,500ft his smiling face flashed past the C-337. Sean and David had got the A-23 Musketeer into position as test conductor and dived with us toward the impact zone, calling the cadence. Approaching 1,000ft AGL, it was obvious that we would be short of the high-speed camera pit. We had achieved our first objective by safely arriving to this point; our secondary was to hit the profile for the science. At 800ft I let her go and pulled engine 2 to idle.

The QB-727 dropped out of the sky dramatically, impacting flat with wings level, as planned to minimize the potential for fire, in the middle of the 9,000 x 500ft impact zone at 1,500fpm. The contact seemed to be in slow motion as the main gear sheared and she bounced slightly off her fuselage. The nose gear was driven up and compromised the structure just aft of the cockpit; she shed her nose. Internally the trigger system fired and an incredible amount of data was recorded.

IMPACT!

Airborne cameras captured the event; all three objectives were met. Surprisingly two of the Pratt+Whitney JT8D-9s (1 and 2) were still running at high power as we returned to base. Mission complete, the Broken Wing Team scattered quickly; there was no time to celebrate. Perhaps after our next project? ∎

Leland C Shanle Jr (SETP) is CEO of Broken Wing, test pilot, author and a retired Lt Cdr US Navy. He is based in the USA.

BEHIND THE TRIAL

The purpose of the test was to replicate a representative aircraft landing mishap, provide a platform for scientific safety experiments. The aircraft was to be operated unmanned only during the final five minutes of flight, configured for landing to a controlled impact with terrain. A limited authority remote control system that included a separate flight termination system was incorporated.

Ground and flight tests were completed to verify functionality of the remote control system, evaluate electromagnetic interference (EMI), map reception range and evaluate receiver saturation. Pitch and roll response were very smooth. Throttle response was adequate with definitive but consistent lag. No EMI or receiver saturation were observed. 7.1 hours of flight test concluded with the aircraft impacting within the cleared kinetic impact zone approximately 4000ft short of the intended impact point, slightly nose low at approximately 130 KIAS with a rate of descent of 1500ft-per-minute. The aircraft broke into two major sections with the cockpit shearing off on impact.

After impact the Number 1 (left pod) engine ran for approximately 15 minutes and the Number 2 (center) engine for approximately one hour and 15 minutes before shutting down due to fuel starvation. All test objectives were met.

Bill Warlick, flight plan author and US Navy Test Pilot School instructor

Emission critical

North America is a hotbed for the development of alternative fuels and the engines they power. *Aerospace Testing International* investigates how fuel quality is being improved and emissions reduced

BY JOHN CHALLEN

Regular references to increased efficiency, better fuel economy, and cleaner skies are nothing new in the aerospace sector. But now, more than ever, there seems to be an even greater desire by regulators, engine manufacturers, researchers and engineering institutes alike to address these issues and push forward measures that will help make the industry greener.

There have been raised eyebrows regarding the use of alternative fuels to power airplanes, but studies into the fuels themselves, as well as their performance, are continuing around the world. Such studies include NASA's Alternative Aviation Fuels Experiment (AAFEX), which dates back to 2009 when a team of researchers tested a fuel made from natural gas feedstock and another from coal.

The space agency has taken its lead from the US Air Force, according to Bruce Anderson, chief scientist of the studies. "The Air Force has a rigorous program of fuels, and buying fuels in large quantities to test in their fighter aircraft," he explains. "At one point it was trying to get all their aircraft to fly on a 50% blend of regular Jet-A or JP-8 and alternative fuels. We've tried to look at what is available as drop-in alternative fuels."

NASA INVOLVEMENT

In 2011, NASA started experimenting with fuels formed from beef tallow that the Air Force donated to NASA for testing at the agency's facility in Dryden, California, using a DC-8 'flying lab' test aircraft powered by CFM56 engines. "It has a lot of atmospheric science instruments on it, and it flies all over the world studying composition," explains Anderson. "We'd been collaborating with the aeronautics people on emissions, so when the notion of

ABOVE: As part of its Alternative Aviation Fuels Experiment (AAFEX), NASA has completed numerous tests on a specially modified DC-8

FILTRATION FOR THE FUTURE

Alongside the numerous studies investigating the reduction of aerospace emissions, for engines fed alternative fuels as well as jet fuel, the fuels themselves are also subject to stringent testing and monitoring. Bound by two primary specifications – EI 1581 and EI 1583 – devised by the Energy Institute in collaboration with filter manufacturers such as Velcon Filters, fuels are subjected to a process of continuous improvement to ensure efficiency as well as quality, through filtration, for airplane manufacturers and operators.

Now into its fifth edition, EI 1581 covers the performance of filter/water separator systems, while EI 1583 (sixth edition) regulates fuel filter monitor design, laboratory test procedures and minimum laboratory performance levels for selected aspects of these systems.

Velcon Filters lays claim to the largest indoor jet fuel testing laboratory in the world at its Dinius product development facility, where Tom Muzik is vice president of engineering. "We are mandated to qualify our filters as fit for use through these specifications," he explains. "We test the filters in our labs in fuel to those EI specifications, using ASTM (American Society for Testing and Materials) test procedures. Filtration is a critical technology to ensure, as the fuel is transferred from refining to the aircraft wing, that it continues to meet Jet-A/A-1 standards. Industry testing will be ongoing to ensure that alternative fuel feedstocks continue to meet the high standard of fuel quality."

The challenges of keeping the fuel clean and, more importantly, away from water, can appear an uphill struggle for Muzik and his team at Velcon. "Each time we move the fuel, offloading and uploading it into and out of tanks, we see the contaminants silica and oxides from pipes – more commonly known as dust and limescale," he explains. Using a cocktail of iron oxide and what Muzik calls fine test dust, the filter is tested to ensure downstream quality meets specifications.

"The other, more dangerous, part is water – which is an evil thing," he says. "It can shut an engine off and make life very difficult, and is the thing that causes fear and creates the most problems. The primary procedure for removing bulk water from the fuel at the tank farm is coalescing, where small water droplets are gathered into larger ones and separated from the fuel, as per the EI 1581 specification.

"Filter monitors qualified under EI 1583 perform water and solids removal at the wing of the aircraft, but also offer the added benefit of shutting down fueling if hit by a slug of water," explains Muzik. "Both filter monitors and coalescers are key to ensuring clean, dry fuel."

In the lab, Muzik and his team contaminate the fuel to the extreme with dirt and water. "What we do is so far beyond what is seen in the real world. Typically we load filters in hours to a level that could take a year or 18 months in actual use. What we do in the lab is severe, but we can see what the filters can handle."

"IN ORDER FOR THE FUELS TO MAKE AN IMPACT, THE PRICES HAVE TO COME DOWN BECAUSE SOME OF THEM COST US$30 TO US$40 A GALLON"

LEFT: **Rolls-Royce engineers testing the two-shaft engine core 3/2d, part of the company's E3E program**

ABOVE: **The DC-8 will take to the skies in 2013 for more evaluation of alternative fuels and their impact on performance and the environment**

testing alternative fuels arose, I approached the people that operated the DC-8 as we needed something that was reminiscent of the current fleet."

More than a year later, Anderson and his NASA team are drawing conclusions from their development work. "There doesn't seem to be any sacrifice in performance in using these fuels," he confirms. "Some of them are a little less dense, so they occupy a larger volume of fuel tank space, but nobody is proposing to fly on 100% alternative fuel. One problem is that they don't have any aromatics in them, and most older aircraft rely on those components to swell the seals. When you have a fuel that doesn't have any aromatics, pretty soon you've got massive leaks, so the approach is to mix the fuels 50:50 with Jet-A."

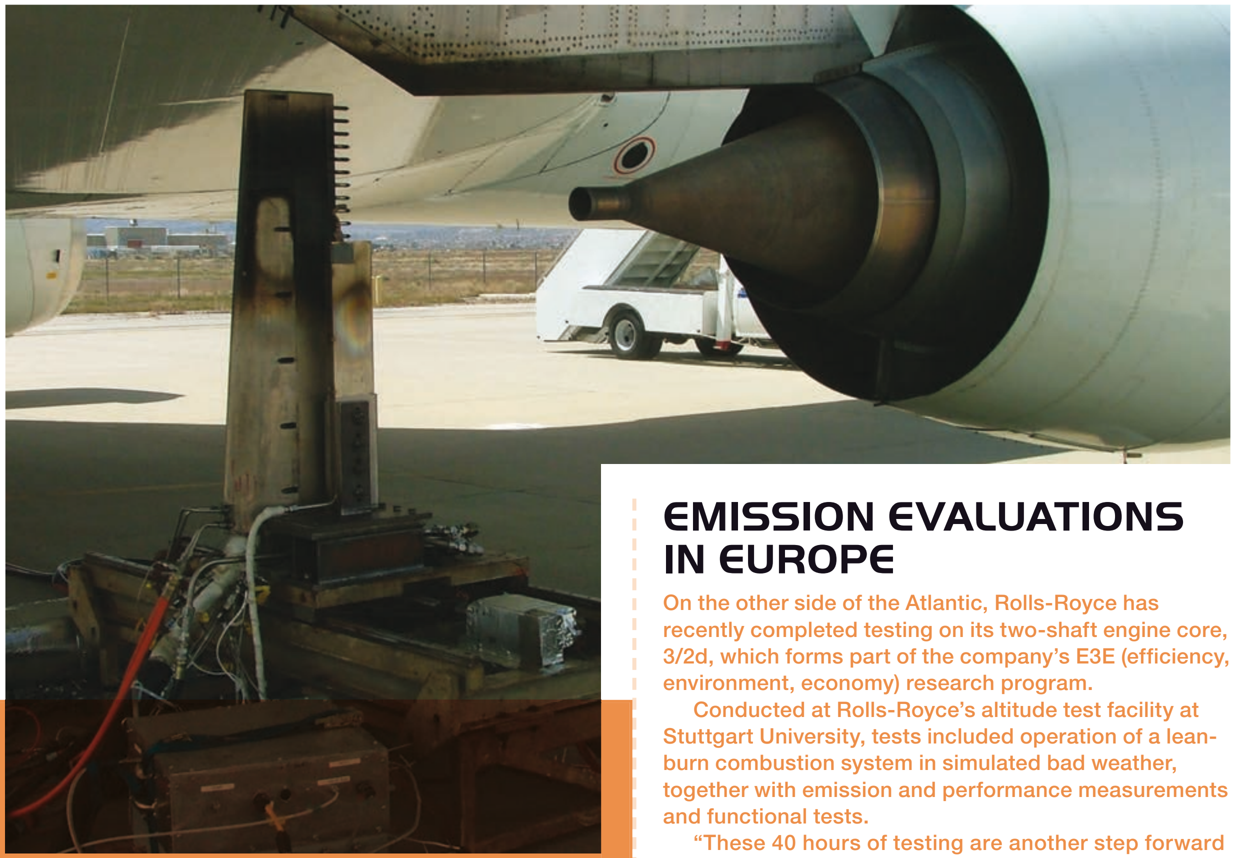
All the alternative fuels are also devoid of sulfur, a major precursor for particle formation. "We've seen a reduction in solid particle emissions, and these particles are much less soluble because no stratospheric sulfate aerosols are formed when the exhaust plume cools," says Anderson. "If you have sulfur in the fuel, about 1-3% gets converted to sulfuric acid, which forms into tiny particles as the exhaust plume cools."

Using alternative fuels also cuts soot emissions as well as the sulfate and sulfuric acid emissions, confirms Anderson, adding that when tested on the CFM56 engines, the reduction of black carbon mass emissions was 80% at idle and 50% at take-off thrust.

The next step is to head to the skies in the DC-8. "Some people believe that soot particles from aircraft seed the formation of condensation trails at flight altitude," Anderson states. "So if you could reduce the number, size and water solubility of particles coming out of an aircraft engine, you might reduce its tendency to form clouds. That is something we are going to be studying this year, with a flight program in the DC-8."

According to Anderson, up to five flights are planned for February and March 2013, cruising at a range of altitudes and looking for different contrail formations. "We're documenting the emissions so that we can run models to see how they affect climate and what the benefits are of flying altitudes and burning these fuels," he says. "We will also have measurement of fuel flow and exhaust gas temperature to document the performance of the fuel on engine performance.

"All our tests have been at ground level, and more than 90% of the fuel is burned during flight," he continues. "An A225 Guardian – a more powerful version of the Falcon 20 – will be modified and instrumented with a payload of gas-phase and aerosol instruments. The plan is to fly behind the DC-8 and measure the PM and NOx emissions. We haven't selected the blend, but I think it is going to be a plant-based hydro-treated renewable jet fuel, or a hydroprocessed esters and fatty acids (HEFA) fuel."



RIGHT: Following the analysis of a 50:50 beef tallow: Jet-A fuel blend, emission reductions of up to 80% (idle) and 50% (take-off thrust) have been recorded by the NASA team

EMISSION EVALUATIONS IN EUROPE

On the other side of the Atlantic, Rolls-Royce has recently completed testing on its two-shaft engine core, 3/2d, which forms part of the company's E3E (efficiency, environment, economy) research program.

Conducted at Rolls-Royce's altitude test facility at Stuttgart University, tests included operation of a lean-burn combustion system in simulated bad weather, together with emission and performance measurements and functional tests.

"These 40 hours of testing are another step forward in our continuing work to develop environmentally friendly technologies," says Dr Karsten Mühlenfeld, director – corporate and engineering, Rolls-Royce. "These technologies will enable future Rolls-Royce engines to contribute significantly to the goal of the Advisory Council for Aeronautics Research in Europe (ACARE) to reduce nitrogen oxide emissions by 80% by 2020."

Technology developed as part of the E3E program forms the basis of the Rolls-Royce Advance2 future two-shaft engine program, designed to reduce fuel-burn by 15%, compared with similar engines currently in service. E3E lean-burn combustion technology will also make a major contribution toward meeting future emissions targets.

THE FAA AND FUELS

Elsewhere, the FAA is driving developments via its CAAFI (commercial aviation alternative fuels initiative) and CLEEN (continuous low emissions energy and noise) initiative.

The overall goal is to help further mature aircraft technology and alternative fuels," states James Hileman, chief scientist, energy and environment, FAA. "We have set out specific goals in the areas of fuel burn, noise and NOx reduction, and we want to further the use of alternative fuels and remove barriers to entry of drop-in sustainable alternative jet fuels."

Forming part of the FAA's wider NextGen program, CLEEN has a target of a 60% reduction in emissions, with much of the work being undertaken by project partner GE, which completed test work on an advanced engine combuster, TAPS II (twin annual premixed swirler), at the beginning of 2012. Results show that landing and take-off NOx emissions were reduced by 60% compared with ICAO Civil Aviation Environmental Protection (CAEP) 6 standards, meeting one of the CLEEN goals.

The combuster is due to enter production in 2015, by which time the FAA should be well on its way to achieving a key fuel goal. "We have a target to have a billion gallons of alternative jet fuels in aviation in the USA by 2018," reveals Hileman. "We are feedstock agnostic; we have already used the Fischer Tropsch and HEFA approaches, and now we are looking at things like alcohol as an intermediate step. We want to make alternative fuels as economically sustainable as we can."

Anderson confirms that NASA is also looking at non-food related fuel sources for the future. "We just did a small-scale test with an aircraft auxiliary unit, where we tested a camelina fuel (jet-fuel-based versions of which are claimed to reduce carbon emissions by around 80%) as well as sugar-based fuel.

He has reservations, but believes they can be overcome. "In order for the fuels to make an impact, the prices have to come down, because some of them cost US$30 to US$40 a gallon. But as the production processes are improved, they will make an impact on pollution." ▮

John Challen is a UK-based journalist who specializes in engineering and technology in the aerospace, automotive, and transport industries

Breathe in new life

The German Aerospace Center (DLR) is testing the flight dynamics of gyroplanes, raising the profile of a fascinating technology. Is this the beginning of a new era?

BY DR HOLGER DUDA

In October 2012 DLR's Institute of Flight Systems started a testing program to improve the understanding of gyroplane flight physics. Until now only limited research has been conducted into the area of autorotation flight, so there exists great potential to improve the craft's flying qualities and performance. The studies will also have an affect on other aircraft systems.

A gyroplane is an aircraft that gets lift from a freely turning rotor and derives its thrust from an engine-driven propeller. The self-sustained turning of the rotor without the application of any shaft torque is called autorotation. Historically this type of aircraft has been known as autogiro or gyrocopter and was invented by Juan de la Cierva in 1923. Gyroplanes became largely neglected after improvements in helicopters, but today several manufacturers successfully sell single- and two-seater gyroplanes, mostly for the private aviation market. German company AutoGyro has produced and sold more than 1,500 lightweight gyroplanes since 2004.

It's the simplicity and fascinating flying characteristics, in combination with the robustness and cost efficiency, of this kind of flight vehicle that explains the recent boom, triggering DLR's focus on the technology. Gyroplanes may take over several tasks performed by helicopters today, at much lower operational costs. Successful military and police missions have demonstrated this potential. In comparison with a helicopter, the rotor system of a gyroplane is much less complex, since no transmissions, gearboxes, tail rotors or drive shafts are needed. However, a gyroplane cannot hover like a helicopter.

AIRPLANE OR HELICOPTER?

The body structure of a gyroplane is closer to a helicopter than to an airplane due to the rotor system. On the other hand it has components of an airplane, including the landing gear, horizontal and vertical tailplanes as well as an engine providing forward thrust via a propeller. Since its operation is similar to an airplane, with a short take-off run and a landing approach with a flare before touchdown, we may say that a gyroplane looks more like a helicopter but behaves more like an airplane.

The main difference from an airplane is its ability to fly very slowly, such as minimum airspeed of 20kts leading to very short take-off and landing distances. And, surprisingly, a gyroplane is extremely robust with respect to turbulence and can be operated safely under very gusty conditions.

FLIGHT SAFETY

Several rumors exist regarding a gyroplane's flight safety. Helicopter pilots feel uncomfortable with the continuous autorotation status of the rotor since they associate it with an emergency situation. Airplane pilots consider it dangerous to push the control stick forward since the rotor may be unloaded and stop spinning. On the other hand it is widely accepted that a gyroplane is very safe since it is impossible to stall and its rotor is continuously in autorotation, so its behavior does not change in the event of an engine failure.

However there has been a relatively high accident rate for gyroplanes in the past decades. This can be explained by poor flight education standards in conjunction with the use of home-built gyroplane with reduced flight stability due to ineffective horizontal tailplanes. These gyroplanes were prone to pilot induced oscillations (PIO) due to low-pitch damping during forward flight. PIO is no longer relevant for modern gyroplanes certified under German BUT (Bauvorschriften für Ultraleichte Tragschrauber) or BCAR (British Civil

MAIN: **MTOsport flight simulator by Simtec Systems GmbH (Photo by Peter Pohl)**

Airworthiness Requirements) Section T. Their horizontal tailplanes provide sufficient pitch damping.

However other types of accident have occurred, such as flying too low at too low an airspeed (on the backside of the power curve) or applying an incorrect procedure during take-off (control stick in forward position). All these may be considered pilot errors and may be overcome by improved training. A major uncertainty exists within the community on a maneuver that has been part of the training in several flight schools in Germany – the sideslip. The reason for teaching this maneuver is the ability to control flight path and airspeed in order to touch down precisely on a very small landing field in case of an engine failure.

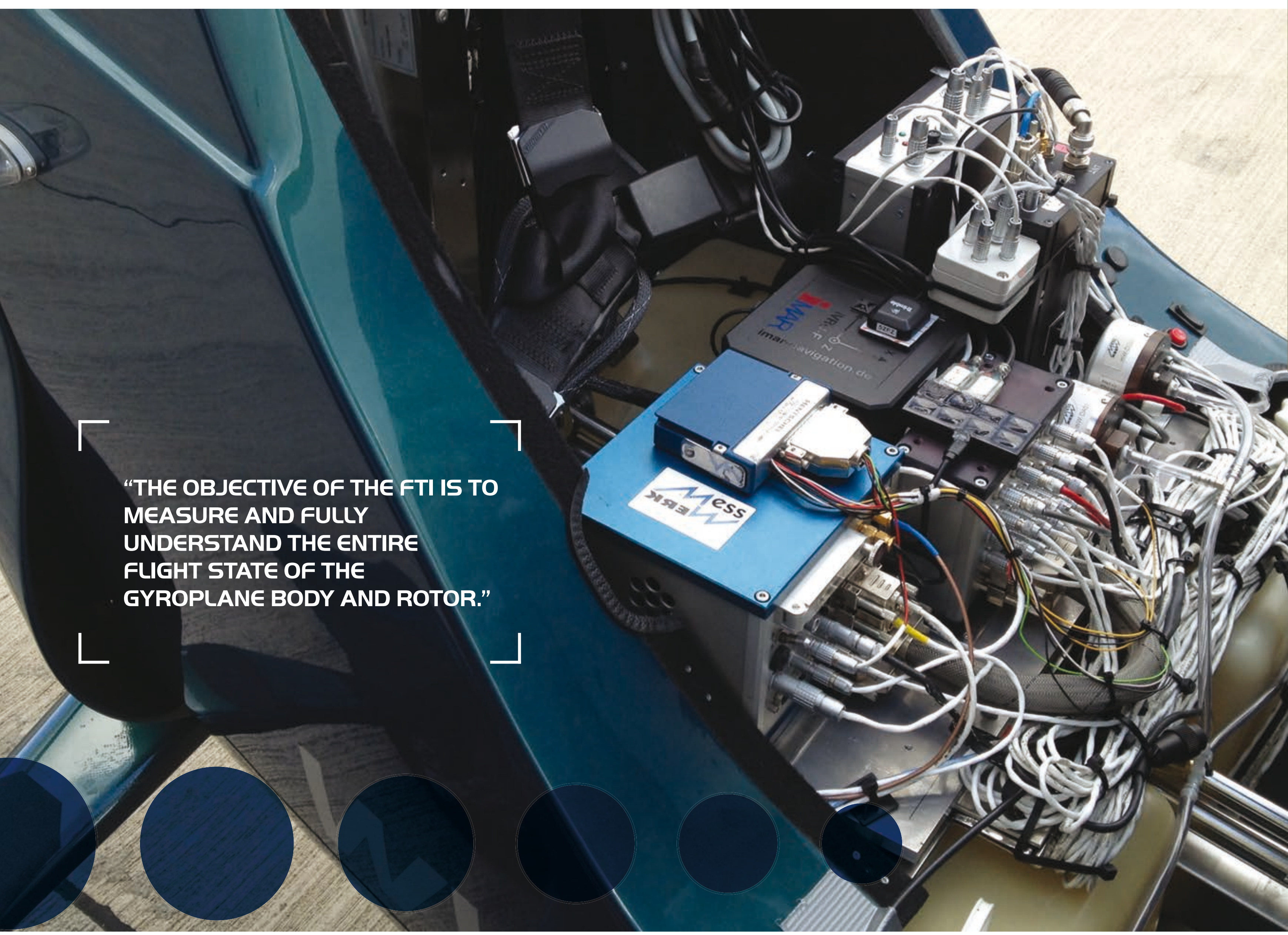
The lack of understanding of a gyroplane's flight dynamics during sideslip has been the trigger to start a new flight-test campaign to gather objective data. For this purpose DLR used an MTOsport gyroplane by AutoGyro – the D-MTOS. This lightweight gyroplane, which has an MTOW of 450kg, is a two-seater tandem configuration driven by a Rotax 912 ULS engine with a propeller in pusher configuration.

The two-blade rotor is constructed as a teeter-head system with a central flapping hinge that allows the blades to flap up and down in a periodic manner under the action of varying aerodynamic loads during forward flight.

FLIGHT TEST INSTRUMENTATION

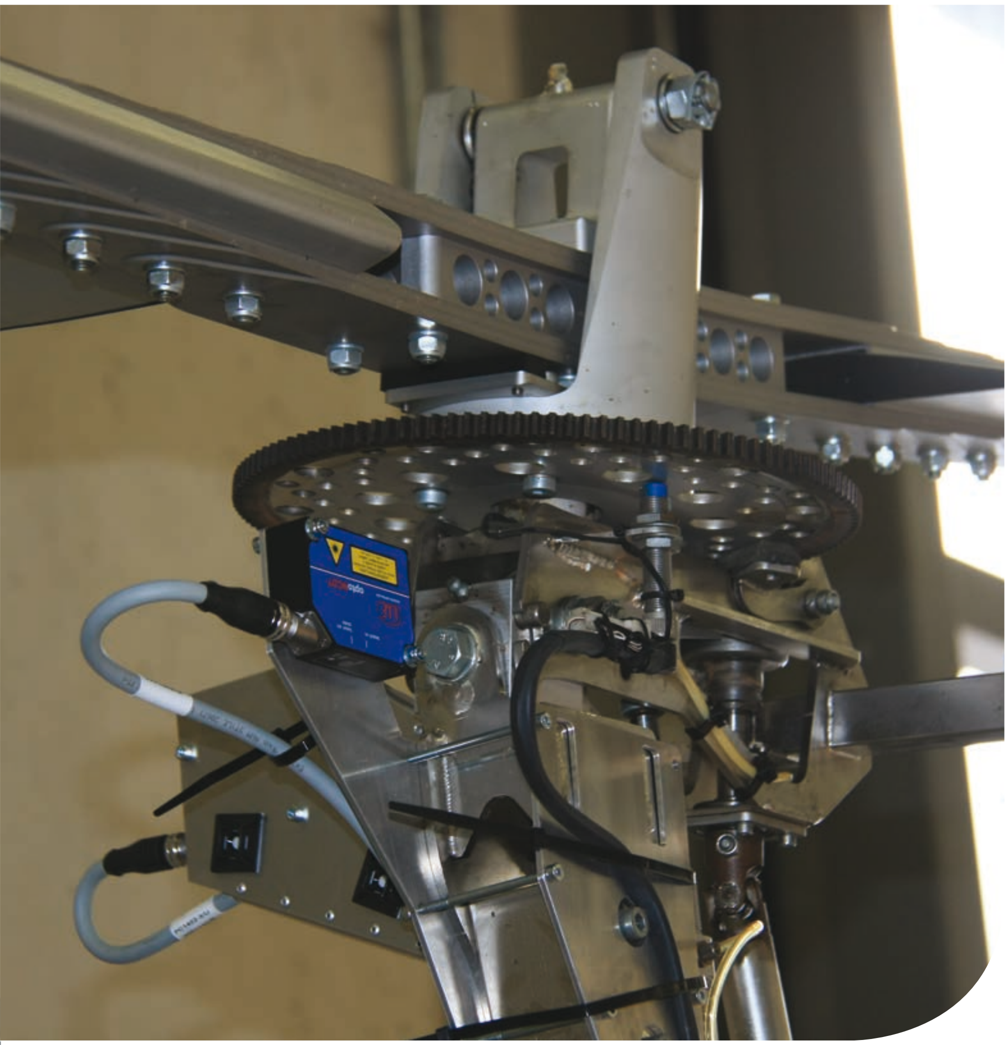
The flight test instrumentation (FTI) has been conducted in cooperation between DLR and messWERK, according to the requirements of flight dynamics analysis. The objective of the FTI was to measure and fully understand the entire flight state of the gyroplane body and rotor.

The design of the FTI was optimized with respect to the limited space and payload of a small aircraft. This enabled the use of highly accurate sensors and an advanced real-time data-acquisition system that is usually used in larger aircraft. As only the pilot was on board, the system was set up to require a minimal workload.



BELOW: **Measurement equipment mounted in place of the rear seat of the D-MTOS**

"THE OBJECTIVE OF THE FTI IS TO MEASURE AND FULLY UNDERSTAND THE ENTIRE FLIGHT STATE OF THE GYROPLANE BODY AND ROTOR."



The main components of the measurement equipment were mounted in the space normally occupied by the rear seat. A data-acquisition system, a battery and an interface control box were installed, together with an inertial platform (iMAR iVRU). An easily accessible panel with switches and indicator lights was provided, enabling the pilot to start and stop the data acquisition and to supervise the state of the system. All measured flight parameters were recorded at 100Hz.

The inertial platform provided the roll, pitch and yaw rates, the corresponding attitude angles, the longitudinal, lateral and vertical accelerations, GPS positions, and the ground speed. The roll and pitch stick forces were measured by strain gauges; the corresponding deflections by potentiometers, as were the pedal deflection and thrust lever position. Taps of the basic avionics provided the rotor and propeller rotational speeds.

In order to deliver high-quality measurements of the airflow, a nose boom with a length of more than two meters was installed. At its tip special vanes for measuring the angle of attack and sideslip were installed. Compared with fixed-wing aircraft, the measurement range of the airflow angle is a real challenge as the angle of attack reached values of up to 80°. Static and dynamic pressures were measured to provide airspeed and altitude. A special flight-test procedure

LEFT: **Rotorhead of the D-MTOS equipped with laser sensors for measurement of flapping angle**

IS IT A CAR? IS IT A PLANE?

In April 2012 a Dutch company successfully concluded test flights of what it calls its flying car, PAL-V (Personal Air and Land Vehicle). The vehicle flies in the air like a gyroplane with lift generated by an auto-rotating rotor and forward speed produced by a foldable push propeller on the back.

The Dutch National Aerospace Laboratory and Delft University are involved in the development. The driving prototype was fully tested in 2009 and the flying-driving prototype has now made its first flights.

Speaking to Aerospace Testing International, Mike Stekelenburg, COO and chief engineer says: "We have finalized what we call Phase 1 testing both for driving as well as flying. In Phase 1 flight testing, we have examined control margins, flight stability, control response, vibrations, take off and landing properties, rotor bending moments, engine parameters, climb speed, control forces and simulator predictions versus reality.

"We found out that the stick control force had a static roll component. Fortunately, this could easily be corrected by a introducing a small offset between the rotor axis and the roll hinge position.

"Next step is Phase 2 testing in which we need to examine variations in weight, variations in center of gravity, higher *g* loading, and a higher speed range."

It runs on gasoline and there will also be versions that use biodiesel or bio-ethanol. According to the company it can reach speeds of 180km/h (110mph) on land and in the air. On the ground the three-wheeled vehicle combines the comfort of a car with the agility of a motorcycle due to its 'tilting' system. In driving mode, a PAL-V accelerates "like a sports car".

FLYING FULL TILT

Today's lightweight gyroplanes are controlled by tilting rotor systems. The rotor head can be tilted around the pitch and roll axes by control stick movements, thereby controlling the rotor lift force. The horizontal tailplane is needed purely to increase pitch damping and hence flight stability. The yaw control of the gyroplane is performed by a rudder, which is needed to maintain coordinated flight, compensate for propeller slipstream effects and perform crosswind take-offs and landings. Finally, the throttle is conventional and provides the means to control engine power and thus propeller thrust.

using inertial and GPS data was conducted to calibrate the airflow measurements.

The measurement of the rotor blade flapping angle was also a challenge. One possibility would have been to measure the angle in the central flapping hinge, but that would have required the sensors to be installed on the rotating rotor system. Instead two laser sensors were mounted at the top of the rotor mast, providing distance measurements that may be used to determine the blade flapping angle at two positions (forward and right-hand side). With this measurement technique the blade azimuth angle may also be determined.

This measurement equipment enables complete determination of the flow velocity and angles of the gyroplane rotor and body.

FLYING THE SIDESLIP

Following a specific flight safety review with respect to severe sideslip maneuvers, the flight test campaign was initiated. Test pilot Jörg Seewald, who has more than 5,000 hours flight experience on gyroplanes, climbed to an altitude of 2,000ft and trimmed the D-MTOS at 100km/h before moving the ruder pedal carefully to the left limit. The throttle was in idle position to represent a landing approach.

After careful reproduction on the right-hand side, the first data was analyzed and reviewed with respect to flight safety. No major stability problems were uncovered and the data did not show any cause for concern. Several further sideslip maneuvers were flown at different airspeeds with gentle control stick movements in the roll and pitch axes as well as power changes. Sideslip angles of above 50° were measured. No significant changes in flapping angle amplitude were found but there was a reduction in rotor rotational speed from about 320rpm to 290rpm.

It will take several months to evaluate the data gathered in order to fully understand what happens during severe sideslip flights with gyroplanes. In the next step the gyroplane simulation model available at DLR will be validated within this flight regime by means of the new data package and implemented in the MTOsport flight simulator by Simtec Systems.

The sideslip maneuvers conducted during the flight trials will then be repeated in the simulator but with more severe control stick inputs in order to uncover potential unstable behavior. This hybrid test technique, with a test aircraft and simulator, is needed here since it is unclear whether the gyroplane may recover once the limit of safe operation has been crossed.

GYROPLANE FUTURE

The results of this analysis, in combination with the validated gyroplane simulation model, are the basis for future research on gyroplane improvements. DLR's main areas of interest include the improvement of flight performance and comfort by advanced rotor systems with four blades and modern airfoils.

ABOVE & BELOW: **Flight test MTOsport gyroplane registration: D-MTOS by AutoGyro GmbH**

Additionally the reduction of parasitic drag for higher cruising speed by employing advanced rotor-head designs and minimized fuselage drag are to be investigated. These results will be valuable for manufacturers with respect to overall system design and the development of larger gyroplanes with considerably higher performance and endurance. ∎

Dr Holger Duda is head of department at the German Aerospace Center, Institute of Flight Systems Flight Dynamics and Simulation, based in Germany. Pictures from DLR, messWERK, SimTec Systems (by Peter Pohl)

Feel the air force

A look at a combined system for the non-destructive testing of military aircraft

BY MICHAEL WANDELT & MANFRED JOHANNES

During operations, military aircraft and helicopters are exposed to extreme mechanical loads. For the early detection of defects on its aircraft, the German air force uses a novel inspection system based on a combination of active thermography and phased-array ultrasound. This mobile system enables rapid non-contact inspection of large areas. Some additional advantages are that it can be used worldwide under field conditions and its ease of transportation.

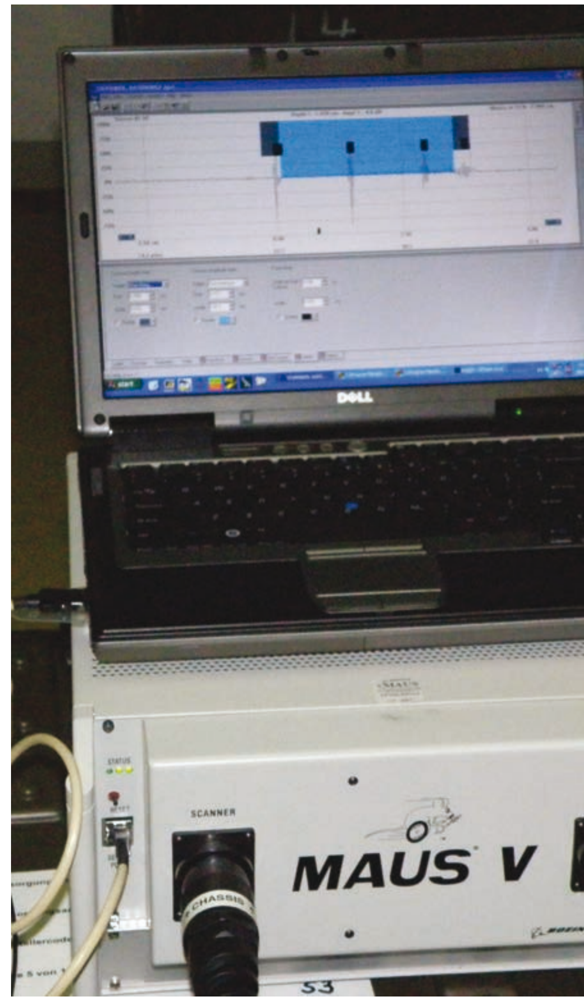
Despite the use of advanced materials and high-quality manufacturing, the components of modern military aircraft are not resistive against aging due to extreme dynamic loads during take-offs, landings and flight operations. In addition, damage can occur during take-off and landing, for example by impact from stones and tire debris or by bird strikes.

It is particularly under the extreme military operational conditions, that failure of aircraft components can lead to catastrophic events. Therefore even the smallest defects must be identified, assessed and repaired at the earliest possible stage, so that they do not lead to high risks.

Methods for the maintenance and overhaul of military aircraft non-destructive inspection (NDI) have been established for many years. A wide range of techniques such as radiography, ultrasound and dye penetrant testing are available. However, these methods have various disadvantages – often the components must be disassembled and

RIGHT: **German air force mechanics mount the phased-array module on a fighter wing**

BELOW: **Inspection of a helicopter rotor blade with active thermography**



the inspection process takes a long time. The results are not easy to interpret, so the detection of defects is highly dependent on the experience of the inspector. However, the inspection work can often simply be carried out in a workshop on a military airfield.

TESTING TECHNIQUES

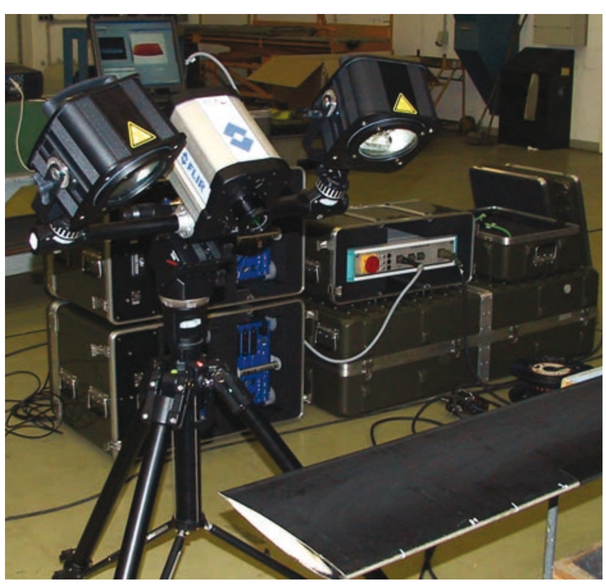
Radiography uses a source to emit x-rays that travel through a part and are recorded on film or by an electronic sensor. The resulting image is more exposed where more photons have passed through the part, which may be caused by a void, thinner material or a material difference. The technique can be universally used for various materials and material combinations. It can provide detailed information about the inner material structure and with the more advanced tomography it generates 3D pictures or 2D slices.

However, radiography also has some disadvantages. For example it requires two-sided access that is not available in many applications, the capability for detecting cracks and disbonds is limited in most orientations, and interpretation and flaw discrimination are very difficult for complex parts. Because of health-and-safety guidelines, the purchase and maintenance of the facility is expensive.

Ultrasound is probably still the most popular NDT technique in aerospace for detecting subsurface defects and for measuring the thickness of materials. In this technique, a transducer transmits a sound pulse into a part and receives returning echoes. With C-scanning one can get a detailed image of the inner structure of the inspected part. However, ultrasound also has several disadvantages for practical applications. For example, it requires the use of a liquid or gel couplant on the part. Recorded data sets can be large and require complex interpretation. The method is not effective on porous or multilayered materials, or those with a complex inner structure. The nature of C-scan imaging requires mechanical scanning.

Dye penetrant inspection is commonly used for the detection of surface cracks. It requires coating the part with a dye that wicks into surface cracks. The surface is wiped or washed and often treated with a developer coating. Cracks are detected by visual observation of the dye in the cracks. Dye penetrant inspection is highly inspector dependent and is very difficult to automate. Surface artifacts such as roughness and scratches can have large influences on the detectability of flaws. The technique is limited to the detection of surface cracks of certain geometries: the dye will not wick into very tight cracks and it will be washed out from very open cracks.

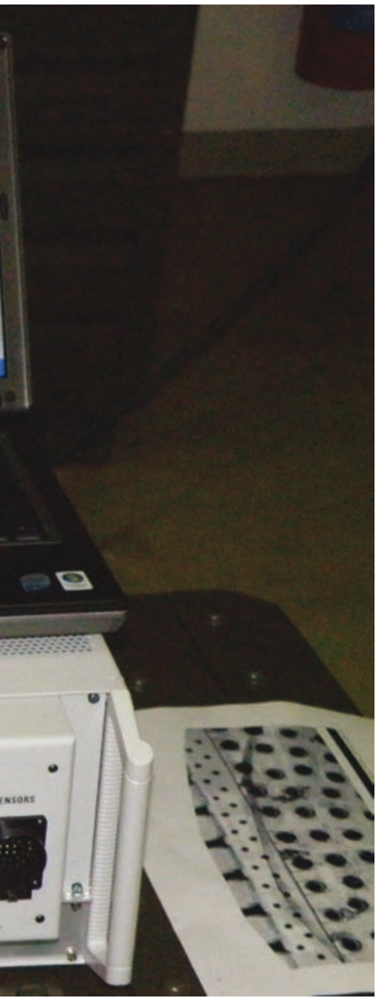
"ULTRASOUND IS PROBABLY STILL THE MOST POPULAR NDT TECHNIQUE IN AEROSPACE FOR DETECTING SUBSURFACE DEFECTS"



USING METHODS IN HARMONY

In contrast to established methods, the combination of active thermography and phased-array ultrasound enables inspections of large areas in a time- and cost-effective way; extensive disassembly of the components to be inspected is usually not necessary. In the novel modular system used by the German air force, the advantages of both methods complement each other perfectly, enabling inspections of all types of components made from all kinds of materials and material combinations.

The measurement results are displayed as images, which can be assessed relatively easily. With active



ABOVE: Operator console for the phased-array module

BELOW: The dark spots represent inner-surface defects or delaminations

EXAMPLE ONE: TORNADO

One major problem that the German air force shares with other air forces is the aging of its aircraft. And as the aircraft get older, the cost of their inspection and maintenance rapidly increases. One main cost driver is corrosion, but also a lot of composite components are facing difficulties due to life extension and age. In addition, the increased use of composites means a growing need for composite inspection on new-generation aircraft. Faced with these challenges, the German air force decided to develop and procure a new combined inspection system.

The following examples show typical inspection tasks on the Tornado fighter, which has been in use with the air force for more than 30 years.

CORROSION ON THE WING BOX

A widespread problem of the Tornado jets is corrosion of the joint between the wing box and the swing wings. For frequent inspections the phased-array ultrasound module is used, which enables easy and fast identification of corrosion problems.

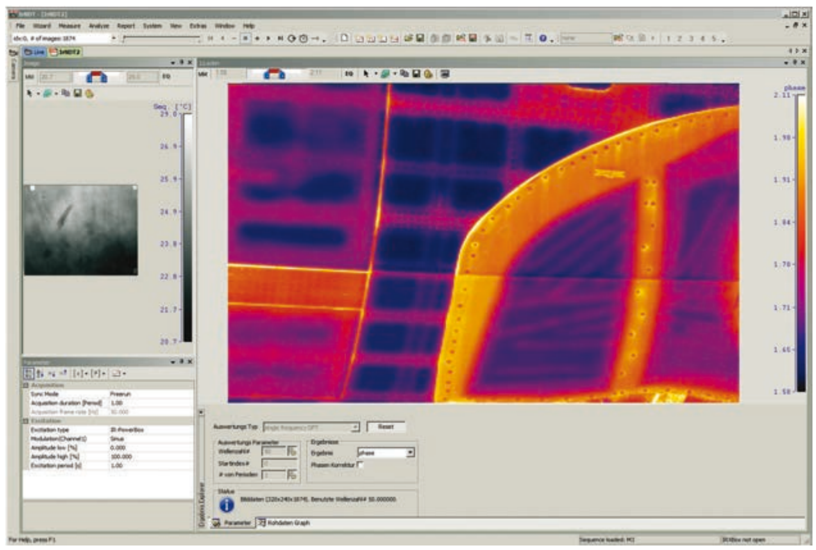
DELAMINATION

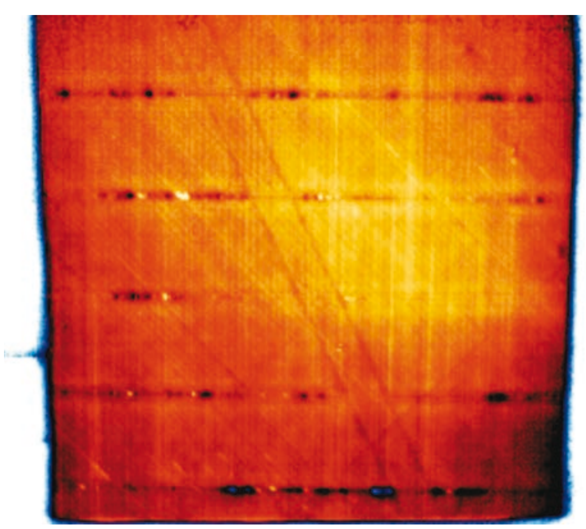
Due to aging there are also delamination problems on composite components such as the horizontal tail. For these inspections the active thermography module is used. Pulse thermography with flash excitation is a particularly good technique for assessing parts with an aluminum honeycomb core.

thermography the measurement process is completely non-contact. The easy transportability of the system and the robust design of all components according to MIL standards enables worldwide use under field conditions.

ACTIVE THERMOGRAPHY

Active thermography is still a young, yet highly efficient and powerful technique for the non-destructive testing of aircraft. With a suitable excitation source, thermal energy is induced into the part to be inspected while the temporal behavior of the surface temperature is recorded with an infrared camera. By applying an appropriate mathematical analysis to the recorded temperature data, defects in the interior of the component, such as delaminations, cracks and water inclusions, become visible. The advantages of the technique are evident: it enables non-contact inspection of large areas, the required measurement times are short and the results are displayed as high-resolution images. A single measurement can cover an area of up to 1m^2, and depending on





the selected method, the measurement time ranges from a few seconds up to one minute. Most of the possible defects can therefore be identified quickly and with little effort.

For the inspection of different components and materials, such as composites and metals, the modular system provides various measurement methods such as 'lock-in' and pulse thermography. This allows an optimal adaptation of the measurement of the component and the material properties. The methods differ mainly in the applied excitation sources and in the mathematical analysis. With lock-in thermography, periodic harmonic-modulated energy is applied to the surface of the inspected object. For this kind of measurement, the system is equipped with high-power halogen lamps.

The evaluations are performed with special algorithms that effectively filter out interferences and noise components. The lock-in method is especially suitable for the inspection of composite materials, however it can also be used, for example, in the investigation of the adhesive bonding of metals.

Pulse thermography is used for the inspection of materials with high thermal conductivity. Here a high-energy flash system supplies thermal energy to the object surface in a very short time and the subsequent cooling behavior is analyzed.

EXAMPLE TWO: TIGER HELICOPTER

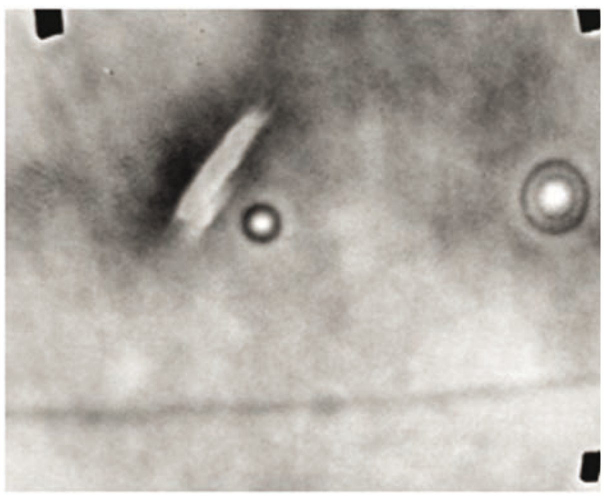
In addition to examining conventional aircraft structures made of metal, the combined NDT system is especially suitable for inspection of new-generation aircraft such as the Eurofighter EF2000 and the Tiger helicopter EC665. So far, conventional measurement techniques have reached their limit in examining this kind of aircraft, with their high proportion of composite materials.

For the Tiger helicopter, approximately 80% of the airframe is constructed of composite materials in order to minimize weight. The frames and beams are fabricated from Kevlar and carbon laminates. Panels are composed of Nomex honeycomb material with carbon and Kevlar skins, and the helicopter blades are of fiber-composite construction.

One main challenge for NDT on such a complex composite structure is its vulnerability to impacts where the damage will often not be visible. Impact threats to air structures are numerous: stones from the runway or landing area; a direct hit by a bird; impact of ice particles; and the occasional dropping of a tool. Also, the blast and associated elevated pressure loads that are caused by the helicopter's own weapons hardware can mean a threat to the helicopter. In addition there is a need to assess repairs of impact damages, which are also not visible if skillfully done. All this requires an NDT system that is easy to use, mobile and enables the rapid inspection of large areas.

PHASED-ARRAY ULTRASOUND

The active thermography inspection system also includes a phased-array ultrasound module. This module can also perform detailed inspections on components made of metals and composite materials. Its main advantage is the increased depth range, so it is particularly applicable to thicker components and is therefore an ideal complement to active thermography. Measurements are more time consuming and require a coupling medium (water). The measuring process can be carried out automatically. The results are displayed as high-resolution images that show the internal structure of the component, enabling easy identification of defects.



ABOVE AND LEFT: Assessment of a horizontal tail. Left image shows the setup, above shows the image

INTEGRATED DATABASE

The system software includes a database that is optimally tailored to the needs of aviation. Through a graphical user interface all image data, measurement charts, reports, and additional information about the aircraft can be managed. The database contains high-performance image-processing modules such as stitching, image enhancement, geometric measurement functions, comparison, evaluation, identification, etc., and supports all formats of the resultant images as well as all standard bitmap formats. Measurement reports can be generated directly in Microsoft Word and PowerPoint formats. The database also gives an essential benefit for the easy operation of the system. Data from previous measurements on an aircraft, as well as sets with measurement parameters, can be downloaded for quick and easy configuration of the system.

Large-area inspections on military aircraft have often been associated with great effort and high costs. This novel system enables these inspections to be performed much faster, greatly reducing inspection time and aircraft downtime. The presentation of results as high-resolution images enables reliable identification of defects and reduces the dependence on the human factor. Various materials, such as composite materials and metals, can be handled, making the system particularly suitable for inspecting the latest-generation aircraft. The completely modular system is designed for mobile use under field conditions in military aviation. ▮

Manfred Johannes is from the CSIR (Council for Scientific and Industrial Research) in South Africa. Michael Wandelt is from AT (Automation Technology) in Germany

Typhoon season

Even as the Eurofighter Typhoon matures in service, its manufacturers, including BAE Systems, continue to test for planned upgrades and fatigue monitoring

BY PAUL E. EDEN

Last year's Operation Ellamy allowed the UK's Royal Air Force to show off its Eurofighter Typhoon in combat for the first time. Initially deployed in an air defense role against a threat that failed to materialize when the RAF began exploiting the type's latent ground-attack potential, air forces the world over sat up and began to pay attention.

The results of that campaign and the jet's impressive performance are well known; less apparent was the role of prime contractor BAE Systems in helping prepare sufficient aircraft for combat. This preparation involved traditional engineering, but also the switching around of software 'squirts' and other scheduled capabilities to optimize the aircraft for Ellamy sorties. And none of this would have been possible without BAE Systems' robust test campaign, which continues to prove incremental upgrades in accordance with customer requirements for future deliveries and in-service upgrades.

Typhoon is inherently upgradable, with new capabilities and weapons systems introduced through scheduled, carefully managed development and test programs. These upgrades are managed as numbered Phase Enhancements; the Tranche 2 aircraft are about to receive the first half of the Phase One Enhancement (P1E), known as P1EA.

P1EA should be with the customer before the end of 2012 and, BAE Systems' Typhoon chief test pilot, Mark Bowman, says, "We are already development flying for part B. It's a yearly cycle and we are already talking about what comes after that." Of course, what comes next is P2E, P3E, and so on, but how does BAE Systems approach a complex, ongoing series of tests, while also supporting the need for long-term test operations, such as those for fatigue monitoring?

FLIGHT TEST

The company maintains a dedicated flight test team at its facility in Warton, UK. Using telemetry direct from the airborne test subject, engineers monitor the test process in real time, with feeds delivering simultaneous live repeats of the imagery on up to four of the aircraft's cockpit displays, as well as other data to the flight test computers.

Testing a jet like Typhoon is an expensive business and each test flight is carefully defined. By the time new

"IN ORDER TO FIND ANY DAMAGE, THE TEST TEAM CARRIES OUT A DAILY WALK AROUND AND RUNS MINOR INSPECTIONS"

ABOVE: Paul 'Lobbers' Lobley, senior flight test engineer at Warton (Ray Troll/BAE Systems)

software reaches flight test it will already have undergone extensive bench testing, so the team sets out to gather data demonstrating not only that the software behaves as expected, but also that its effects on aircraft performance are as planned. Paul 'Lobbers' Lobley, senior flight test engineer at Warton, explains how a software upgrade might be tested: "We look at the results from the rig tests and also at the problems the new software is supposed to fix. We will also look at any possible issues it might still have and from that we devise a test that we feel is required. That, in turn, will help us decide how many times we might have to fly. "In the early days on the radar it was a 70-flight program. Now the aircraft is relatively mature and the testing process is short and sharp. Nowadays, you're looking at something much closer to the 10-flight mark."

The flight test team's involvement in each flight is intense, as it takes responsibility for pilot briefings, sortie planning – how many test runs will be needed – target choices, and even switch selection. Once the aircraft has left Warton, the flight test team and the test pilots continue to work together. The pilots are careful to fly the mission exactly as briefed, while making their own observations and noting any concerns. Should an air-to-air target be required, BAE Systems can put up a second development Typhoon, or call in an RAF aircraft. If a live weapon launch is planned the team heads out of Warton, taking its telemetry receiving gear with it in a specially designed truck. Lobley describes a typical weapons test: "When we're testing weapons systems we'll do various runs, some looking up at the target, some looking down, some with the fighter in the rear, and so on. These are done with simulated missile firings, but we do have trials with live targets and live missiles.

"These are the crème de la crème and we have to go to a place where there's lots of space over the water. So we've been up to the Hebrides [off the west coast of Scotland] for these tests."

KEEPING TRACK

Most of the standard test work is carried out along a 120-mile (195km) section of the Irish Sea, where a supersonic corridor allows flight throughout the Typhoon's speed range. The test aircraft typically operates between 20,000 and 35,000ft (6,095 and 10,670m), although the target might be as low as 2,000ft (610m).

Flying to the west of the Isle of Wight is forbidden and an army firing range on the coast is avoided, unless specific test parameters require the jet's self-defense systems to respond to 'threats'. Great care is taken to deconflict with commercial traffic using Manchester Airport, and the team tracks the test subject constantly.

Lobley says, "The aircraft have GPS pods accurate to about 6ft (1.8m). This enables us to compare radar data with calculated 'reference' data, checking the accuracy of range, speed, and angular parameters. Because we get information back in real time, we can repeat a run if we're not happy with some of the data. In the past, we would only find out long after the aircraft had landed and that would mean another flight.

"As the pilot conducts actions on the flight schedule, we're gathering data so that by the end of a flight we know if there is a problem that needs investigating further," he continues. "Very often, because we're seeing everything in real time, we spot the same things as the pilots, and we may have already started looking at some of the same issues.

TIME WILL TELL

The Typhoon was designed for a 6,000-hour fatigue life, but BAE Systems is testing to 18,000 hours. In the past it might have tested out to 30,000 hours, but such extensive and expensive work is no longer required, as Jonathan Cograve explains: "Testing used to be carried out to a factor of five-to-one, partly to cater for variations in how each aircraft was flown. But all Typhoons carry embedded instrumentation, which is one of the reasons why we can reduce the factor to three."

"Indeed, in some cases, we can be ready with an answer before they get back. After each flight there's a debrief session and this is a chance for the pilots to raise a problem. Sometimes these will be highlighted as issues, or it might be that the system is working as designed."

STRUCTURAL TEST

At the Broughton structural test facility in North Wales, the Typhoon, Hawk, and UAVs project group keeps a constant eye out for Typhoon fatigue issues. The group's leader, Jonathan Cograve, explains, "Fatigue tests are used to identify any damage, including cracking, fretting or, in the case of carbon fiber, delamination, that the aircraft structure would develop during the course of its working life, with the objective of ensuring that it remains capable of withstanding the original design loads."

Typhoon's major airframe fatigue test (PMAFT) is currently underway in Broughton's giant rigs. Typhoon fatigue testing began in 2005 and is scheduled to continue into 2018. The PMAFT is a regular Typhoon airframe, minus internals, loaded to replicate a typical lifecycle for the aircraft in service.

Fatigue testing is all about the early induction of inevitable failure. As Cograve points out, "As you try to optimize the performance of a military aircraft, there is inevitably a trade-off between this and the life of its structure. The value our facility adds is early information. In reality, most fatigue tests identify failures that require further work, therefore our objective is to identify issues early enough that they can be managed and hence avoid any delays to the operator's use of the aircraft.

"In order to find any damage, the test team carries out a daily walk around and runs minor inspections at 1,000-hour increments, intermediate inspections at 3,000 hours, and major checks every 6,000 hours. At some point in this process a failure will be found. At that point we formally report it to the structures team. We give an accurate depiction of failure – the extent, the location, test position, when it was last inspected, and the method of inspection."

This information is assessed by the Joint Structures Team in Madrid, which communicates its findings with the company responsible for the airframe section that has failed. It then goes back to Broughton, ordering further investigation, monitoring of the failure, or a repair. Sometimes it might be appropriate to fit a new strain gage in the area, adding to more than 2,500 already in place.

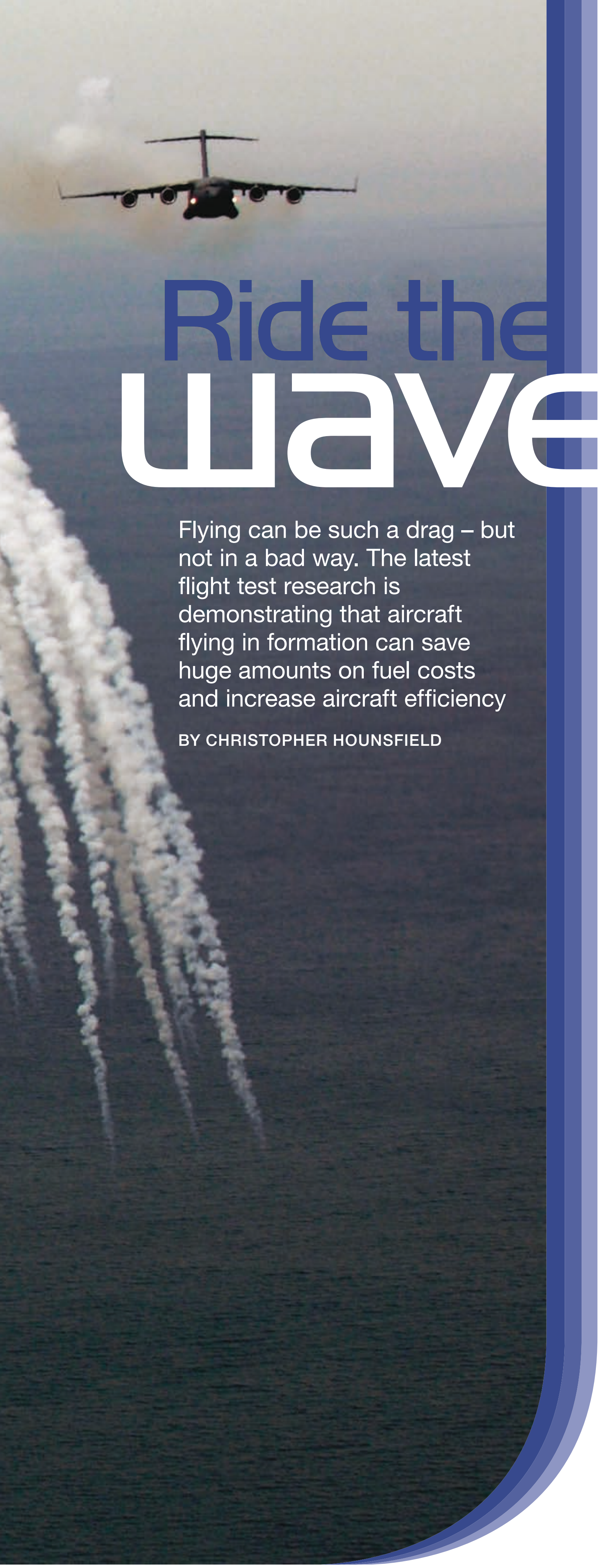
With PMAFT already far ahead of the fleet, the project group has to ensure that the airframe remains viable. "What the structures and test teams won't risk is compromising the test specimen," says Cograve. "It is the only one of its kind that provides the clearances for every Typhoon and is therefore irreplaceable. It is treated like a living and aging beast and, while its wrinkles need examining, it needs to be protected at all costs.

"The onus is on us to work with the people in structures to make sure the test is ahead of the fleet leader. The rate that we can apply on the test is greater than in normal usage because the test has the ability to run 24 hours a day. Fairly early on you gain a lead and then try to maintain it so that if any issues come to light you've got sufficient time to resolve them, before it starts to impact the people who are operating the aircraft." ∎

Paul E. Eden is a UK-based writer for Aerospace Testing International and also a specialist freelance writer and editor in the aviation industry

ABOVE: **Display work is a natural offshoot of trials. For his routine at the 2011 Royal International Air Tattoo, Typhoon chief test pilot Mark Bowman took four 1,000 lb Paveway II bombs, two ASRAAM, and a pair of drop tanks aloft (BAE Systems)**

Dr Donald Erbschloe, Air Mobility Command's chief scientist



Ride the wave

Flying can be such a drag – but not in a bad way. The latest flight test research is demonstrating that aircraft flying in formation can save huge amounts on fuel costs and increase aircraft efficiency

BY CHRISTOPHER HOUNSFIELD

In October 2012 *Aerospace Testing International* reported that the US Air Force was test flying cargo aircraft in formation, 'dragging' off one another, as it was described, on long-haul flights. It is a test program intended to save on fuel. It could also have massive ramifications on military and civilian flying.

Flight tests using C-17s 'vortex surfing' at Edwards Air Force Base have demonstrated potentially large savings of fuel and money by doing what geese do naturally. Tests show that flying in formation might be smarter than flying alone.

As a way of reducing its overall fuel consumption, the US Air Force believes vortex surfing may be the way forward. "The concept, formally known as Surfing Aircraft Vortices for Energy [$AVE], involves two or more aircraft flying together for a reduced drag effect like you would see with a flock of geese," explains Dr Donald Erbschloe, Air Mobility Command's chief scientist. Erbschloe provides technical counsel to the command leadership on a variety of issues, including energy efficiency.

A series of test flights involving two aircraft at a time, enabled the trailing aircraft to 'surf' the vortex of the lead aircraft, positioning itself in the updraft to get additional lift without burning extra fuel. Early indications from the tests promise a reduction of fuel consumption by up to 10% for the duration of a flight. Over long distances, and with even a small fraction of Air Mobility Command's average of more than 80,000 flights a year, the fuel and cost savings could reach into the millions of dollars, experts say.

THE FORMATION WAY

Bombers, fighters, even mobility aircraft, fly in formation. But the main driver for almost all formation flying has been operational need – such as getting large masses (armaments, troops, or supplies) to designated targets, or escorting and protecting other aircraft. Formation flying for fuel efficiency is usually not a consideration, or, if it is, it's just a secondary one.

Erbschloe goes into more detail: "You could say that birds in the air and fish and mammals in the oceans first came up with the idea of reducing drag and gaining energy by following a leader and placing themselves in an advantageous location."

Erbschloe puts this into a modern aircraft context: "This current effort with C-17s originated in a joint Defense Advanced Research Projects Agency (DARPA)/Boeing project, working under the name $AVE. The flight tests added a few more partners to this list: Air Mobility Command; the 412TH Test Wing at Edwards Air Force Base; and the Air Force Life Cycle Management Center.

"We adopted the term 'vortex surfing' to distinguish this procedure from standard, historical formation flying. They are similar, but different in some significant ways. First and foremost, in traditional formation flying the trailing aircraft position themselves off the aircraft in front of them. For vortex surfing, the trailing aircraft positions itself off the wingtip vortex, which is usually invisible and, dependent on winds and flight conditions, can be displaced some distance laterally from the lead aircraft. In addition, we are looking at a large longitudinal (front to back) separation, typically many aircraft spans back. Most of our tests were flown at between 2,000ft and 5,000ft behind lead," says Erbschloe.

THE FACTS BEHIND THE TEST

The scientific facts show that anything moving through the air is disruptive. This effect is particularly strong around an abrupt edge such as the tip of a wing. The air is churned up by the aircraft, at an energy cost to the aircraft (this generates drag). However it is the form of the agitated air at the wingtip that is of interest to the scientists and engineers. The air tends to wrap into a tight core or vortex. This vortex stays intact for miles behind the aircraft. Erbschloe expands: "If you were looking in the forward direction of flight, the circulation of the vortex off the right wingtip would be counterclockwise (and reversed on the opposite side). Now consider another aircraft to the side of this vortex, if you are on the right side of the aircraft and just to the right of the core, you are in the updraft. That means you are getting lift for free. Your aircraft engines don't need to work

RIGHT: The Air Force Research Laboratory will analyze the data for possible application to other aircraft on a variety of missions

as hard to push their way through the air, you can reduce your power setting and maintain altitude and airspeed at a fuel savings. In short, you have effectively transferred energy from the lead aircraft to the trail aircraft or 'receiver'. A catch, and this is a big catch, is that the closer the receiver's wingtip approaches the vortex, the rougher the ride. Pilots have long known to avoid the vortex. The trick is to get close enough that you are getting energy benefit without being buffeted too severely or working too hard."

This potential has been known for decades and has been tested in a variety of aircraft, typically fighters and usually at very close ranges (wingtips a few feet apart) and hand-flown (no autopilot). This is a very pilot-intense experience and is wearing on aircrews for any long duration. "What we eventually want is an automated system, have the autopilot of the receiver fly to and hold an optimal position off the wingtip vortex with just the right balance of safe position, efficiency gain, and ride quality," notes Erbschloe.

C-17 GLOBEMASTER

The C-17 Globemaster III was used as the test aircraft because it is highly instrumented, has excellent computational fluid dynamics (CFD) models, and contains the requisite equipment (auto-throttles, autopilot, and station-keeping equipment) to conduct the test. It also consumes the lion's share of fuel in the US Air Force.

Erbschloe goes into more detail: "As well as the addition of a few sensors and monitors, the main modification was to the flight equipment software. We need to be able to measure a number of important parameters. Fuel savings for the receiver is certainly one. But we also need to know the effects on the airframe. It is easy to see that flying off a vortex puts an asymmetric load on the aircraft; the receiver wingtip closer to the vortex feels a stronger force than the distant wingtip. We also want to measure any dynamic (time-dependent) loads on the airframe and engines. We added sensors, such as accelerometers, and monitors for all those.

"As with any test, there were some things that didn't work as planned," Erbschloe says. "The computer models, particularly those that predicted the location of the vortex in straight and level flight, were particularly good. However, before this can be adopted fleetwide, software enhancements will be needed, for example to give better prediction of vortex location in a turn. We also found that the geometry of the aircraft locations was important. Although the receiver is flying in a position off the vortex, it still needs to know the location of the lead aircraft. Occasionally the cross-talk between the aircraft was blocked (due to the location of the antennas), but this was remedied by moving the receiver position back."

"A LOGICAL RAMP FROM MILITARY TESTING OF VORTEX SURFING TO THE COMMERCIAL SECTOR WOULD BE IN CARGO CARRIERS"

THE FUTURE

The preliminary results are very encouraging and the savings that have come from the tests has proved an 8-12% drop in fuel burn for the receiving aircraft. "It would be useful to look at any of our operations where aircraft fly in pairs or groups. Normally mixing aircraft types would not make much sense; different airframes are tuned to peak efficiency at different altitudes, speeds, and configurations," adds Erbschloe. "However, if we purposely partner different types of aircraft, why not fly them in the most efficient manner? For example, we often have one or two large tanker aircraft 'dragging' a small flotilla of

MODEL BEHAVIOR

DARPA's Formation Flight for Aerodynamic Benefit Program analyzed the wingtip vortices using CFD models, predicted optimum formation positions, and modified C-17 formation flight system (FFS) software, enabling precise auto-pilot and auto-throttle operations.

The program was then transitioned to the Air Force Research Laboratory, where the $AVE project accomplished the latest flight test with the software developed during the DARPA project.

fighter aircraft. Computer models suggest that a small aircraft vortex surfing off a large aircraft could see substantial fuel savings, perhaps as much as 38% – as a 2003 test of an F-18 off a DC-8 showed."

Possibly the most important question is whether this program can be extended to civilian aircraft. Could it be envisaged that airliners could fly in formation across major oceans? "A logical ramp from military testing of vortex surfing to the commercial sector would be in cargo carriers," says Erbschloe. "These businesses typically fly scores of sorties from hubs, many of which head off to the same location or, at least, in the same general direction. A saving of 8-12% for the trail aircraft should be a powerful benefit. Once the methodology is proved safe and formalized, then I think passenger airlines might want to consider vortex surfing. How many times have you been at the departure monitor at an airport to see flights headed to the same destination taking off within minutes of each other? Surely the airlines could work out arrangements to share the benefits."

On a final note, Erbschloe thinks the technology should go elsewhere: "I feel there is great potential for unmanned systems. This could include autonomous or remotely piloted cargo aircraft, packs or swarms of small UAVs, or formations where functions are distributed or shared across displaced flying entities." ∎

US AIR FORCE RESEARCH LABORATORY

Over the course of the two-week tests, Edwards Air Force Base flight crews conducted multiple flights during which two highly instrumented test C-17s, a lead aircraft, and a trail aircraft, were flown with the trail aircraft following 4,000ft or more behind the lead. The flight tests also collected engine and aircraft structural lifecycle data to confirm previous flight tests, which showed that $AVE operations would not impact the lifecycle of the airframe or the aircraft engines. All flights were completed successfully. Early indications from the tests showed a reduction of fuel consumption of up to 10% on the trail aircraft.

"It is possible for pilots to fly in the proper $AVE formation position manually, but precise flying for extended periods requires complete concentration and is fatiguing," says Bob Arbach, program manager at DARPA's Tactical Technology Office.

The tests showed the C-17 trailing aircraft achieves and then maintains proper formation flight position automatically without active assistance from pilots. This test was the first flight demonstration of the autonomous $AVE capability. Military and potentially commercial use of the technology could save millions of dollars in fuel costs annually. The US Air Force Research Laboratory will now analyze the data from these tests and investigate the implementation of $AVE technology for other aircraft types.

Mitsubishi's rising son

Engine testing continues on the Mitsubishi Regional Jet program, while its hydraulic and flight control system test rig is helping to further speed development

BY DAVID OLIVER

The aerodynamic and fuel efficient Mitsubishi Regional Jet (MRJ) – the first Japanese commercial airliner for 50 years

It is exactly 50 years since the last Japanese-built regional airliner took to the skies. The twin-turboprop YS-11 was built by NAMC, a consortium of Japanese aerospace companies, one of which was Mitsubishi Heavy Industries (MHI). In 2006, this same company launched its twin-jet Mitsubishi Regional Jet (MRJ) program focused on the 70-100 seat regional jet market that is envisioned to exceed more than 5,000 units over the next 20 years, in competition with the Bombardier C Series and Sukhoi Superjet regional airliners.

Mitsubishi Aircraft Corporation claims that the MRJ offers more fuel-efficient engines, reduced noise and emissions, advanced aerodynamics, and heightened comfort for passengers, as well as lower operating costs.

The selection of the new fuel-efficient Pratt & Whitney Canada PurePower PW1217G geared turbofan engines was crucial to the MRJ's success in the market. Bob Saia, vice president, next-generation product family, at Pratt & Whitney, claims that, "Overall airport noise will drop by 75% and the reduction in fuel consumption is 15%. Historically, the introduction of a new powerplant would bring 5-6% in fuel efficiency and low single digits in noise reduction. We really believe we have made several step changes to deliver that 20% lower cash operating cost we targeted more than seven years ago."

THE TEST PROGRAM

After ground testing at Pratt's flight development center in West Palm Beach, Florida, the fourth of four initial Block 1 PW1217G test units, which has a thrust range of 15,000 to 17,000 lb, successfully completed its first flight test program on June 21, 2012, following 23 flights and 127 hours on a specially designed stub wing aboard Pratt & Whitney's Boeing 747SP flying testbed.

The program, which began on April 30, 2012 successfully validated the PW1200G series engine's inflight performance, operability, and control systems. To date, Pratt & Whitney has completed more than 1,500 hours and nearly 6,000 cycles in testing the PW1200G engine. Certification of the PW1217G was on track for the end of 2012, but due to delays in the MRJ program, it has been rescheduled for late 2013.

The PurePower engine family uses an advanced gear system, enabling the engine's fan to operate at a different speed than the low-pressure compressor and turbine. The combination of the gear system and an all-new advanced core delivers significant improvements in fuel efficiency, environmental emissions, and noise.

The final assembly and acceptance tests of the PW1217G engines for the MRJ will be carried out at the

"THE 'IRON BIRD' IS MORE THAN A FULL FLIGHT SIMULATOR AS IT CAN BE USED TO TEST THE OPERATIONS OF MAJOR COMPONENTS SUCH AS THE LANDING GEAR"

Mitsubishi Heavy Industries (MHI) Nagoya Guidance & Propulsion Systems Works, located in Komaki, in the production phase. After the final assembly, the engines will be installed on the wing at the newly constructed MRJ final assembly line located next to Nagoya Komaki Airport, where the first flight will take place. Pratt & Whitney is one of more than 20 international aerospace companies involved in the development and production of the MRJ.

MHI selected Rockwell Collins' Pro Line Fusion integrated avionics system for the MRJ which features 15in diagonal LCD flight displays and will include optional capabilities for enhanced and synthetic vision.

Parker Aerospace will supply the hydraulic systems; Spirit Aerosystems the engine pylons; Hamilton Sundstrand the APU, electrical power, and air management systems; and Nabtesco the flight control actuators.

Taiwan's Aerospace Industrial Development Corporation will design and build the slats, flaps, belly fairings, rudders and elevators; and Eurocopter Germany the aircraft doors.

BAE Systems has won a number of contracts from MHI, including an agreement under which BAE Systems Regional Aircraft provided engineering, development, and integration services, related to flight test equipment and systems for the MRJ. BAE Systems has designed a trailing cone system for use in flight test work, a weight and balance control system to simulate flight and loading conditions, and an electrical load bank system that simulates the various power systems in the aircraft.

BAE Systems Regional Aircraft is also, separately, working on providing engineering expertise on a number of work packages for the aircraft which include powerplant, pylon, nacelle, auxiliary power units, and fuel systems.

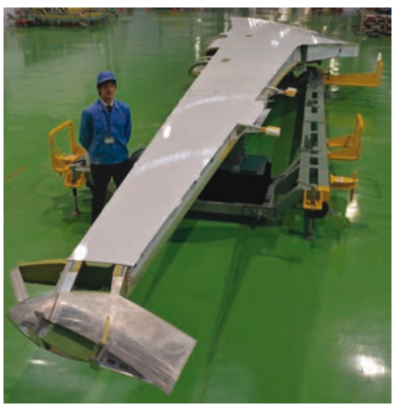
In addition, the Saab Group signed a contract with Mitsubishi Aircraft Corporation in 2009 to provide the technical publications for the MRJ program based on the company's experience of S1000D technical publication development.

The complex nature of the design and construction of the MRJ, all of which has to be tested and certified by Japan's Civil Aviation Bureau (JCAB), has presented several challenges. Even the new slim passenger seat designed for the MRJ is made with unique three-dimensional net fabric that enables the base and back of the seat to be thinner than conventional seats, producing extra leg room. The 0.25in-thick fabric also disperses body pressure and dissipates heat from the body, which will offer improved comfort for passengers.

STAYING WITH METAL

More importantly, the original wing box design was constructed from carbon fiber composite materials, but after extensive testing, Mitsubishi found that there was no weight-saving advantage over the conventional aluminum wing box of a small regional aircraft and by switching to aluminum, much of the time-consuming stress testing of the composite structure would be eliminated. However, this was one of many design reviews of the MRJ that have resulted in delays to the program.

Nevertheless, Mitsubishi announced in January 2012 that a virtual MRJ successfully became airborne in its hydraulic and flight control system test rig. It was known as the 'Iron Bird', and was designed to test the flight characteristics of the aircraft. The system comprises a flight deck, hydraulic and flight control equipment, onboard software to be loaded on the actual aircraft, and simulation computers that create the entire flight environment. The Iron Bird is more than a full flight simulator as it can be used to test the operations of major components such as the landing gear, including the



RIGHT: The first prototype MRJ main wing that will be used for engineering testing (Mitsubishi)

FAR RIGHT: The MRJ's new Pratt & Whitney Canada PW1200G geared turbofan engines are being flight tested on a Boeing 747SP (Pratt & Whitney)

PILOT TRAINING

For pilot training of the real aircraft, CAE and Mitsui & Co announced at the 2011 Paris Air Show that they are forming a joint venture to establish and operate a training center in Japan for the MRJ and will also deploy an MRJ simulator in a training center in central USA, in 2013. In support of the Mitsubishi agreement, CAE is developing two CAE 7000 Series MRJ Level D full-flight simulators, as well as CAE Simfinity integrated procedures trainers.

CAE will also design curricula and courseware, and provide CAE-led training for pilots, maintenance technicians, cabin crew, dispatchers, and ground support personnel.

LEFT: With more than 250 Mitsubishi Regional Jets on order, the first deliveries are set to commence in 2015 (Mitsubishi)

strut, wheel and tire assembly, and braking system, the first Iron Bird was delivered by Sumitomo Precision Products Co, in July 2012. As well as the control functions of raising and lowering the landing gear, Iron Bird is able to replicate the impact on the landing gear during take-off, landing, and taxiing, to verify its durability.

ONGOING SUPPORT

Another boost to the MRJ program came at the 2011 Paris Air Show when Boeing announced that it had come to an agreement with MHI to deliver round-the-clock customer support to MRJ customers covering spare parts provisioning, service operations, and field services.

However, the MRJ program was facing further delays, despite a sales breakthrough at Farnborough 2012 when Mitsubishi Aircraft Corporation and SkyWest Inc (the holding company for SkyWest Airlines and ExpressJet Airlines, the two regional air carriers that conduct the world's largest combined regional airline operations) reached an agreement in principle in anticipation of completing a firm order for 100 Mitsubishi Regional Jets (MRJs) worth a potential US$4.2 billion.

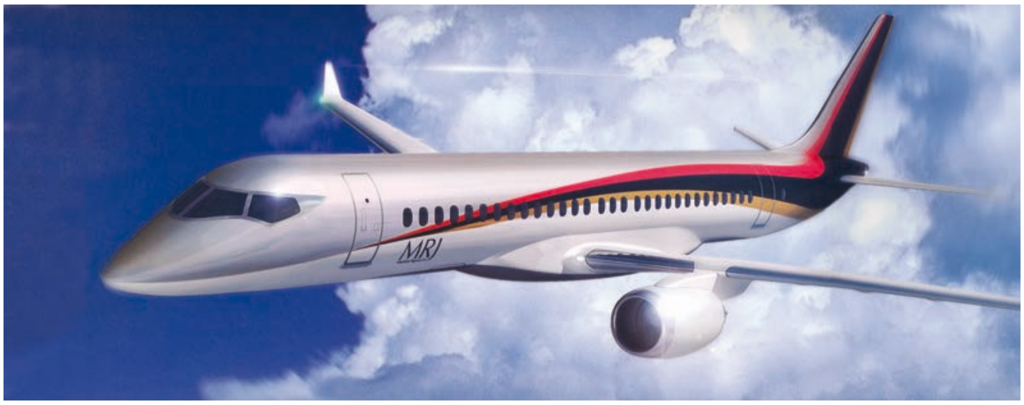
In addition, Mitsubishi has received orders and options for 130 aircraft including 25 (15 firm and 10 options) from All Nippon Airways; 100 (50 firm and 50 options) from Trans States Holdings; and five from ANI Group Holdings. However, this news coincided with more problems in the MRJ development program when Mitsubishi Aircraft Corporation's director of marketing, Yugo Fukuhara, announced the decision to push back the first flight to late next year and the first delivery to the third quarter of 2015. One issue involved MHI "not in full compliance with production procedures", and a second issue, he explained, occurred during the type certification process when "more documentation was required unexpectedly", which resulted in the JCAB rejecting some documents detailing the construction process of certain components, including an engineering test wing that will have to be built again.

This has inevitably delayed the first flight of the MRJ until the end of 2013, and first deliveries until late 2015 – and all this assuming that the ground and flight testing and certification is on schedule.

Hirohide Takaseki, director of strategic planning in the MRJ project management office, admits that Mitsubishi Aircraft Corporation has not fully detailed its MRJ production plan, although it has said the maximum would be five aircraft a month. According to Takaseki, the company would like to achieve that rate sooner than planned and then increase it further.

Despite the setbacks of developing Japan's first commercial aircraft for 50 years, Mitsubishi is investing some US$2.3 billion in the program and is set on developing an extensive MRJ family that will range from the 78-passenger MRJ70 and 92-passenger MRJ90, to the projected 100-seat MRJ100X. ∎

David Oliver is a freelance aviation writer, author, and an IHS Jane's consultant editor based in the UK



ABOVE The MRJ was originally designed with a composite wing box, but later changed to an aluminum one (Mitsubishi)

Integrate, demonstrate, and aviate

Following the US Army's expansion of its use of unmanned aircraft systems, we look at the integration and test activities that put enhanced sensors, weapons, and interoperability into field units

BY FRANK COLUCCI

The first full US Army company equipped with the Gray Eagle unmanned aircraft system (UAS) deployed to Afghanistan in April 2012, joining two quick reaction capability (QRC) platoons already in theater. Imagery from the Predator derivative can now be seen in the cockpits of Block II Apache Longbow attack helicopters via Level II interoperability hardware and software. UAS data and helicopter-generated imagery can also be relayed to ground soldiers with the one system remote video terminal (OSRVT).

Manned-unmanned teaming technology continues to evolve in the new Apache Block III (AB3). Level IV interoperability lets the co-pilot/gunner in the helicopter steer an unmanned aerial vehicle (UAV) and its sensor payload from more than 50km away. "That AB3 capability is a superset of what we provided on the OSRVT," explains Lars Ericsson, senior scientist for the project manager UAS (PM UAS) in the Army Program Executive Office for Aviation in Huntsville, Alabama. He adds, "The key ingredient is the joint government-industry collaboration."

PM UAS still relies on industry resources to integrate new sensors, datalinks, and other enhancements on Gray Eagle, Shadow, and Raven UASs. However, the army has its own rapid integration and acceptance center (RIAC) at Dugway Proving Ground, Utah, dedicated UAS Technical and Certification Centers at Redstone Arsenal, Alabama, and a joint systems integration laboratory (JSIL) also at Redstone. RIAC director Marvin Nichols summarizes: "We use the RIAC as the end-state of the testing. We use all these other assets to do the up-front integration."

PM UAS engineers, for example, recently finished qualification testing of FUSE, the Federated Universal Synchronization Engine, which disseminates geo-registered UAS data via wide- and narrow-band datalinks from a universal ground control station (UGCS). The work was aimed at a QRC deployment by the end of 2012.

The Dugway RIAC has seen an MQ-1C Gray Eagle in production prove-out testing launch additional Hellfire missiles on targets laser-designated by a

LEFT: An MQ-5 Hunter UAS assembled from the remains of two aircraft that crashed in Afghanistan simulates flight at the UAS Joint Service Integration Lab

BELOW: The AH-64D Apache and MQ-1C Gray Eagle MUSIC demonstration

ABOVE: The Army RIAC orchestrated the first drop of the laser guided Shadow Hawk from the Shadow 200 UAS to meet a Marine Corps requirement (Lockheed Martin Missiles and Fire Control)

Block II Apache Longbow. MQ-1C deputy product manager Jeff Crabb notes, "Gray Eagle has the unique capability of off-azimuth shots – you don't have to have the target right off the nose." Gray Eagle testing at Dugway continues with the StarLite Ground Moving Target Indicator radar and extended-range data relays. Crabb explains, "You launch one Gray Eagle and put it in an orbit at say 200km, then launch a second at another 300km to extend your range to 500km or 600km without using satellites. That's a kind of unique thing we do with Gray Eagle."

The RIAC enabled PM UAS to integrate an electronic warfare (EW) jammer into the MQ-1C quickly, and it will test the T-POD signals intelligence (SIGINT) sensor and other EW payloads. "We use Dugway a lot," acknowledges Crabb. He adds, "A lot of the initial design engineering work for the payloads will be done at the contractor's."

BITS AND PICTURES

The manned-unmanned teaming (MUM-T2) capability flying in Operation Enduring Freedom grew out of 10 years of interoperability research, development, test, and evaluation. Early guidance from the US Secretary of Defense stipulated that manned and unmanned platforms should share broadband radio frequency connectivity via the tactical common data link (TCDL). "That rolled into our interoperability profiles (IOPs)," explains Lars Ericsson. "We started with the OSD-mandated guidance for the common data link and refined it to isolate exactly where we were going to meet."

Within an industry-government interface control working group, PM UAS engineers clarified levels of interoperability ranging from Level I indirect image and data transfer to Level V full UAS control including take-offs and landings. In 2007 the Army Aviation Applied Technology Directorate (AATD) at Fort Eustis, Virginia, prototyped VUIT-2 (Video UAS Intelligence Teaming–Level 2) to display Shadow UAS imagery in the Block II Longbow Apache cockpit. VUIT-2 also enabled Apache crews to send imagery from their Modernized Target Acquisition/ Designation Sight (MTADS) to the ground-soldier OSRVT. AATD teamed with MTADS integrator Lockheed Martin, datalink supplier L3 Communications, and Shadow maker AAI to test VUIT-2 at Fort Eustis and Fort Rucker, Alabama.

Fully integrated Level IV interoperability in the Block III Apache Longbow extends active control to the UAS sensor and flight path using existing Apache cockpit controls and displays. The AB3 helicopter with Level IV capability finished Initial Operational Test and Evaluation (IOT&E) in April 2012 and was reported operationally suitable and effective by the Army Test and Evaluation Command and the director, operational test and evaluation.

The MQ-1C, now in its own IOT&E, meanwhile gives the army an extended range multipurpose UAS with weapons. Apache Block III (AB3) product manager Lt Col Dan Bailey notes, "As the Gray Eagle begins to finish up integration of weapons, one of our requirements is to control all the payloads, which would include weapons." Apache manufacturer and integrator Boeing in Mesa, Arizona, and Gray Eagle maker General Atomics in Poway, California, made the manned AB3 and unmanned MQ-1C architectures interoperable in their systems integration laboratories (SILs).

The first time a real Block III Apache worked with a flying Gray Eagle vehicle was in August 2011 during Apache Block III developmental testing. Software verification testing in this year cleared the way for the AB3 IOT&E. Development timelines for the Block III Apache Longbow and MQ-1C Gray Eagle were nevertheless out of synch and according to Bailey, "They were a little behind us finalizing their software. We had to do a couple of iterations on software spin before we went to IOT&E. We proved it could be done fairly quickly."

Government and industry engineers bridged the gap between the helicopter and UAS IOPs. Bailey explains, "One of the changes we made back in January was because the Gray Eagle software was in a state where they couldn't make changes at that time. There was one nuance that was disruptive to the operator and it was not the most efficient interface. We made a

"DUGWAY FOR US IS THE BEST WE'VE EVER HAD. THE GROUND FACILITIES HAVE AFGHANISTAN-LIKE TERRAIN, BEST SPECTRUM AVAILABILITY, AND A GREAT RANGE TEAM"

ABOVE: JSIL technicians use a universal ground control station at the Redstone JSIL to 'fly' a UAS in a hardware-in-the-loop simulation (US Army)

change on the Apache side to take either compliant or non-compliant software, and it works just fine."

Apache Block III IOT&E put the production attack helicopter and developmental UAS together again at the National Training Center (NTC). AB3 crews at the NTC exercised full Level IV UAS control over Gray Eagles launched from El Mirage on missions in support of ground units in a regular training rotation. "The Gray Eagle and the Apache Block III provided standard assets for the ground commander at that location," notes Bailey. "It was really a slick test integrated with part of a ground maneuver force rotation. At the end, once the rotation was over, they did specific testing to validate systems that were not validated as part of the training rotation. We did shoot a Hellfire from a Apache Block III using the UAS sensors as the designator and control. We went to a live-fire range for that."

WIDE OPEN RANGE

Weapons testing opportunities on laser-safe ranges at the NTC, the Army's Fort Huachuca UAS Training Center can be limited. Airspace conflicts with manned aircraft can also complicate and slow UAS testing. Though the army Dugway Proving Ground remains dedicated to developing and testing biological detection and protection equipment, the 800,000 acres surrounded by the Air Force Utah Test and Training Range are also well-suited to UAS testing. "We've got long legs within that environment to test the datalinks," observes Nichols.

Dugway was selected in 2009 as the site of the UAS Rapid Integration and Acceptance Center (RIAC). Michael Army Airfield at Dugway has an 11,000ft runway and 9,000ft taxiway for manned and unmanned aircraft. "We implemented a capability at Dugway for all of our aircraft to be on-site and fly out there without a lot of interference," says Nichols. Though UAS testing continues at other ranges, he notes, "Dugway for us is the best we've ever had. The ground facilities have Afghanistan-like terrain, best spectrum availability, and a great range team – actors to emulate insurgents, vehicles, and so forth. They're also the most cost-effective, I've ever dealt with."

"Weapons integrations, of all the integrations, are probably among the slowest because of the safety considerations," acknowledges Ericsson. The Shadow Hawk drop used a ground designator to expedite testing, but the RQ-7 UAS is being integrated with the IAI POP300D sensor payload to self-designate. While Gray Eagle testing has already proved Hellfire capability on the MQ-1C, the army has begun laboratory demonstrations with the Griffin and other small laser-guided munitions less likely to cause collateral damage.

Dugway facilities also support other UAS demonstrations. The manned-unmanned system integration capability (MUSIC) demonstration linked Hunters, Ravens, Shadows, and Gray Eagles to Block II Apache and Kiowa Warrior helicopters and to ground users. A ground-based sense-and-avoid (GBSAA) test system now uses two lightweight surveillance and target acquisition radars (LSTARs) with maneuver algorithms to cue UAS operators to conflicting air traffic. According to Crabb, "The long-term plan is one [GBSAA system] at each Gray Eagle site. For most of the places we're going to fly Gray Eagle to, you're going to have to fly through some piece of controlled airspace to get to it."

Frank Colucci is a helicopter expert. He covers rotorcraft design, civil and military operations, test programs, materials and avionics integration

HARDWARE AND SOFTWARE

RIAC and the other army UAS integration sites also investigate promising 'off-axis' payloads outside the Gray Eagle and other big programs of record. The Army PM UAS has, for example, tested payloads for the A160T Hummingbird unmanned helicopter flown by US Special Operations Command. Wide area aerial surveillance (WAAS) technology is a growing area of interest. According to Lars Ericsson, "We create scenarios, both technical and operational. We measure the target location accuracy, the image usability and the resolution, to have confidence in the integration, to get it qualified in each of the airplanes."

Army payload development teams use the UAS JSIL at Redstone Arsenal and collaborating UAS Technical and Certification Centers. The UAS Technical Center, for example, modified the TCDL to send UAS data to ground systems via the Army's NET-T network and 3G cellular networks. The UAS Certification Center meanwhile verifies payloads adhere to the Army and OSD interoperability profiles. The Alabama laboratories use hardware-in-the-loop simulations and other tools to integrate air vehicles with other equipment such as the Universal Ground Data Terminal and OSRVT. The JSIL, previously home to Hunter, Shadow, and Raven air vehicles for integration, this year received its own Gray Eagle and UGCS.

PM-UAS will also transition technologies developed in the autonomous technologies unmanned aircraft systems (ATUAS) joint capabilities technology demonstration (JCTD) for eventual deployment. ATUAS uses the cargo-carrying K-MAX helicopter previously flown by the US Navy at Dugway and now resupplying US Marines in Afghanistan. ATUAS manager AATD plans a new round of flying at Fort Picket, Virginia, next spring to give Army leaders information, should they formulate unmanned cargo requirements. As Ericsson explains, "That JCTD is not about the K-MAX; it's about what we use the K-MAX to demonstrate."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Good closed-loop satellite vibrations

A complete system of electrodynamic shakers, hundreds of channels of high-frequency data acquisition, and a full suite of data processing applications – all from one manufacturer

Satellites are fragile, expensive and unique structures, so vibration testing is vital to prevent their dangerous delivery trips reducing them to useless, multimillion dollar pieces of space-junk. Similarly, the NASA rover Curiosity, which is now exploring Mars, also endured vibration testing to ensure it arrived safely – after surviving the rigors of launch, a supersonic descent, and a 9*g* shock when its parachute deployed.

As the testing of satellites is fraught with danger, it must be conducted as safely as possible to ensure that no damage results. What's more, repeating a test after failing to capture data is simply not an option due to time restrictions and the fragility of the test object, making test reliability essential so that all necessary data is recorded in one go.

For mechanical satellite qualification and acceptance testing, the quality of the data is also of paramount importance. In these tests, first the engineering model and finally the actual flight model of the satellite are placed on large shaker systems and precisely vibrated to check that the satellite matches up to its CAE design in terms of structural and modal performance. The flight model is also tested for its response to shocks and the structural resonances that can cause damage during the stressful launch phase of its life. Typically, many hundreds of channels of vibration test data are acquired at high sampling rates.

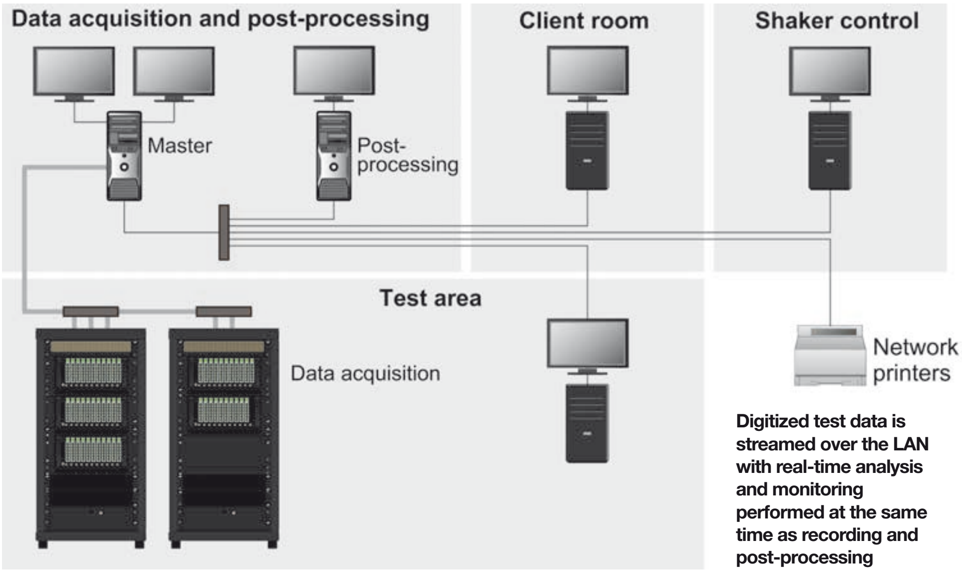
Vibration test applications for satellite qualification include acoustic fatigue, transient, random, and swept-sine analysis. The acoustic fatigue tests are carried out in large reverberation chambers, where extremely high-level sound excites the satellite and its response is measured. The random and swept-sine tests are made on shakers to accurately determine the structural properties of the test object. To simulate the short shock transients experienced during launch, and the long transients such as when solar panels are deployed, the response to pyroshocks of the satellite and its subsystems must also be determined.

SYSTEM NETWORK ARCHITECTURE

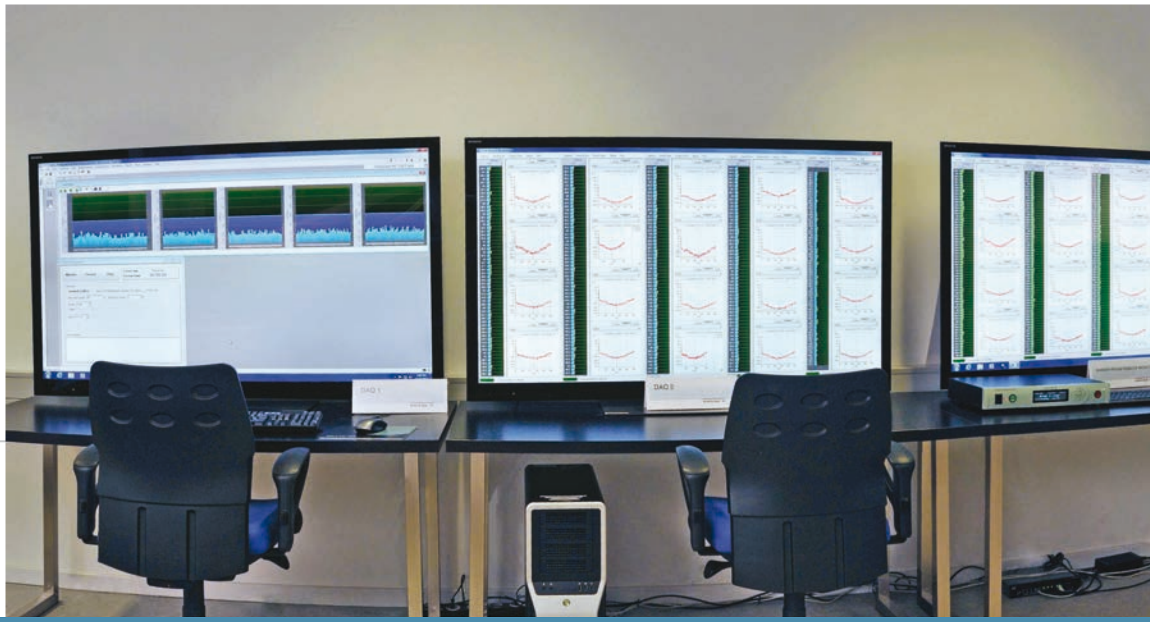
Qualification and acceptance testing is often performed at specialist facilities where time is hired out by satellite manufacturers. Such facilities benefit from an integrated test data stream that fulfills different functions at different levels, including displaying real-time results to clients. The measurement data is digitized immediately and piped around the facility over a LAN, allowing many users to access the same data stream as required. As well as recording large amounts of data to disk, remote LAN-based workstations enable simultaneous real-time level, FFT, CPB, and time-signal monitoring on all channels.

The complete test workflow is organized from a dedicated control console, where the test engineers plan the test, set up the data acquisition and the required analyses, calibrate the system, monitor the recording, initiate post-processing, visualize the results, create reports, and archive the data. Dedicated qualification test software guides them logically through the workflow with a clear user interface that governs and coordinates the many applications.

The system is designed to enable test engineers and clients to validate and witness data recording in real time, and to get quick and precise access to the results that need investigating. Local, real-time monitoring of the test progress is also performed on screens in the test area, close to the test object, while the actual data analysis and post-processing takes place in another location. Close monitoring of the excitation levels is done in the shaker control



Digitized test data is streamed over the LAN with real-time analysis and monitoring performed at the same time as recording and post-processing



Racks of modular data-acquisition hardware stand in front of monitoring screens, with each screen displaying the data and functions required by the observers' roles

Quad shaker arrangements handle the largest satellites and can test payloads of more than six tons

room. Direct real-time analysis and monitoring of the test in progress can be performed in the comfort of the dedicated client room, where the post-processed data is made available through the LAN a few minutes later for the client to review and print reports.

THE DATA ACQUISITION SYSTEM

Reliable data recording is enhanced by placing data-acquisition hardware close to the measurement object, which improves the signal-to-noise ratio of the measured data as only short analog signal cables are required between the satellite and data-acquisition system. Having short cabling avoids many of the problems that long cables can present, such as cost, clutter and damage risk, and the combination of short cabling and mobile data acquisition systems allows accelerometers to be left on the satellite while it is moved from one testbed to another, greatly reducing the time involved with accelerometer mounting and setup. Automatic transducer recognition and calibration using TEDS data sheets further speeds setup procedures.

Brüel & Kjær's LAN-XI data-acquisition hardware can be installed in mobile cabinets containing hundreds of channels of LAN-XI data-acquisition hardware. These cabinets are highly practical and can be easily moved around the test area as desired along with the satellite, bringing multiple practical benefits. As with other system components, the mobile cabinets connect to the network using network switches and simple LAN cables, which are used as standard by LAN-XI data-acquisition hardware.

This COTS system is modular, with each module, frame of modules, or cabinet of frames connecting to the data-acquisition network via a single LAN cable connection – giving easy portability. Each physical channel connector contains an LED ring light that clearly displays the channel's status at a glance, indicating overloads, overload history, and cable breaks. More detailed instant feedback is provided by an LCD screen on each module, showing configuration information.

The data-acquisition hardware uses two analog-to-digital convertors working in parallel that automatically switch between each other, so that one is always ready to take over from the other when it reaches the limit of its capabilities. Consequently, initial input ranging can be eliminated, greatly reducing setup errors and time and eliminating overloads. For tests with wide dynamic input ranges, this provides the benefit of eliminating the need to run a preliminary low-level test to make sure all the input ranges are properly set for the full-level test.

MODULAR SYSTEM BENEFITS

Systems based on the LAN-XI platform can be scaled up to hundreds and even thousands of channels as required with the addition of modules. Arranged in racks of up to 11 each, these modules can be swapped with ones featuring alternative input configurations, measurement bandwidths, and sampling rates – which can be as high as 262kHz for shock measurements.

At a smaller level, the front-panels of each module can be swapped to alter input connection configurations. This enables them to be swapped when recalibration or maintenance is required, limiting any problems to a readily removed unit and leaving the rest of the system unaffected. Interchangeable front panels give microphone, accelerometer, and auxiliary inputs, resulting in fewer patch panels, adaptors, and cabling.

CLOSED-LOOP VIBRATION TEST CONTROL

Test safety requires a precise and dependable vibration test system, and this is further enhanced by integrating the data-acquisition system with the vibration controller, which gives the ability to locate hundreds of individual abort monitors all over the test structure – limited only by the number of channels.

Closed-loop control of the shaker is achieved by feeding the actual acceleration and movement experienced by the test object back into the vibration controller, so that the input of the shaker into the system is altered in real time to match test requirements. Critically, Brüel & Kjær's VC-LAN vibration controller also has a safety shutdown mechanism to ensure that in an emergency or loss of power the test comes to a stop without unplanned stresses.

The VC-LAN vibration controller and LDS vibration systems are used worldwide in cleanrooms and controlled environments, and the LDS V900 shaker family is renowned for delivering low-frequency performance with a relatively modest amplifier output. An additional slip table further extends test capabilities, while guided head expanders and bespoke attachment mechanisms permit mounting of the largest satellites, and safe testing of satellites with irregular weight distributions. The ability to safely handle the massive loads demanded by the increasing size of modern satellites is critical, and LDS shakers have even been combined in quad arrangements to test satellite payloads in excess of six tons.

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Sound machines

Helicopters are complex machines that generate a huge amount of vibration and acoustic phenomena that need standardized sound metering

In order for a helicopter to survive and perform satisfactorily, it must be thoroughly tested and validated during the modeling and prototyping stages so that when the final design enters the production phase, its ability to function as expected is maximized.

A litany of testing must be undertaken, which includes vibration, strain, and acoustic measurements to substantiate the helicopter's ability to operate successfully. Sources of potential damaging vibration and harmful noise include the engine, gearbox, and in-flight aerodynamic excitation. Standard procedures and requirements must be considered in order to ensure that any measurement results obtained will be viewed as being valid. For example, IEC 61094 is a standard addressing condenser microphones while IEC 61672 addresses sound level meters.

NOISE MEASUREMENTS

Noise sources on helicopters include structural vibration and rotating components, which result in disturbances that can be measured from within the cabin or external to the craft. External measurements can be further categorized as surface, near field, and far field. In-cabin acoustic measurements address comfort studies for occupants, safe exposure limits, and noise source identification. Acoustic measurements external to the cabin are also utilized to identify noise sources as well as for certification and environmental compliance purposes. A quieter helicopter is obviously more desired from the perspective of the occupants as well as people on the ground, at airports, and in communities in which the aircraft will operate. The manufacturer of a quieter helicopter will also have an advantage over others from a marketing and customer acceptance viewpoint.

COMFORT AND HYGIENE STUDIES

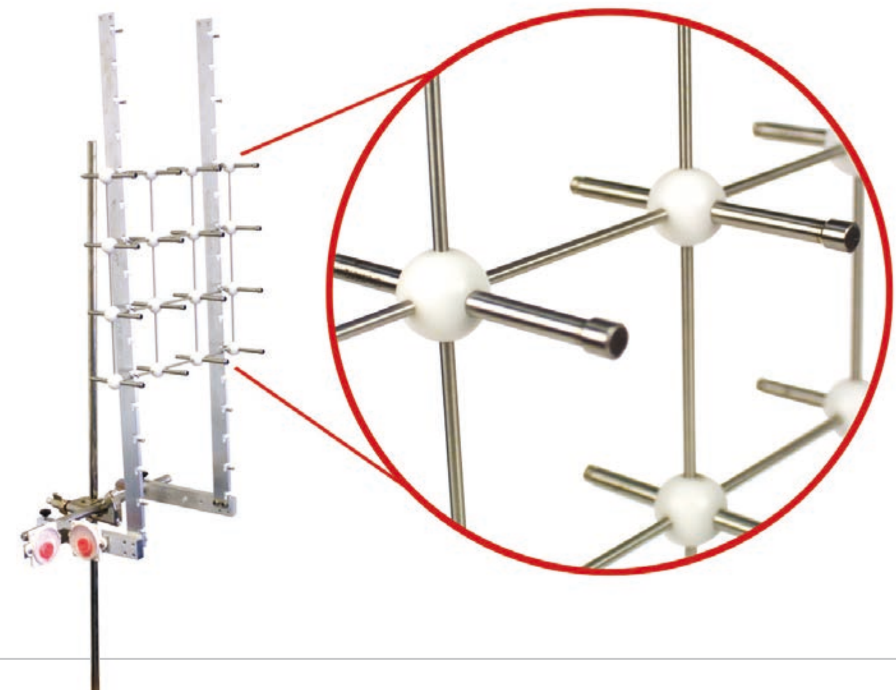
For safety purposes, it is typical for pilots as well as passengers to wear hearing protection. To ensure that adequate protection is used during helicopter flight, noise comfort studies are carried out. Acoustic measurements are generally conducted at the normal position of any occupant's head with a goal of quantifying, as a minimum, the global noise level in dBA.

NOISE IDENTIFICATION

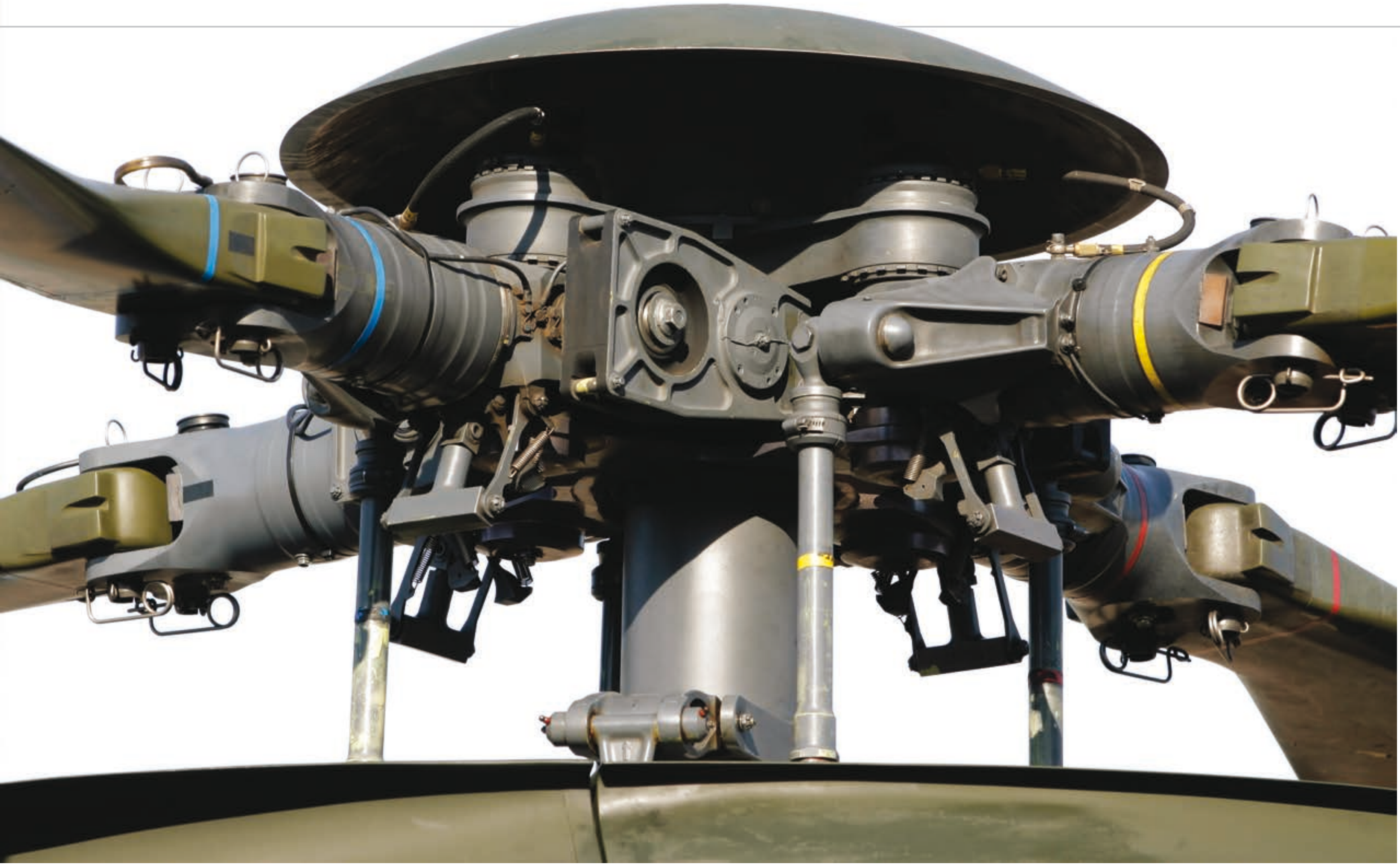
The goal of noise source identification is to determine the root cause of the offending noise so that corrective action can be undertaken to reduce noise at its source. Once the noise source is determined with a suitable measurement campaign, then a noise reduction program can be undertaken. A noise reduction program begins by acquiring acoustic data with a variety of measurement techniques, which may include sound pressure measurements, sound intensity measurements, and acoustic holography.

Sound pressure measurements are accomplished using a precision microphone, typically 0.5in size, along with sound level meters or a real-time analyzer, and the test requirements will determine whether the microphone should have a pressure, random incidence, or free-field response.

Sound intensity is defined as the sound power per unit area and is quantified in units of



The main rotor is one of the principal noise sources; action is required to minimize the problem (above right). Microphone array grid (left). Precision microphones (below). Typical ICP array microphone (bottom). Surface microphones (below right)



watts per square meter (W/m²). A sound intensity responds to sound pressure with respect to direction, or origin of the noise source. The sound intensity probe utilizes a matched pair of precision microphones that are oriented in an opposed manner with an appropriate spacer.

Acoustic holography is a technique for measuring the spatial propagation of acoustic waves and determining noise sources. It utilizes Fourier transform techniques on multiple measurement channels that originate with an array of microphones positioned in a grid. Since many channels may be desired and results are focused more on data that is relative from channel to channel, a lower-cost microphone is typically used rather than a precision measurement type. Such "array microphones" may operate from ICP sensor excitation, which also contributes to a much lower cost per channel.

SURFACE ACOUSTICS AND TURBULENCE

Low profile ICP microphones are used for acoustic and turbulence studies on rotor blades and the exterior skin of the helicopter. This type of testing is targeted more for investigations with regard to performance and aerodynamic behavior. The microphones are typically fixed directly to the surface to be tested, however, to minimize drag and interference, the microphone may even be embedded into a pocket on the surface.

Special acoustic measurement and data logging instrumentation is also available for studying the impact that helicopter noise may have on the environment.

ACOUSTIC CERTIFICATION

In order for a helicopter to become commercially viable, it must pass certification testing and prove conformance to certain standards. FAR Part 36 is the most widely used noise standard for helicopters and contains all the measurement criteria and instrumentation details necessary to conduct such certification testing.

Safety, comfort, and performance are certainly all desired for a helicopter or any aircraft. As acoustic measurement sensors become more capable in their ability to detect anomalies and inefficiencies, final products such as helicopters will continue to improve and offer better comfort and reliability to users.

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Cell structure

Very large engine test cells regularly suffer from infrasound disturbance, but the latest research demonstrates that the science exists to alleviate this concern

As aircraft engines become larger, so do the facilities required to test them. It is therefore not surprising that many large-engine test facilities suffer from low-frequency noise, or infrasound, a phenomenon commonly associated with testing large engines. Infrasound is defined as high-amplitude, low-frequency, test cell-generated standing waves and is the leading phenomenon known to cause engine instability.

The company MDS has gone to great lengths to understand the causes of infrasound in large-engine test facilities. Research spans almost two decades and includes scale model and full-size measurements as well as numerical modeling to develop comprehensive design guidelines that ensure engines will run smoothly with high repeatability, and that the test cell and surrounding buildings will not be subjected to destructive and potentially dangerous low-frequency pulsations.

In addition to affecting engines themselves, these low frequencies are known to trigger structural vibrations in the test cell and its support buildings, leading to structural damage along with physical and psychological effects on personnel and operators (such as headaches and nausea). This phenomenon is increasingly becoming the driving criterion in large test cell aero-acoustic design. This tendency is exacerbated by the increased proximity of test cells to residential and commercial areas, which has led to more stringent infrasound emission regulations.

AERODYNAMIC INSTABILITY

Test cell infrasound is the result of one or more resonance phenomena, triggered by the interaction between the engine's turbulent jet and the test cell exhaust system through which it flows. More specifically, the key driver of the infrasound is the aerodynamic instability generated by the highly energetic turbulent exhaust jet as it flows through the ejector system (augmentor tube, diffuser and basket). These instabilities are amplified by the test cell enclosure through natural resonances.

A free subsonic jet, such as the one produced by a gas turbine, usually produces noise with a continuous spectrum that is absent of any characteristic dominant frequencies. This broad-band acoustic noise is due to turbulent fluctuations of different turbulent scales. Once inside the test cell, the spectrum of the jet noise undergoes a major transformation, with resonance peaks dominating the spectrum.

In general the amplitude of the infrasound increases with the amount of air entering the test cell exhaust system (high augmentor tube velocity). Therefore turbofan engines with greater thrust create higher infrasound than those with less thrust. The infrasound can exhibit different frequencies as each volume (intake section, augmentor tube, exhaust stack and the whole test cell) resonates at a different frequency. Resonance frequencies, for each of the volumes, have been observed in model tests with varying degrees of intensity.

TEST CELL GEOMETRY

In short, infrasound frequencies are functions of the test cell geometry. The magnitudes and severity of the infrasound are driven by the exhaust gases flowing into the test cell ejector system.

The challenges facing test cell designers are the increased demand for lower infrasound and audible noise limits. Lowering the emitted noise requires 'plugging up' the test cell intake and exhaust with silencing material – however this is one of the leading triggers of infrasound. There are therefore careful trade-offs between a test cell's acoustic performance (how quiet it is) and its aerodynamic performance (how comfortable and natural the engine feels running inside a building). For instance a low test cell bypass ratio (a measure of the air flowing around, not through, the engine) leads to flow instability (such as engine sucking vortices from adjacent walls and hot-gas re-ingestion). On the other hand, an overly high test cell bypass ratio can lead to excessive ejector system flow momentum, which will almost certainly result in test cell infrasound.

Test cell designers must therefore satisfy all these seemingly conflicting needs. And how better to achieve that aim than by arming themselves with the best empirical data and design guidelines in the industry? It is important to understand the causes of infrasound and, even more importantly, the mitigating measures that will result in very large engines running happily in their test cells.

Air France Industries' 150,000 lb thrust test facility designed by MDS has set a new industry standard for aerodynamic stability and infrasound

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Go to online reader enquiry number 103

Observer in the sky

SOFIA is a flying telescope on board a very specialist and adapted Boeing 747. Opening the main doors at 800km/h and an altitude of 12,000m needed some precise equipment

The Stratospheric Observatory for Infrared Astronomy, or SOFIA for short, is a converted Boeing 747SP with a 2.5m telescope on board with which astronomers can observe phenomena such as the growth of young stars and planet systems, and investigate precisely the center of our galaxy. The infrared radiation from these objects is particularly interesting to scientists, but it cannot penetrate the water vapor in the Earth's atmosphere, so earthbound telescopes can detect it only imperfectly. At an altitude of 13,000m, however, atmospheric effects are negligible, leaving the way open to observe the infrared radiation from astronomical objects.

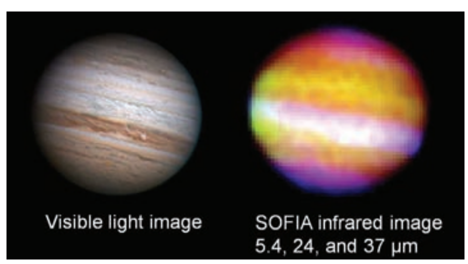
JOINT PROJECT BY NASA AND DLR

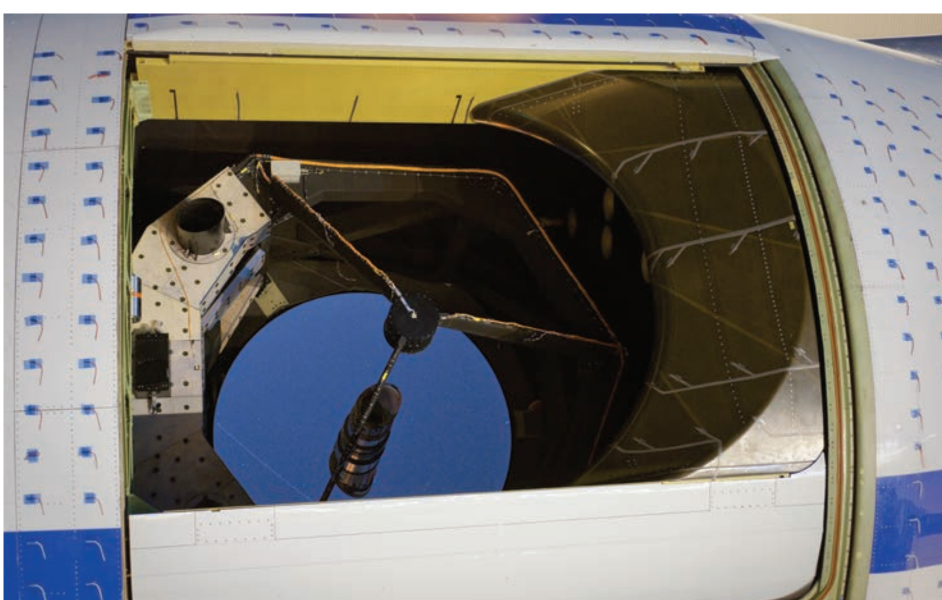
SOFIA is a unique observation platform constructed and operated in a joint project by NASA and the German Aerospace Center (DLR). SOFIA has a planned life of around 20 years, during which time about 120 astronomical measurement flights will be performed each year. Each flight lasts approximately 10 hours.

SOFIA will be used by about 50 research groups that are selected annually by a scientific committee. The German SOFIA Institute (DSI) of the University of Stuttgart is coordinating SOFIA's science operation on behalf of DLR.

Another of SOFIA's vital components, apart from the telescope itself and all its measurement instruments, is the 4.6 x 4.3m door in the aircraft's hull, which has to open and shut the telescope cavity at a flying speed of approximately 800km/h and an altitude of 12,000m. The door control system consists of two redundantly driven actuators for accurate positioning and speed control.

A dSPACE prototyping system consisting of a DS1005 Processor Board and various I/O boards was used to design the control algorithms for the door opening mechanism, which was engineered by MPC Products (now Woodward MPC). To develop the actuator control system, the engineering team used the dSPACE system to construct a test setup that simulates the system environment. Various effects on the door had to be taken into account – mainly aerodynamic forces, but also factors such as inertia and icing.





THE PROJECT

SOFIA is a joint project of DLR and NASA. It is funded on behalf of DLR by the Federal Ministry of Economics and Technology, based on legislation by the German Parliament, the state of Baden-Württemberg and the Universität Stuttgart.

Scientific operation for Germany is coordinated by the German SOFIA Institute (DSI) of the Universität Stuttgart, and in the USA by the Universities Space Research Association (USRA).

FIRST MEASUREMENT FLIGHTS

After the telescope was installed and various modifications were made to the aircraft, test flights began in April 2007. Since the beginning of 2008, SOFIA has been at its primary operating location – the Dryden Aircraft Operation Facility (DAOF) belonging to the NASA Dryden Flight Research Center. In December 2009, engineers started preparing SOFIA for operation with an extensive program of test flights.

The first astronomical test measurement, called the 'first light' flight, was performed in May 2010. By September 2011, over 20 further measurement flights had been made with the US instrument FORCAST (faint object infrared camera for the SOFIA telescope) and the German instrument GREAT (German receiver for astronomy at terahertz frequencies). The results included the first-ever detection of two new molecules in space and a study of the envelope around an aging star.

These results from the very first observation campaign by SOFIA and the GREAT receiver demonstrate SOFIA's enormous scientific potential. It promises unique astronomical observations in the coming years in areas such as the development of galaxies and the birth and growth of stars and solar systems from interstellar clouds of molecules and dust.

Shown above is an image of Jupiter in the visible spectrum, and for comparison an infrared image taken with SOFIA (other pictures) showing the heat radiating out through Jupiter's cloud cover (Left image: Anthony Wesley; right image, NASA)

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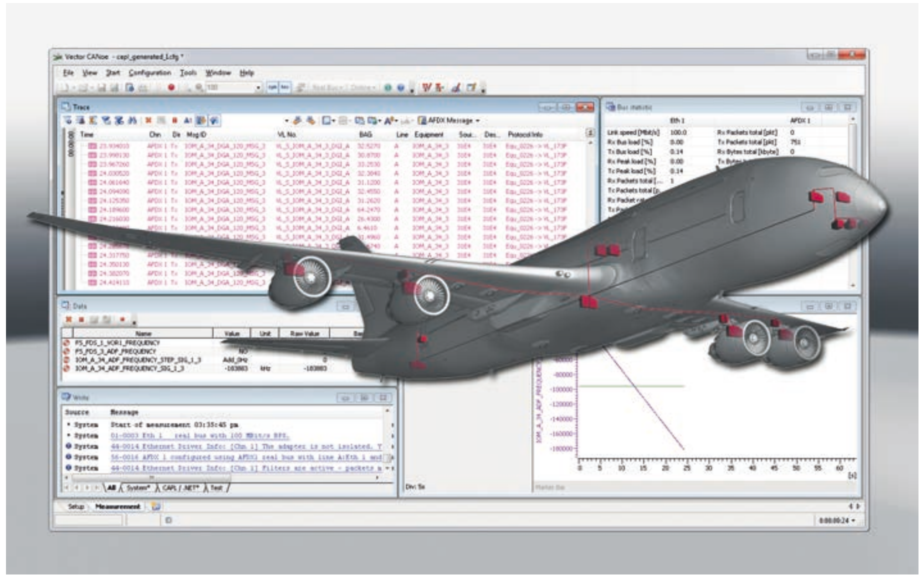
Go to online reader enquiry number 104

Development and analysis of avionics networks



With the new .AFDX option, Vector is extending the application range of its CANoe and CANalyzer development and analysis tools to avionics networks. This gives developers of networked electronic units in an aircraft a solution that provides detailed access to the exchanged data right down to the level of single Ethernet frames.

CANoe and CANalyzer are used as multibus tools to evaluate the AFDX communication in temporal relation to other communication channels such as ARINC 825. If a network description is provided in the form of ICD files, this information is available within the tool. Virtual links, for example, are then displayed not just as numeric values, but with the name specified in the ICD. Likewise, the specified signal name can be used to access the respective data payload. The Data and Graphics windows provide a clear and simple display of the signals. For specific, substantive display of values, custom panels can be defined.

The user can implement complex analysis scenarios using the built-in programming language CAPL. Individual AFDX messages can also be stimulated with ease using this C-like programming language. CANoe handles both the scheduling of the message and its transfer via the corresponding PC interfaces. Playback of previously recorded log files is also possible. The comprehensive and versatile basic functions of CANoe/CANalyzer and the AFDX extension facilitate the analysis of complex networks.

FURTHER INFORMATION

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Next generation of generators

The design and manufacture of generator test benches has been one of the core design skills of Test-Fuchs.

In partnership with a customer, the company has developed a new generation of generator test benches that are set to become its flagship in testing systems for the future. This kind of test bench is capable of testing all power-generating components such as the IDG, AC generators, DC generators, DC starter generators, CSD and VSCF installed on various aircraft types including but not limited to current aircraft from Embraer, Bombardier, Airbus, Boeing and new and future aircraft such as the A380, A350 and B787-Dreamliner.

The test bench is a modular design offering several variants, modules and options. This allows the arrangement of an ideal composition of the test bench to suit each customer's requirements.

Utilization of the newest technology for the drive and load unit creates a competitive advantage for the customer. The biggest innovation in this new kind of generator test system is the absence of a gearbox: there is a direct connection between the generator and the unit undergoing testing. This reduces the number of components used and saves costs due to a higher level of efficiency.

To reduce investment costs for the customer, a universal generator control unit (GCU) has been developed. The major advantages of this unit are full integration into the test equipment and a single investment for all test capabilities.

The generator test bench supports a high level of automation and optimizes test duration. Only minimal intervention by the operator is necessary. Easy and fast adaptation between the units undergoing testing was one of the key design elements. Test-Fuchs now offers an easy, fast coupling system that considerably reduces the installation time of the units. In addition to manual testing with automation, the system is capable of fully automated test runs.

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or go to online enquiry card 106

Flight test using SYNC-CLOCK technology

Flight test is challenging. Dewetron is able to measure every kind of analog sensor output plus digital states, counters, multiple videos, GPS, IRIG, CANbus, ARINC and 1553. Everything is synchronized to a highly accurate clock, ensuring deterministic data timing. This proprietary technology is called the SYNC-CLOCK.

With SYNC-CLOCK technology and high-isolation input amplifiers it is easy to monitor the power bus, vibration, strain and temperature fully synchronised to ARINC data, video feeds from onboard cameras in NTSC and PAL formats and higher-speed videography in order to analyze actuators. All data is synchronized from the very beginning to eliminate the need to time align multiple files later. This provides a better 'look in' to the data during the measurement, which can prevent the need for expensive retesting, as well as better overall test results. A single instrument covers a wide range of measurements, provides easy setup and powerful online and offline functions and screens.

Dewetron makes portable, bench-top and 19in rack mounting systems that enable busy flight engineers to get the most from their time in the air and on the ground.

Environmental test catalog available

PCB Piezotronics, a global leader in the design and manufacture of microphones, vibration, force, torque, load, strain and pressure sensors, as well as a pioneer of ICP technology, is pleased to announce the completion of an environmental test catalog for the aerospace and defense markets.

The new catalog is a compilation of the most popular sensors used in environmental test applications including: HALT/HASS, thermal stability, shock, low outgas, cryogenic, force limited vibration, underwater, high temperature, pressure and torque. The 28-page catalog offers a brief explanation of each application, followed by the recommended sensors with specifications.

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Efficient navigation by GPS simulation

GPS simulators are virtually essential to aerospace testing due to the impracticality of live testing. They allow the test engineer to control the generation of multiple GPS signals, as well as other global navigation satellite systems (GNSS), through a virtual scenario. A scenario includes the start date and time, number of transmitting satellites from the various systems and on different frequencies, their power levels, any impairments typical of these signals, the GPS receiver's starting position, and much more. These simulators adjust signal transit time and relativistic effects to ensure the navigation system is capable of performing under any dynamic motion conditions. The receiver's trajectory – even those with extremely high rates of velocity and acceleration – can be simply simulated via a number of tools.

A new feature of its GPS simulators enables integration into test systems for complex navigation systems that combine GPS receivers with inertial navigation systems (INS). Known as real-time scenario generation, the data from inertial motion simulation is streamed to the GPS simulator, which in turn generates satellite RF signals with low fixed latency. The result is one real-time simulation scenario for testing the combination of GPS and inertial motion data. In a similar test case, data from accelerometers, gryos and other motion sensors, in six degrees of freedom, can be used for hardware-in-the-loop testing of the entire aerospace navigation system.

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Secure data loading technology for LRU-updates

New secure data loading technology, GARDT, has been released by TechSAT for its portable data loader family. The technology fulfills the latest requirements of the aerospace industry and authorities for protected LRU updates.

GARDT (guarded data loading technology) is patent pending and will be marketed worldwide as a standalone and as a built-in solution in existing PDL products. The design of the GARDT device is a hardware/software combination based on a decentralized architecture that runs on a separate, autonomous platform.

The TechSAT PDLs are the perfect example of how state-of-the-art technology masters the requirements of the aerospace industry for secure, fast, robust and practical tools.

The portable data loaders allow direct retrieval of loadable software over a network from a central airline repository and upload straight into the airborne LRUs. There is no need any more to use obsolete and increasingly expensive floppy disk media. The loading speed of the TechSAT PDLs outperform existing time-consuming data loaders by up to 50%, but are still compliant to the ARINC standard and all common PDL adapter cables.

In addition, the PDL can run on aircraft power (115V/400Hz) during data load, eliminating the risk of data load interruptions caused by battery issues. These fast, reliable and unattended data loads greatly reduce the workload of the maintenance team and save aircraft ground time.

The RANGER PDL is designed and manufactured based purely on COTS products. This approach means an enormous economic and technical benefit to all operators of commercial aircraft.

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Index to advertisers

The engines produce in excess of 2,500 lb of thrust

On the start grid

The Rocket Racing League is taking the excitement of NASCAR and Formula 1 into the space age with airborne races. Another goal has been reached after rigorous tests of the propulsion system

BY NEIL MILBURN & MICHAEL D'ANGELO

The Rocket Racing League and propulsion partner Armadillo Aerospace of Caddo Mills, Texas, recently reached an important milestone in endurance testing of their current propulsion system, the LE13000FC.

The test objectives were to determine the number of sequential firing and relights the propulsion module could sustain before requiring field service. That number is important to the operational model of the Rocket Racing League, which plans to compete rocket powered aircraft in a variety of race formats: live in front of spectators and through integrated real-time video gaming activities at venues around the world. In order to reliably populate the playing field to satisfy the needs of sponsors, fans and real-time game players, the aircraft must run reliably for extended periods without field service, and this was the purpose of the endurance test program.

The testing was conducted over a period of several weeks at Armadillo Aerospace's facility. The test engine was installed on one of the league's Rocket Racers, anchored to the tarmac at a location suitably set back from the engine control areas within the main Armadillo hangar.

THE PROPULSION SYSTEM

The engine is based on Armadillo Aerospace's proven liquid oxygen-ethanol propulsion technology and can develop a maximum thrust of nearly 3,000 lb. However, for this application it is derated to 2,500 lb-ft to increase the durability and longevity of the propulsion system.

The LE13000FC is a film-cooled engine that injects a small portion of the ethanol fuel down the chamber walls. This fuel creates an insulating vapor barrier that insulates the chamber wall from the 5,000°F gases that would otherwise melt it in a fraction of a second. The propellants are pushed into the chamber by high pressure helium and ignited with a small radial torch fueled by the same propellants, which are spark ignited.

The endurance test program also doubled as an opportunity to efficiently test not only the engine but also the entire propulsion system, installed in a Rocket Racer vehicle with all its safety systems online. The test protocol was to load the propellants and pressurant (helium) precisely as if the vehicle was about to be flown – a process that further extended the test to exercise the flight support team, and other primary flight and ground support systems and subsystems.

The propellants were transferred into the racer's propellant tanks using low-pressure helium and the tanks were then pressurized to flight pressure with helium. The test regimen required multiple ignitions per propellant load, with full thrust burns ranging from five to 10 seconds with 10 to 20 burns per load. This aggressive program pushed the limits of durability given the extreme nature of the start-up and shut-down transients, as the heat loads produces large swings in component temperature. When combined with high pressure loading from the combustion process and expansion of gas through the rocket nozzle, these temperature swings create significant loading conditions with time-varying stresses and strains.

The vehicle itself was restrained by massive chain boxes in front of the wheels and additional tie-down chains to the rear. The vehicle was controlled remotely through redundant wireless means, negating the need for a person to operate the Rocket Racer from the cockpit. Ignition, shut down, and monitoring of engine and system performance were all conducted remotely, wirelessly pulling data from numerous pressure, temperature, position, and other sensors at high data rates for real-time monitoring and archiving in the control room.

THE RESULTS

The results were extremely impressive. Over a period of several weeks the vehicle and propulsion system were subjected to more than one thousand ignition events (and an equal number of engine shut down events). The engine ran for more than two hours in total, consuming in excess of one ton of propellants.

There was no maintenance required other than routine tightening of fittings and there were no system failures whatsoever. The engine itself showed no signs of heat degradation, as indicated by the even coloration of the stainless steel combustion chamber and nozzle.

While this was a single test, and not a statistically significant measure of engine reliability, it does provide data strongly suggestive of considerable progress in establishing a baseline propulsion module, meeting the requirements of the Rocket Racing League in reliability, safety, and total cost of operation. Meeting such a standard is not only important to the ongoing growth of the Rocket Racing League, but is also an important demonstration of readiness for such systems to serve as reliable baseline propulsion for the rapidly emerging suborbital space vehicle industry. ■

Neil Milburn is vice president, Armadillo Aerospace, and Michael D'Angelo is COO, Rocket Racing League